Adaptive Gait Changes Due to Spectacle Magnification and Dioptric Blur in Older People

David B. Elliott and Graham J. Chapman

PURPOSE. A recent study suggested that updated spectacles could increase fall rate in frail older people. The authors hypothesized that the increased risk may be due to changes in spectacle magnification. The present study was conducted to assess the effects of spectacle magnification on step negotiation.

METHODS. Adaptive gait and visual function were measured in 10 older adults (mean age, 77.1 ± 4.3 years) with the participants’ optimal refractive correction and when blurred with +1.00, +2.00, −1.00, and −2.00 DS lenses. Adaptive gait measurements for the leading and trailing 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 stereovision.

RESULTS. The blur lenses led to equal decrements in visual acuity and stereovision for the +1.00 and −1.00 DS and the +2.00 and −2.00 DS lenses. However, they had very different effects on step negotiation compared with 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 leading heel position on the step. Negative lenses led to the opposite of these changes.

CONCLUSIONS. The step negotiation 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 farther away and smaller with negative ones. Magnification is a likely explanation of the mobility problems some older adults have with updated spectacles and after cataract surgery. (Invest Ophthalmol Vis Sci. 2010;51:718–722) DOI:10.1167/iovs.09-4250

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.5 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 orientation10 and balance control after cataract surgery.11

These epidemiologic, clinical, and laboratory-based studies strongly predict a beneficial effect of correcting refractive error and performing cataract surgery on the likelihood of older adults falling. The prevalence data on correctable visual impairment further suggest that correction can have significant benefits in the older population. However, intervention studies on fall rates to date have not shown the expected results. Day et al.12 examined changes in fall rates after exercise, home hazard management, and treatment of poor vision (a referral to the usual eye care providers 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 the rate of falls after surgery,13,14 whereas the other two reported no change in the 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 had an optometric intervention and obtained updated spectacles, whereas participants in the control group were left to their own devices. The study surprisingly found an increased rate of falls in the intervention group. The authors proposed that the patients in the intervention group may 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 intraocular implant that replaces their cataractous lens18), perhaps difficulties in adapting to a new refractive error and/or new spectacles is also the reason that cataract surgery does not always provide the expected benefit of a reduced falls rate. A possible cause of difficulties in adapting to new spectacles and intraocular 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 and Howland20).

In this study, we assessed the step negotiation changes that occur when vision is blurred by equal amounts of myopic and hyperopic dioptric blur. We hypothesized that (1) the dioptric blur would lead to safety gait adaptations that older adults use under conditions of diffuse blur, such as increased leading vertical 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 leading vertical toe clearance, as the step would look smaller and farther away due to minification; and (3) some combination of 1 and 2. The advantage of this approach is that it allowed any effects of spectacle magnification on adaptive gait to be assessed in comparison to the known effects of blur.21 The disadvantage of this approach is that newly prescribed spectacles provide clear vision with altered spectacle magnification and not blurred vision.
METHODS

The study complied with the Declaration of Helsinki and had the approval of the University of Bradford Ethics Committee, with written informed consent being obtained from all participants. Ten participants (mean ± 1 SD; age, 77.1 ± 4.3 years; height, 161 ± 9 cm; mass, 73.5 ± 16.3 kg; distance correction sphere median, 0.00 DS; range, −2.75 to +2.25 DS; five hyperopic and five myopic participants; astigmatism median, 0.75 DC; range, 0.00 to 2.00 DC; 6/20 eyes with astigmatism above 0.75 DC; 10 well-adapted habitual spectacle wearers; three men and seven women) were recruited from the University Eye Clinic. The difference between habitual and optimal refractive correction was minimal in all cases (no more than 0.50 D). 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). Participants were excluded if they had any history of neurologic, musculoskeletal, or cardiovascular disorders that could affect their balance or gait or had a history of eye disorders. All participants were able to negotiate and complete the experimental task unaided.

The optimal refractive correction at 4 m was determined for each participant using faciometry (lensometry) and subjective refraction techniques, including Jackson cross-cylinder evaluation for astigmatism.22 Binocular visual acuity and contrast sensitivity and stereoview were measured with the optimal refractive correction and binocular blur trial lenses of +1.00, +2.00, −1.00, and −2.00 DS, with a randomized order of measurement. Binocular visual acuity was measured by using a high-contrast ETDRS chart at 4 m with a chart luminance of 200 cd/m², additional working-distance lenses of 2.00 DS binocular refractive blur using trial case lenses in a trial frame that was adjusted to fit each participant, in an attempt to equalize the amount of blur at the step edge provided by the additional +1.00 and −1.00 DS lenses and the +2.00 and −2.00 DS lenses. Each trial was repeated three times, giving a total of 15 stepping measurements for each participant. The stepping trials occurred immediately after the blur lenses had been added, and no attempt was made to allow the participants to adapt to the lenses. To limit the effectiveness of using somatosensory feedback from previous trials to estimate the height of the step, four “dummy trials” were included, where the height of the step was randomly adjusted by −10 or +5 mm every fourth trial. No data were collected during these trials, and the participants were advised that the height of the step would be varied throughout the study. The order of all step negotiation measurements was randomized.

Three-dimensional lower limb segmental kinematic data of the stepping action were collected (at 100 Hz) with an eight-camera motion-capture system (Vicon MX, Oxford Metrics, Ltd., Oxford, UK). Reflective markers (6 mm on feet, 14 mm diameter on other locations) were attached directly onto the skin, clothing, or shoes in the following locations: superior aspects of the second and fifth metatarsal heads, end of the second toes, lateral malleoli, and posterior aspect of the calcanei. 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 second and fifth metatarsal heads and end of second toe. The 3-D 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 analyzed can be found in an earlier report.23

All confidence levels for ANOVA were set at P < 0.05. Bonferroni post hoc analyses were performed to further analyze vision and adaptive gait data that were significantly affected by dioptric blur (SPSS for Windows, ver. 16.0; SPSS, Chicago, IL).

RESULTS

The mean binocular visual acuity, contrast sensitivity and stereoview data are shown in Table 1. Dioptic blur had a minimal effect on Pelli-Robson contrast sensitivity (F₁,₄₆ = 2.5, P = 0.06), but caused large changes in binocular visual acuity (F₁,₄₆ = 37.8, P < 0.0001) and stereoview (F₁,₄₆ = 11.55, P < 0.0001). Visual acuity and stereoview losses were greater at ≤2.00 than ±1.00 DS (post hoc, P < 0.05), but losses were

<table>
<thead>
<tr>
<th>Method</th>
<th>+2.00 DS</th>
<th>+1.00 DS</th>
<th>Optimal Correction</th>
<th>−1.00 DS</th>
<th>−2.00 DS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual acuity (logMAR)</td>
<td>0.30 ± 0.17</td>
<td>0.05 ± 0.07</td>
<td>−0.11 ± 0.07</td>
<td>0.03 ± 0.07</td>
<td>0.50 ± 0.14</td>
</tr>
<tr>
<td>Log contrast sensitivity</td>
<td>1.76 ± 0.14</td>
<td>1.79 ± 0.13</td>
<td>1.81 ± 0.12</td>
<td>1.80 ± 0.13</td>
<td>1.76 ± 0.14</td>
</tr>
<tr>
<td>Log stereoview, log s arc</td>
<td>2.56 ± 0.43</td>
<td>2.17 ± 0.43</td>
<td>1.96 ± 0.45</td>
<td>2.11 ± 0.39</td>
<td>2.53 ± 0.41</td>
</tr>
<tr>
<td>Trailing foot position before the step, mm</td>
<td>195.6 ± 34.1</td>
<td>177.5 ± 44.2</td>
<td>164.6 ± 44.9</td>
<td>149.5 ± 38.3</td>
<td>136.1 ± 41.5</td>
</tr>
<tr>
<td>Leading foot position before the step, mm</td>
<td>642.6 ± 51.3</td>
<td>626.4 ± 65.3</td>
<td>604.0 ± 94.7</td>
<td>624.3 ± 46.6</td>
<td>615.0 ± 56.0</td>
</tr>
<tr>
<td>Trailing horizontal toe clearance, mm</td>
<td>353.8 ± 35.9</td>
<td>316.3 ± 38.1</td>
<td>284.3 ± 65.5</td>
<td>286.1 ± 43.1</td>
<td></td>
</tr>
<tr>
<td>Leading horizontal toe clearance, mm</td>
<td>159.5 ± 31.4</td>
<td>121.8 ± 24.5</td>
<td>105.8 ± 25.7</td>
<td>95.6 ± 26.9</td>
<td></td>
</tr>
<tr>
<td>Trailing vertical toe clearance, mm</td>
<td>26.4 ± 9.2</td>
<td>28.5 ± 10.1</td>
<td>26.9 ± 11.2</td>
<td>24.6 ± 11.4</td>
<td>27.0 ± 17.1</td>
</tr>
<tr>
<td>Swing duration, s</td>
<td>0.60 ± 0.05</td>
<td>0.61 ± 0.04</td>
<td>0.59 ± 0.03</td>
<td>0.60 ± 0.04</td>
<td>0.59 ± 0.04</td>
</tr>
</tbody>
</table>
approximately 0.04 logMAR (20/20) acuity was reduced to 0.30 logMAR (20/40) and stereoacuity to 1.75% (2000/2000) for the optimal refractive correction and with 2.00 DS (Table 1, post-hoc, P < 0.0001; Fig. 1), leading vertical toe clearance (F4.46 = 23.6, P < 0.0001), leading horizontal toe clearance (F4.46 = 26.8, P < 0.0001), trailing horizontal toe clearance (F4.46 = 50.9, P < 0.0001), and leading heel position on the step (F4.46 = 23.6, P < 0.0001; Fig. 2). Equal values of dioptric blur led to very different changes in step negotiation as +1.00 and +2.00 DS led to much larger values than −1.00 and −2.00 DS, respectively (post-hoc P < 0.05) for leading toe position before the step, leading vertical toe clearance, leading horizontal toe clearance, and trailing horizontal toe clearance and smaller values for leading heel position on the step (Table 1; Figs. 1, 2). Trailing vertical toe clearance (P = 0.65), swing duration (P = 0.51), and leading foot position before the step (P = 0.09) were all unaffected by dioptric blur.

In 18 trials (12% of all trials) of six subjects, a momentary loss of balance (with the trailing foot and/or arm movements used to help regain balance) occurred, or a compensatory movement strategy (often an additional small step or shuffle on the step) was used. These missteps occurred most with +2.00 DS (nine 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 stereocuity, and losses were essentially the same at the same dioptric level—that is, visual acuity was reduced to 0.30 logMAR (20/40) and stereocuity to approximately 2.55 log seconds of arc (555 seconds) for both +2.00 and −2.00 DS (Table 1). The amount of blur and the depth information available at the step edge should therefore have been very similar in the +1.00 DS and −1.00 DS conditions and the +2.00 and −2.00 DS conditions for all participants when standing two walking paces away from the step edge at the start of each trial.

Previous results from studies investigating the effects of diffuse blur on step negotiation would suggest that the dioptric blur would lead to safety strategies, such as the use of increased vertical toe clearance, 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 stereocuity 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 +1.00 and −1.00 DS and increasing further with +2.00 and −2.00 DS (Fig. 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% (+2.00 DS), +1.75% (+1.00 DS), −1.70% (−1.00 DS), and −3.50% (−2.00 DS), 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 farther away and smaller with minus lenses or closer and taller with plus lenses. For example, as the step appeared farther away with negative lenses, the trailing foot position before the step was placed significantly closer to the actual step than in the control condition. The step looked closer with positive lenses, the trailing foot position before the step was placed significantly farther away from the actual step than the control condition. The minification of the step with negative lenses meant that the leading vertical toe clearance was reduced with −1.00 and −2.00 DS. Similarly, magnification of the step with positive lenses increased leading vertical toe clearance. Given the reduction in toe clearance with negative lenses compared with the optimal refractive correction, the increased toe clearance (and other step negotiation changes) with positive lenses do not appear to be a safety strategy, but essentially driven by the magnification changes. Indeed, not only do magnification effects appear to drive adaptive gait changes, but they override any safety adaptations due to blurred vision. Other properties that are different for posi-

![Figure 1](http://iovs.arvojournals.org/pdfaccess.ashx?url=/data/journals/iovs/932966/)  
**FIGURE 1.** Mean ± 1 SD data for leading vertical toe clearance in 10 older participants with optimal refractive correction and with +1.00, +2.00, −1.00, and −2.00 DS dioptric blur. The mean and ±1 SD data of adaptive gait parameters during step negotiation are shown in Table 1. Several parameters were significantly affected by dioptric blur: trailing foot position before the step (F4.46 = 23.6, P < 0.0001), leading vertical toe clearance (F4.46 = 22.3, P < 0.0001; Fig. 1), leading horizontal toe clearance (F4.46 = 26.8, P < 0.0001), trailing horizontal toe clearance (F4.46 = 50.9, P < 0.0001), and leading heel position on the step (F4.46 = 23.6, P < 0.0001; Fig. 2). Equal values of dioptric blur led to very different changes in step negotiation as +1.00 and +2.00 DS led to much larger values than −1.00 and −2.00 DS, respectively (post-hoc P < 0.05) for leading toe position before the step, leading vertical toe clearance, leading horizontal toe clearance, and trailing horizontal toe clearance and smaller values for leading heel position on the step (Table 1; Figs. 1, 2). Trailing vertical toe clearance (P = 0.65), swing duration (P = 0.51), and leading foot position before the step (P = 0.09) were all unaffected by dioptric blur.

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![Figure 2](http://iovs.arvojournals.org/pdfaccess.ashx?url=/data/journals/iovs/932966/)  
**FIGURE 2.** Mean ± 1 SD data for leading foot heel position on the step/raised surface in 10 older participants with optimal refractive correction and with +1.00, +2.00, −1.00, and −2.00 DS dioptric blur. The edge of the raised surface/step is represented at 0 mm (y-axis). Positive y-axis values correspond to the leading foot stepping higher than the raised surface/step. Dashed line: hypothetical changes in vertical toe clearance if they were safety driven and due to blurred vision.

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tive and negative lenses, such as pin cushion distortion, additive axial chromatic aberration, and decreased field of view for positive lenses and barrel distortion, reduced chromatic aberration, and increased field of view for negative lenses were considered as possible causes of the adaptive gait changes, but no plausible links were found. If gaze fixation of the step edge was continued closer than two walking paces, vision with the positive lenses would improve, whereas vision with negative lenses would get worse. Results in previous research\textsuperscript{23,24} suggest that if this occurred, it would lead to increased vertical toe clearance with negative lenses compared with positive lenses, which is the opposite of what occurred.

The major strength of the method used in this study was that it allowed the strong influence of lens magnification on adaptive gait to be highlighted. Magnification drove adaptive gait changes and dominated any safety adaptations due to blurred vision. Limitations of this method were that the adaptive gait changes could have been due to other properties of the trial case lenses (although this explanation is very unlikely, as has been discussed) and that newly prescribed spectacles provide clear vision with spectacle magnification and not blurred vision. In this respect a useful alternative approach would have been to assess the effect of positive and negative size lenses on adaptive gait. Size lenses alter magnification without changing the clarity of vision, properties that are similar to those provided by newly prescribed spectacles.

Spectacle magnification effects also change the vestibulo-ocular reflex (VOR) gain\textsuperscript{,24} which links the vestibular system with the extraocular 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 relearnt.\textsuperscript{25,26} Before this relearning, the world “swims”\textsuperscript{24} as some patients report. It is of interest that declines in the VOR with age have been linked with gait and balance measures.\textsuperscript{27} Changes in astigmatism can cause even more problems initially because different amounts of magnification occur along two meridians and along different meridians in the two eyes, so that objects look distorted. Symptoms can include walls, doors, and floors sloping.\textsuperscript{22,28} Clinicians suggest that adapting to new spectacles is more difficult for older adults\textsuperscript{22,28} and it is certainly a major concern for older patients attending an eye examination.\textsuperscript{29} For these reasons, some clinicians recommend only prescribing partial changes in refractive error to help adaptation, particularly in older patients.\textsuperscript{22,28} Unfortunately, these recommendations are not supported by any research evidence (they are based on clinical experience gained from dissatisfied patients who return to complain about their spectacles) and do not appear to be widely used (for example, the optometric intervention study of Cumming et al.\textsuperscript{17} made no use of partial prescription of large refractive correction changes in frail older adults). Certainly, the magnification effects of changing spectacles and having cataract or refractive surgery focus on the positive effect on visual acuity with myopia reduction,\textsuperscript{19} 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 to a new refractive correction in older adults. In the meantime, given the apparent increase in the fall rate with large changes in spectacle correction,\textsuperscript{12} we suggest that partial changes in correction be prescribed in such cases when the patient is an older adult with a high risk of falling.\textsuperscript{22} In addition, all older patients should be appropriately warned of the effects of changed refractive error after cataract surgery and/or when they first receive 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 farther away and hyperopic shifts cause steps to appear larger and closer.

\textbf{Acknowledgments}

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\textbf{References}

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