VISUAL IMPAIRMENT AND POSTURAL SWAY AMONG OLDER ADULTS WITH GLAUCOMA

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ABSTRACT

PURPOSE: To investigate the effect of visual impairment on postural sway among older adults with open-angle glaucoma.

METHODS: This study included 54 community-dwelling participants with open-angle glaucoma, aged 65 and older. Binocular visual field loss was estimated from merged monocular Humphrey Field Analyzer visual field results and retinal nerve fiber layer (RNFL) thickness was obtained from the Stratus Optical Coherence Tomographer. Postural sway was measured under four conditions: eyes open and closed, on a firm and a foam surface. Data were collected for additional vision measures (visual acuity and contrast sensitivity), physical performance measures (self-reported physical activity levels and six-minute walk test), and demographic measures (age, gender, body mass index and medical history). Multivariate linear regressions, adjusting for confounding factors, were performed to determine the association between visual loss and postural sway.

RESULTS: Participants with greater binocular visual field loss or thinner RNFL thickness showed increased postural sway, both on firm and foam surfaces, independent of age, gender, BMI and physical performance levels. These visual loss measures were significant predictors of postural sway, explaining almost 20% of its variance on the foam surface. Furthermore, participants with greater inferior hemifield visual field loss showed increased postural sway on the foam surface. Increasing glaucomatous visual impairment was accompanied by a steady decrease of the visual contribution to postural control.

CONCLUSION: Among older adults with glaucoma, greater visual field loss or thinner RNFL thickness is associated with reduced postural stability. This postural instability may be a contributing factor in the increased risk of falls among older adults with glaucoma.

KEY WORDS: glaucoma; visual field; postural sway; balance; ageing
Falls occur increasingly frequently as people age, with more than a third of adults aged 65 and older experiencing a fall each year.\textsuperscript{1,2} Many experience physical and emotional injuries as a result,\textsuperscript{1,2} with falls being the leading cause of injury-related hospitalization and death in the older population.\textsuperscript{3} A number of visual function measures have been identified as contributing to falls,\textsuperscript{4} which is important given the increasing loss of visual function with age.\textsuperscript{5} In particular, ageing is associated with an increased prevalence of visual field loss, primarily due to glaucoma.\textsuperscript{6,7} Several large population studies have found significant associations between visual field loss and poor mobility\textsuperscript{8} or falls.\textsuperscript{7,9,10} Individuals with glaucoma report difficulties with mobility,\textsuperscript{11} demonstrate reduced mobility performance,\textsuperscript{12} and are more likely to experience a fall\textsuperscript{1,13} or a hip fracture\textsuperscript{14} than those without glaucoma. There is also evidence that the use of nonmiotic topical glaucoma medications (predominantly beta-blockers) can increase the risk of falling in this population.\textsuperscript{2,15} However, the underlying factors that lead to falls among older adults with glaucomatous visual field loss are not fully understood.

Reduced postural control is an important factor in terms of falls assessment as it has been identified as an important risk factor for falling.\textsuperscript{16,17} The visual system plays an important role in postural control, together with the vestibular and somatosensory systems.\textsuperscript{18} It has been well documented that postural control among individuals with normal vision is impaired in the presence of simulations of visual impairment, including refractive blur,\textsuperscript{19-21} cataract blur,\textsuperscript{20} and visual field restriction.\textsuperscript{21,22} Studies have also demonstrated reduced postural stability in individuals with true visual impairment including age-related macular degeneration,\textsuperscript{23} and cataracts, with improvements in postural stability being recorded following cataract surgery.\textsuperscript{24} Of direct relevance to the research reported here is the study of Shabana et al\textsuperscript{25} who assessed postural stability using force platform analysis in 35 open-angle glaucoma patients and 21 age-matched controls. While no significant differences in sway measures between the two groups were found, their sample of glaucoma patients was relatively young (aged 40-66 years) which is not necessarily representative of glaucoma patients in general. It is important to fully explore the relationship between visual field loss and postural stability within an older population, given the increasing prevalence of glaucoma in those aged 60 years and older.\textsuperscript{6}

Evidence suggests that ageing is associated with an increase in the contribution of vision to postural control, which acts to compensate for the age-related deterioration in the
somatosensory and vestibular systems. However, ocular disease is accompanied by a decrease in the visual contribution to postural control. Shabana et al demonstrated that visual field loss from glaucoma was significantly associated with a reduction in the visual contribution to postural control, by an amount that correlated with the extent of visual field loss. Similar studies have found that the visual contribution to postural control is reduced among individuals with retinitis pigmentosa and with central field loss. These findings suggest that older adults with visual impairment arising from ocular disease are more likely to show signs of reduced postural stability due to declines in several balance sensory systems.

The current study aimed to examine the effect of glaucomatous visual impairment on postural sway in a community-based sample of older adults and to assess its impact on the visual contribution to postural control. This study extends previous research by assessing postural sway in an older glaucoma population, with adjustment for several possible confounding factors and incorporating a comprehensive set of vision measures.

METHODS:
Subjects
Fifty-four community-dwelling individuals aged 65 or older diagnosed and currently being treated for open-angle glaucoma were recruited for this study. Participants were recruited from the clinical records of the Queensland University of Technology Optometry Clinic and private ophthalmology practices. Participants were required to have no significant ocular or visual pathway disease leading to visual field loss, other than glaucoma, including any form of cataracts graded 3.0 or worse as defined by the Lens Opacities Classification System III. Participants with Parkinson’s Disease, with a history of dizziness or vestibular disease, who used walking aids, or with signs of cognitive impairment (Mini-mental State Examination score <24 out of 30) were excluded. The research followed the tenets of the Declaration of Helsinki, and informed consent was obtained prior to participant assessment. The research was approved by the Queensland University of Technology Human Research Ethics Committee.

Visual Function Assessment
All participants underwent an eye examination which included ophthalmoscopy, slit-lamp biomicroscopy and fundus photography, to confirm eligibility for the study. Presenting
monocular visual acuities (VA) were measured with participants’ habitual refractive correction using the Bailey-Lovie high contrast letter chart at 6 metres. Visual acuity was scored as the total number of letters read correctly, converted to logMAR units.\textsuperscript{33} Contrast sensitivity (CS) was measured monocularly with habitual refractive correction using the Pelli-Robson letter chart at 1 meter with a +0.75DS working distance correction in place,\textsuperscript{34} and scored as the number of letters correctly identified.\textsuperscript{35} The better of the two monocular scores were used, given that they closely predict binocular visual function.\textsuperscript{36}

Visual fields were assessed using the Humphrey Field Analyzer II (model 750, Carl Zeiss Meditec Inc., Dublin, CA). All participants had previous experience with automated perimetry, and testing was performed by an experienced optometrist (AB) to ensure reliable visual field data. Monocular 24–2 SITA-Standard threshold tests were performed, and graded using the Advanced Glaucoma Intervention Study (AGIS) visual field scoring criteria.\textsuperscript{37} The right and left fields were merged to create a binocular visual field extending 60° horizontally (VF60), based on the more sensitive of the two visual field locations in each eye,\textsuperscript{38} and a mean deviation score was calculated. In addition, monocular 81-point, single intensity (24dB) screening strategy tests were performed. The results were merged to create a 96-point binocular visual field extending 120° horizontally (VF120) based on the more sensitive of the two visual field locations in each eye according to the method described by Turano et al.\textsuperscript{8} The total number of points missed was counted for the binocular VF120 visual field. Retinal nerve fibre layer (RNFL) thickness, in micrometers (μm), was measured for each eye using the Stratus OCT 3000 (software version 4.0.5, Carl Zeiss Meditec Inc, Dublin, CA).\textsuperscript{39,40} Well-focused, centred scans with a signal strength > 6 using the Fast RNFL Thickness 3.46 Scan protocol were included in the analyses. The thicker average RNFL thickness of the two eyes was used as a measure of binocular visual function.

Demographic and Physical Performance Assessment
Data were collected on demographic information (age and gender) and medical information (self-rated health, medical history and current medication use). The number of falls in the 12 months prior to participation in the study was determined by self-report. Cognitive status was assessed using the standardized Mini-Mental State Examination (MMSE) to ensure inclusion eligibility.\textsuperscript{32} Body mass index (BMI) was calculated as weight divided by the square of height. Self-reported physical activity levels were assessed using
the Physical Activity Scale for the Elderly (PASE). This is a validated questionnaire specific to the older population, based on a range of leisure, household, and occupational activities performed seven days prior to assessment. Participants completed a six-minute walk test (6MWT), which is a sub-maximal performance-based measure of functional exercise level, incorporating the impact of co-morbidities, overall muscle strength, endurance and disability. In this test the distance, in metres, that a participant could quickly walk along an indoor, well-lit level corridor for a period of 6 minutes was recorded.

**Postural Sway Assessment**

Postural sway was measured during quiet stance with a swaymeter (Prince of Wales Medical Research Institute, Sydney, Australia) which determines the amount of body displacement at waist height. The device consists of a rod attached to the participant's waist with a firm belt. Body movement is recorded with a pen onto graph paper attached to a table positioned behind the subject. This device provides a simple, valid clinical measure of postural control, used frequently in falls risk assessment.

Full descriptions of the apparatus and procedures along with test-retest reliability have been described elsewhere.

Testing was performed with bare feet set comfortably apart, with arms relaxed by the sides and gaze directed forwards with habitual refractive correction. Sway was measured for 30 seconds in each of four conditions: (i) eyes open, firm surface; (ii) eyes closed, firm surface; (iii) eyes open, foam surface; (iv) eyes closed, foam surface. The firm surface was a carpeted, level floor. The foam surface was a high-density foam rubber (70cm by 60cm by 15cm thick), used to reduce the somatosensory contribution to postural stability. Postural sway in each condition was calculated as the logarithm of the total sway area (mm²), determined by the product of maximal amplitude of anterior-posterior and lateral sway. Larger values indicated a greater amount of postural sway.

The visual contribution to postural stability was calculated using a Visual Stability Ratio (VSR). Previous studies have established that compared to the Romberg quotient, this ratio has less variability and a normal distribution. The VSR was defined as

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\text{Visual Stability Ratio (VSR)} = 1 - \frac{\text{postural sway with eyes open, on foam}}{\text{postural sway with eyes closed, on foam}}
\]
A value of 0 or less indicated no visual contribution to postural stability. Values greater than 0 indicated a visual contribution, such that less postural sway occurred with eyes open as compared with eyes closed.

**Statistical Analysis**

Statistical analyses were performed using SPSS (version 14.0, SPSS, Chicago, IL) and p-values less than .05 were used to indicate statistical significance. Standard measures of central tendency were used to describe the study population with respect to demographic, physical performance and visual function measures. VF60 scores were inverse log transformed and VF120 scores were square-root transformed to normalize their distributions. Bivariate correlations were performed between the demographic, physical performance and visual function measures with the postural sway measures (eyes open and closed, firm and foam surface) and VSR. Correlations were expressed as Pearson’s r unless otherwise stated. Spearman’s rank test was used for variables not considered normally distributed.

Separate linear regression models were used to determine the association between postural sway (eyes open, firm and foam surface) and each of the binocular visual loss measures (VF120, VF60 and RNFL thickness). Characteristics considered likely to be associated with visual impairment and postural sway based on previous literature and clinical judgments were included as potential confounders. Reductions in physical functional status and well-being are associated with visual impairment,\(^{49}\) while reductions in lower-limb and musculoskeletal function can affect postural sway.\(^ {18,50}\) Therefore, the PASE, 6MWT and BMI variables were included in the analyses to adjust for the participants’ level of functional status, in addition to demographics characteristics such as age and gender, regardless of their statistical significance with the visual function and postural sway measures.

To assess the association between the degree of hemifield asymmetry and postural sway, we included the Hemifield Difference Score (HDS) for each binocular visual loss measure into the linear regression models, adjusting for overall visual loss (for that particular measure) and confounding variables. This score was derived due to multicollinearity considerations, as strong correlations existed between loss in the superior and inferior
hemifields on VF120, VF60 and RNFL thickness. Separate scores were calculated for each binocular visual loss measure: difference in percentage of points seen in the inferior and superior field areas on VF120; difference in mean deviation between the inferior and superior field areas on VF60; and difference in RNFL thickness between the better-eye superior quadrant and the better-eye inferior quadrant. In each case, positive values indicated a greater degree of superior hemifield vision loss relative to the inferior hemifield.

Finally, separate linear regression models were used to determine the association between VSR and each of the binocular visual loss measures. Because the VSR determines the visual contribution to postural stability, these models were adjusted only for age and gender.

In addition to obtaining the squared multiple correlation coefficients ($R^2$) for the linear regression models, the squared semipartial correlations ($sr^2$) were examined because these express the unique contribution of each predictor variable to the dependent variable. Residuals were evaluated in all models to confirm the model assumptions of normality, linearity and homoscedasticity. The impact of collinearity among explanatory factors was examined by calculation of variance inflation factors (VIF) and multi-collinearity (unacceptably high degree of correlation between the variables) was defined as a VIF value of 3 or more.51

RESULTS:
The demographic, physical performance, postural sway and visual function characteristics of the 54 participants are presented in Table 1. The mean age was 74.4 years (sd ± 5.8). A greater proportion of men participated in the study (n=33, 61%), although there was no significant difference in age between males and females ($t_{(52)}=0.41, p=0.69$). In the previous 12 months, 19 subjects (35%) reported at least one fall and six subjects (11%) reported two or more falls, with no gender differences between fallers ($\chi^2; p=0.35$) or multiple fallers ($\chi^2; p=0.14$). According to the AGIS visual field scoring criteria in the better-eye, 30 participants had no field loss, 12 mild loss and 12 moderate or worse. There was a high correlation between AGIS visual field scores between each eye ($r=0.71, p<0.001$, Spearman’s). Due to missing or poor OCT scans, RNFL data were only available for 48 participants. The treatment of glaucoma in all but one participant was by
means of topical anti-glaucoma medications. Of these, 19 (36%) were using two or more topical preparations and 22 (42%) were using a topical beta-blocker medication.

The correlations between the demographic, physical performance and visual function measures and postural sway are summarized in Table 2. On the firm surface with eyes open, postural sway was significantly correlated with age and 6MWT, along with VF120, VF60 and RNFL thickness. There were no significant correlations with postural sway on the firm surface with eyes closed. On the foam surface with eyes open, postural sway was significantly correlated with PASE and 6MWT, in addition to AGIS score, VF120, VF60 and RNFL thickness. Only age was significantly correlated with postural sway on the foam surface with eyes closed. Figure 1 shows the relationship between VF120 and postural sway on the foam surface with eyes open. On the firm surface, males had significantly larger postural sway areas compared with females ($t(52)=2.07$, $p=0.04$), however no difference was found on the foam surface ($t(52)=1.42$, $p=0.16$). There were no significant differences in postural sway in all conditions between those using topical glaucoma beta-blocker medications and those not using these medications ($p>0.05$).

Table 3 presents the results from the linear regression models examining the effect of binocular visual loss on postural sway and VSR. With eyes open on the firm surface, postural sway was significantly associated with VF120 and RNFL thickness, independent of age, gender, BMI, PASE and 6MWT, while VF60 just failed to reach statistical significance ($\beta=0.25$, $p=0.08$). Examination of the squared semi-partial correlations revealed that these measures uniquely explained 5 to 8% of its variance. Postural sway with eyes open on the firm surface was not associated with any of the HDS measures, after adjusting for age, gender, BMI, PASE, 6MWT and overall visual loss.

On the foam surface with eyes open, postural sway on the foam surface was significantly associated with all binocular visual loss measures (VF120, VF60 and RNFL thickness), independent of age, gender, BMI, PASE and 6MWT. The squared semi-partial correlations revealed that these measures uniquely explained 17 to 20% of its variance. Postural sway on the foam surface with eyes open was significantly associated with HDS (VF120), after adjusting for age, gender, BMI, PASE, 6MWT and VF120 score, uniquely explaining around 9% of its variance. There was some association between postural
sway on the foam surface and HDS (VF60), but this failed to reach statistical significance ($\beta = 0.24$, $p=0.07$), while no association was found with HDS (RNFL).

Because two participants could not complete the sway testing with eyes closed on the foam condition unassisted, VSR data were available for 52 participants. All binocular visual loss measures were significant predictors of VSR, independent of age and gender. The RNFL thickness measure was the strongest predictor of VSR, uniquely explaining almost 23% of its variance. Figure 2 plots the relationship between RNFL thickness and VSR. There was no significant association between VSR and VA ($r=-0.07$, $p=0.63$, Spearman's), CS ($r=0.18$, $p=0.20$, Spearman's) or age ($r=0.10$, $p=0.48$). There was no significant difference in VSR between males and females ($t(50)=-0.43$, $p=0.67$).

**DISCUSSION:**

This study found a significant association between glaucomatous visual impairment and postural sway in older adults. Greater binocular visual field loss or thinner RNFL thickness was significantly associated with increased postural sway with eyes open, particularly on the foam surface, independent of age, gender, body mass index and physical performance level. This cohort demonstrated similar levels of physical function compared to that of the general community-dwelling older population, in terms of their self-reported physical activity, performance on the six-minute walk test, and the number of reported falls. It is likely that in a frailer population, the effect of glaucomatous visual impairment on postural stability may be even greater.

These results do not support those of Shabana et al, who failed to find any significant differences in postural sway between subjects with glaucomatous visual field loss and those with normal vision, based on measures of force platform sway velocities. To explain their findings, Shabana et al demonstrated that the glaucoma patients, aged between 40 and 66 years, showed greater somatosensory contributions to postural stability to maintain steady stance, as compared to controls. While there are differences in the measures of sway and the degree of visual impairment between studies, it is likely that Shabana et al’s failure to find an association between visual field loss and postural sway is due to their considerably younger sample as compared to those tested in the current study. Ageing, particularly in those aged over 60, is associated with significant declines in the somatosensory and vestibular systems, in addition to an increasing prevalence of
glaucoma. The findings from the current study suggest that older adults with glaucomatous visual impairment are less likely to increase their somatosensory contribution to postural stability, resulting in greater postural sway.

Our results are more consistent with previous studies which have examined the influence of peripheral visual field loss on postural sway among normally sighted individuals. Straube et al and Nougier et al both demonstrated significant contributions of peripheral vision to the maintenance of postural stability, in addition to the contribution of central vision. More recently, Berensci et al reported that peripheral vision provides a stronger postural stabilizing effect than central vision. Their study showed that significant improvements in postural stability occurred with peripheral visual stimulation as compared to stimulation of the central four degrees.

The current study found that the effect of visual field loss on postural sway was considerably stronger on the foam surface, explaining almost 20% of its variance, as compared to almost 8% of the variance on the firm surface. This is consistent with findings from previous studies, as the contribution of vision to postural control increases to maintain balance in compensation for the reduced somatosensory input. Importantly, the findings on the foam surface emphasize the significant relationship between vision and balance and further highlight the detrimental effect of glaucomatous visual impairment on postural control. There was no association between any of the vision measures and postural sway with eyes closed, which was expected given the lack of visual input during these conditions.

There was evidence in the current study to suggest that a greater degree of inferior hemifield visual field loss was associated with increased postural sway, particularly on the foam surface. This was not supported by the findings on the firm surface, possibly due to the weak visual contribution in this condition. In contrast to the visual field loss results, hemifield differences in RNFL thickness were not associated with postural sway on the foam surface. This disparity may be due to the smaller data set used in the RNFL analyses or inaccuracies in regional RNFL measurement, which are known to vary according to the distance measured from the optic nerve rim.
Previous studies with visually impaired individuals have indicated that greater loss in the central and lower visual field areas are significantly associated with reduced mobility performance.\textsuperscript{8,56} Moreover, there is some evidence that falls may occur more frequently in those with inferior visual field loss.\textsuperscript{9} Coleman et al\textsuperscript{9} reported that the odds of falling among older women with severe inferior visual field loss, as compared to no inferior loss, was 91% higher, while the odds of falling among those with severe superior visual field loss, as compared to no superior visual field loss, was 74% higher. While it is likely that the inferior visual area is critical to mobility performance, particularly for obstacle detection and avoidance, the findings from the current study are the first to suggest that the inferior visual field may provide a stronger contribution to postural stability than the superior visual field.

It has been hypothesized that the inferior visual field provides a greater contribution to the dorsal visual pathway, a pathway that travels from the primary visual cortex to the posterior parietal lobe and mediates visually guided movements.\textsuperscript{57,58} A number of behavioral studies have shown that the inferior visual field is more effective in visually guided reaching and aiming movements compared to the superior visual field.\textsuperscript{57,58} The cortical control of postural stability may incorporate this visuo-motor pathway, given our findings that a greater degree of inferior visual field loss reduces postural stability.

In this study, the contribution of vision to postural control was shown to decline steadily with increased binocular visual loss, independent of age and gender, in agreement with previous studies.\textsuperscript{25,29} Shabana et al\textsuperscript{25} demonstrated that individuals with glaucomatous visual field loss reduce their visual contribution to postural stability, by an amount that correlated with severity of field loss. In their study, the mean deviation visual field index in the worse-eye was the strongest correlate with the visual stabilization ratio ($r=0.40$, Spearman's). The magnitudes of association are comparable to the current study, despite the differences in the cohort characteristics and the postural stability and visual field measures analyzed. In a study by Turano et al,\textsuperscript{29} individuals with retinitis pigmentosa demonstrated a steady decrease in visual contribution to stability, correlating strongly with severity of disease ($r = -0.59$). In the same study, they further demonstrated that artificial field restriction in those with normal vision is correlated with a reduction in the visual contribution to stability, although not to the same extent as in those with retinitis pigmentosa.
Interestingly in the current study thinning of the RNFL was the strongest predictor of the visual contribution to postural stability, explaining nearly 23% of its variance, twice that of the binocular visual field measures. This disparity was not evident in the postural sway models. This stronger association may be due to the fact that damage to the RNFL may precede visual field loss, or that RNFL thickness may reflect declines in other visual functions that influence postural control, such as motion detection. This may be an important direction for future research, given that previous studies indicate that motion sensitivity is significantly reduced in glaucoma patients.

This study may have been improved by using force platform analysis, which can provide extensive data pertaining to velocity, area and displacement of the centre of pressure occurring at ground level. However, no one sway measure is able to completely reflect the complex nature of postural stability, due to the many inherent factors that can contribute to the variability of these measures. While the sway measure used in the current study is less detailed than force platform data, it does provide a basic representation of body trunk displacement, shown to be a valid measure of underlying balance impairment. While there was no exclusion of subjects based on any lower limb pathology, the inclusion of alternative measures of physical function (PASE and 6MWT), which is influenced by lower leg strength and co-morbidities, overcomes this limitation.

The strengths of this study include the use of various binocular visual loss measures which reflect the level of visual disability encountered under normal binocular viewing conditions and the use of analytical techniques which adjusted for potential confounding variables. Importantly, this study assessed an older cohort with glaucoma, aged over 65 years who have been identified as being more likely to experience falls or fall-related injuries.

In summary, the findings of this study indicate that greater binocular visual field loss or thinner RNFL thickness in older adults with glaucoma is significantly associated with increased postural sway. Furthermore, postural sway was greater in those with a greater degree of inferior hemifield visual field loss, particularly on the foam surface. Increasing loss of visual field or RNFL thickness was accompanied by a steady decrease of the visual contribution to postural control. These postural changes may be an underlying factor in the increased risk of falls and fall-related injuries among older adults with glaucoma.
Ensuring that eye-care practitioners, supporting health-care workers and individuals with glaucoma are aware of these findings may assist in reducing the occurrence of future falls.

**Acknowledgments:**

This project was supported by Queensland University of Technology and Institute of Health and Biomedical Innovation. We thank all of the subjects who participated in the study, Philippe Lacherez for assistance with statistical advice and Chris Johnson for assistance in visual field data conversion.
REFERENCES


Table 1: The characteristics of the 54 study participants

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
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<tbody>
<tr>
<td>Demographics</td>
<td></td>
</tr>
<tr>
<td>Age (years), mean ± sd (range)</td>
<td>74.4 ± 5.8 (65 - 90)</td>
</tr>
<tr>
<td>Female, n (%)</td>
<td>21 (39%)</td>
</tr>
<tr>
<td>Chronic conditions</td>
<td></td>
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<tr>
<td>Diabetes Mellitus, n (%)</td>
<td>4 (7%)</td>
</tr>
<tr>
<td>Previous hip fracture, n (%)</td>
<td>2 (4%)</td>
</tr>
<tr>
<td>Self-rated health, n (%)</td>
<td></td>
</tr>
<tr>
<td>Excellent, Very Good,</td>
<td>24 (42%)</td>
</tr>
<tr>
<td>Good, Fair</td>
<td>31 (59%)</td>
</tr>
<tr>
<td>Poor</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Falls in previous year, n (%)</td>
<td></td>
</tr>
<tr>
<td>One or more</td>
<td>19 (35%)</td>
</tr>
<tr>
<td>Two or more</td>
<td>6 (11%)</td>
</tr>
<tr>
<td>Body mass index (kg/m2), mean ± sd</td>
<td>26.6 ± 3.2</td>
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<tr>
<td>PASE (weighted score), mean ± sd</td>
<td>126.2 ± 48.5</td>
</tr>
<tr>
<td>Six-minute walk test (metres), mean ± sd</td>
<td>503.1 ± 71.1</td>
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<tr>
<td>Postural sway, eyes open on firm, log(mm²), mean ± sd</td>
<td>2.19 ± 0.37</td>
</tr>
<tr>
<td>Postural sway, eyes open on foam, log(mm²), mean ± sd</td>
<td>2.82 ± 0.32</td>
</tr>
<tr>
<td>Visual Stability Ratio (VSR), mean ± sd</td>
<td>0.16 ± 0.08</td>
</tr>
<tr>
<td>Visual acuity, better eye (logMAR), med (range)</td>
<td>0.05 (-0.26 – 0.52)</td>
</tr>
<tr>
<td>Contrast sensitivity, better eye (logCS), med (range)</td>
<td>1.60 (0.65 – 1.70)</td>
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<tr>
<td>Visual field severity (AGIS score), better eye, n (%)</td>
<td></td>
</tr>
<tr>
<td>No defect (AGIS = 0)</td>
<td>30 (56%)</td>
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<tr>
<td>Mild defect (AGIS = 1-5)</td>
<td>12 (22%)</td>
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<td>Moderate defect (AGIS = 6-11)</td>
<td>6 (11%)</td>
</tr>
<tr>
<td>Severe to end-stage defect (AGIS = 12-20)</td>
<td>6 (11%)</td>
</tr>
<tr>
<td>Visual field VF60, mean deviation (dB), med (range)</td>
<td>-2.50 (+1.60 – -28.00)</td>
</tr>
<tr>
<td>Hemifield difference score VF60 (dB), mean ± sd</td>
<td>0.45 ± 3.84</td>
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<tr>
<td>Visual field VF120, points missed, med (range)</td>
<td>28 (6 - 96)</td>
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<tr>
<td>Hemifield difference score VF120 (%), mean ± sd</td>
<td>4 ± 16</td>
</tr>
<tr>
<td>Average RNFL thickness (μm), better eye, mean ± sd (n=48)</td>
<td>84.7 ± 18.8</td>
</tr>
<tr>
<td>Hemifield difference score RNFL (μm), mean ± sd</td>
<td>-6.73 ± 20.63</td>
</tr>
</tbody>
</table>

PASE = Physical Activity Scale for the Elderly; AGIS = Advanced Glaucoma Intervention Study; VF60 = Binocular 60º visual field; VF120 = Binocular 120º visual field; RNFL = Retinal Nerve Fiber Layer thickness; SD = standard deviation.
**Table 2:** Correlation coefficients between demographic, physical performance and visual function measures and postural sway.

<table>
<thead>
<tr>
<th></th>
<th>Postural sway, eyes open, firm</th>
<th>Postural sway, eyes closed, firm</th>
<th>Postural sway, eyes open, foam</th>
<th>Postural sway, eyes closed, foam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>0.30 *</td>
<td>0.14</td>
<td>0.25</td>
<td>0.40 **</td>
</tr>
<tr>
<td>PASE score</td>
<td>-0.22</td>
<td>-0.21</td>
<td>-0.33 *</td>
<td>-0.08</td>
</tr>
<tr>
<td>Six-minute walk test</td>
<td>-0.30 *</td>
<td>-0.10</td>
<td>-0.27 *</td>
<td>-0.09</td>
</tr>
<tr>
<td>Body mass index</td>
<td>0.07</td>
<td>0.07</td>
<td>-0.14</td>
<td>-0.27</td>
</tr>
<tr>
<td>Visual acuity, better eye†</td>
<td>0.03</td>
<td>0.01</td>
<td>0.21</td>
<td>0.26</td>
</tr>
<tr>
<td>Contrast sensitivity, better eye†</td>
<td>-0.10</td>
<td>-0.11</td>
<td>-0.15</td>
<td>-0.08</td>
</tr>
<tr>
<td>AGIS Score†</td>
<td>0.26</td>
<td>0.11</td>
<td>0.43 **</td>
<td>0.16</td>
</tr>
<tr>
<td>Binocular 120° visual field (VF120)</td>
<td>0.34 *</td>
<td>0.13</td>
<td>0.51 **</td>
<td>0.23</td>
</tr>
<tr>
<td>Binocular 60° visual field (VF60)</td>
<td>0.33 *</td>
<td>0.13</td>
<td>0.46 **</td>
<td>0.23</td>
</tr>
<tr>
<td>Average RNFL thickness, better eye</td>
<td>-0.34 *</td>
<td>-0.01</td>
<td>-0.47 **</td>
<td>-0.07</td>
</tr>
</tbody>
</table>

PASE = Physical Activity Scale for the Elderly; AGIS = Advanced Glaucoma Intervention Study; RNFL = Retinal Nerve Fiber Layer.

*P<.05; **P <.01; †Spearman’s Rank Correlation
### Table 3: Results of multiple linear regression analyses of the association between glaucomatous visual loss and postural sway and visual stability ratio (VSR).

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Predictor</th>
<th>Model R² (%)</th>
<th>Standardized β</th>
<th>Squared semi-partial correlation sr² (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Postural sway with eyes open, on firm</td>
<td>VF120&lt;sup&gt;a&lt;/sup&gt;</td>
<td>26.8</td>
<td>0.27 *</td>
<td>6.3</td>
</tr>
<tr>
<td></td>
<td>VF60&lt;sup&gt;a&lt;/sup&gt;</td>
<td>25.7</td>
<td>0.25</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td>RNFL&lt;sup&gt;a&lt;/sup&gt;</td>
<td>29.9</td>
<td>-0.31 *</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td>HDS (VF120)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>28.5</td>
<td>0.15</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td>HDS (VF60)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>30.4</td>
<td>0.25</td>
<td>4.7</td>
</tr>
<tr>
<td></td>
<td>HDS (RNFL)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>32.2</td>
<td>0.18</td>
<td>2.3</td>
</tr>
<tr>
<td>Postural sway with eyes open, on foam</td>
<td>VF120&lt;sup&gt;a&lt;/sup&gt;</td>
<td>39.7</td>
<td>0.48 **</td>
<td>19.4</td>
</tr>
<tr>
<td></td>
<td>VF60&lt;sup&gt;a&lt;/sup&gt;</td>
<td>37.2</td>
<td>0.45 **</td>
<td>16.9</td>
</tr>
<tr>
<td></td>
<td>RNFL&lt;sup&gt;a&lt;/sup&gt;</td>
<td>37.9</td>
<td>-0.48 **</td>
<td>17.6</td>
</tr>
<tr>
<td></td>
<td>HDS (VF120)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>48.9</td>
<td>0.35 **</td>
<td>9.2</td>
</tr>
<tr>
<td></td>
<td>HDS (VF60)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>41.7</td>
<td>0.24</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>HDS (RNFL)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>38.3</td>
<td>0.08</td>
<td>0.4</td>
</tr>
<tr>
<td>Visual stability ratio (VSR)</td>
<td>VF120&lt;sup&gt;c&lt;/sup&gt;</td>
<td>12.8</td>
<td>-0.35 *</td>
<td>11.4</td>
</tr>
<tr>
<td></td>
<td>VF60&lt;sup&gt;c&lt;/sup&gt;</td>
<td>10.5</td>
<td>-0.32 *</td>
<td>9.1</td>
</tr>
<tr>
<td></td>
<td>RNFL&lt;sup&gt;c&lt;/sup&gt;</td>
<td>24.3</td>
<td>0.50 **</td>
<td>22.9</td>
</tr>
</tbody>
</table>

VF120 = Binocular 120° visual field; VF60 = Binocular 60° visual field; RNFL = Retinal nerve fiber layer thickness; HDS = Hemifield Difference Score.

<sup>a</sup> Adjusted for age, gender, BMI, PASE, 6MWT
<sup>b</sup> Adjusted for age, gender, BMI, PASE, 6MWT, and overall visual loss
<sup>c</sup> Adjusted for age, gender

*P<.05; **P <.01
Figure 1: Binocular 120° visual field score (VF120) as a function of postural sway area (mm²), with eyes open on a foam surface. Dotted line represents the least squares regression fit to the data, \( Y = 0.09 \times + 2.35; \ r = 0.51, \ p < 0.001 \). * Square root transformed.

Figure 2: Average retinal nerve fiber layer (RNFL) thickness in the better-eye (micrometers) as a function of visual stability ratio (VSR). Dotted line represents the least squares regression fit to the data, \( Y = 0.002 \times - 0.018; \ r = 0.48, \ p = 0.001 \).