Glare and Mobility Performance in Glaucoma: A Pilot Study

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Précis: Glare disability affects patients with moderate and severe glaucoma. Under glare conditions, mobility performances of glaucoma patients are reduced.

Purpose: The aim of this study was to evaluate glare disability and its impact on mobility and orientation in glaucoma patients.

Methods: Twenty-two glaucoma patients and 12 age-matched control subjects were included. All patients underwent a clinical evaluation of visual function and halo size measurements to determine glare disability with a glare score (GS) of the best eye and worse eye. Mobility was evaluated by 4 mobility courses on an artificial street (StreetLab) under photopic conditions (P) and mesopic conditions with an additional light source in front of the patient to mimic dazzling conditions (M+G). Mobility time, mobility incidents, trajectory segmentation, distance traveled, preferred walking speed on trial (WS) and percentage of preferred walking speed (PPWS) were recorded, and the Nasa task load index (Nasa-TLX) was evaluated.

Results: GS of the worse eye and GS of the best eye were significantly higher in glaucoma patients than in the control group ($P = 0.001$ and 0.003). It was significantly different between moderate glaucoma patients and controls ($P = 0.001$ and 0.010, respectively) and between severe glaucoma patients and controls ($P = 0.049$ and 0.016). In locomotion tasks, comparing performance under M+G and P conditions, mobility performance was significantly different concerning mobility time ($P = 0.010$), distance traveled ($P = 0.008$), WS ($P = 0.007$), PPWS ($P = 0.006$), and Nasa-TLX ($P = 0.017$) in the glaucoma group. Under M+G lighting conditions, mobility performance for glaucoma patients was significantly worse than controls with regard to WS ($P = 0.038$), PPWS ($P = 0.0498$), mobility time ($P = 0.046$), and Nasa-TLX ($P = 0.006$).

Conclusion: Glare disability was observed in patients with moderate and severe glaucoma and had an impact on their mobility performance.

Key Words: glare disability, glaucoma, mobility

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Glaucoma is an optic neuropathy associated with retinal ganglion cell degeneration with characteristic morphologic changes in the optic nerve head associated with visual field (VF) loss. Glaucoma is a leading cause of blindness worldwide with an estimated 112 million glaucoma patients by 2040.[1,2] Glaucoma can severely alter patients' quality of life, affecting activities of daily living.[3]

Among the visual complaints of glaucoma patients, a common symptom is photosensitivity with glare, which makes activities of daily living, such as outdoor activities and driving, more difficult.[4,5] Glare is defined as a dazzling sensation in relatively bright light, inducing unpleasantness or discomfort that may interfere with optimal vision. Glare disability is caused by intraocular light scattering originating from a bright source, reducing the contrast of retinal images by spreading a veil of light across them.[6,7] Exploring common everyday activities in glaucoma patients, Nelson et al[4] showed that most of them (70%) experienced problems with glare. In the Collaborative Initial Glaucoma Treatment Study, Janz et al[5] showed that over 50% of patients who drove reported difficulties in tasks involving glare.

Studying and measuring glare disability in the glaucoma patient is important to understand its influence on activities of daily living and mobility and to help find countermeasures to decrease its consequences for the patient. Nevertheless, until now, glare disability has been studied and measured mostly in healthy patients' driving tasks, before and after cataract surgery or refractive surgery.[8–11] Only 2 studies have evaluated the impact of lighting conditions on mobility in glaucoma.[12,13] These studies showed difficulties or risks of falling for glaucoma patients in low light conditions or high glare areas. However, evaluation of lighting conditions was based on self-reported questionnaires, and although this method is widely recognized, it is highly subjective and can be affected by numerous physical or psychological factors.[14]

Various tools have been developed to allow objective measurement of glare disability,[15] such as an indirect evaluation by contrast sensitivity (CS) measurements of stray light causing glare disability, or measuring the size of a glare source-induced halo.[15,16] Similarly, research platforms with controlled, reproducible environments have already been used to evaluate glaucoma patients' mobility in everyday conditions.[17,18] Research platforms offer realistic immersion in a real-life environment with adjustable lighting conditions. The controlled environment allows good reproducibility and reliability of mobility performance measurements.

Thus, the purpose of the present study was to evaluate glare disability in glaucoma patients and its impact on mobility performance in a simulated environment compared with control subjects.

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METHODS

Subjects

A total of 34 participants aged 35 to 74 years, including 22 with various stages of glaucoma and 12 age-related and sex-matched controls, were included. Glaucoma patients were followed regularly at the Quinze-Vingts National Ophthalmology Hospital in Paris, France. Each was informed of the purpose of the study, and his or her signed consent was obtained before inclusion. The study was approved by the Pitié-Salpêtrière Ethics Committee (CPP/84-16, number 2016-A0171-50) and the National Agency for the Safety of Medicines and Health Products (ANSM) (2014-A01924-43).

Clinical Tests

All patients underwent an evaluation of monocular and binocular best-corrected visual acuity (VA) measured with decimal notation first then converted to the logarithm of the minimum angle of resolution (LogMAR), and a binocular CS test (Log Contrast). For all patients, monocular and binocular VFs were also recorded. For monocular VFs, patients underwent a Humphrey perimeter 24-2 threshold test with the SITA-Standard program of the Humphrey Visual Field Analyzer (Carl Zeiss Meditec, Dublin, CA). The mean deviations (MDs) of the better and worse eye were recorded. Glaucoma severity was staged using the Hodapp-Parrish-Anderson classification.[19] For binocular VFs, patients underwent an Esterman binocular VF using the Humphrey Visual Field Analyzer. The Esterman score was reported as the number of points viewed out of the 120 points evaluated.

Glaucoma patients had no other ocular pathology such as visually significant cataract or corneal disease. Control subjects were free of any ocular pathology. For each recruitment, an orthoptist or optometrist was in charge of carrying out functional evaluations of their vision. Following the assessments, each participant was seen in consultation by an ophthalmologist. All subjects were required to be autonomous without motor or cognitive difficulties that could interfere with the patient's full understanding of the orders given or the execution of the tests. All patients underwent a Mini-Mental State Examination, and the minimum score required to participate in the study was defined as $\geq$25/30 for control subjects and $\geq$20/25 for glaucoma subjects (adapted version for visually impaired people; the 5 visual items are eliminated). Any subject with musculoskeletal limitations, cognitive or neural limitations, or endurance limitations (eg, coronary problems), was excluded. Patients were required to have stable glaucomatous neuropathy, defined as no change in disease management, intraocular pressure remaining at an individually satisfactory level, and no significant change in VF over 3 years, as confirmed by at least 3 VF examinations. To quantify vision loss associated with light scatter, all patients underwent a glare test.

Glare Test

The halo radius was measured using the Vision Monitor (MonCv3, Metrovision, France) at a distance of 2.5 m. This method has been described extensively by Puell et al.[20] The device has 2 circular white light sources (LEDs) on each side to generate glare. The visual angle of each source from the center of the monitor is 3.8 degrees. The right source was chosen to test right eyes and the left source to test left eyes. The light source illuminates the patient's eye and produces stray intraocular light, reducing the contrast of a foveal target. In this study, the test was performed using a letter luminance level of 5 cd/m^2. Optotypes were arranged in 3 radial lines of letters appearing from the periphery towards the glare source. Each line contains 10 letters forming 10 rings at intervals of 33 minutes of arc at a distance of 2.5 m. Each letter subtends 15 minutes of arc, corresponding to a VA of 0.5 (LogMAR). Monocular testing took place in a dark room with best spectacle correction. Before testing, the patient underwent a dark adaptation period of 5 minutes. For the test, the patient was seated 2.5 m from the monitor with the head aligned with the center of the monitor, using a chinrest. The patient was instructed to cover the untested eye and view the optotypes during simultaneous illumination of the eye with the glare source. The patient was instructed to not look directly at the light source, so as to avoid a retinal afterimage. Then the patient read each line starting from the side opposite the light source; that is, optotypes were read from the periphery towards the glare source until a letter could not be identified. The patient was encouraged to guess each letter when unsure. Letters not identified in each line were recorded, and the test result was calculated as the mean distance from the glare source for the 3 lines. This distance was taken as the radius of the halo. The visual angle formed by the radius of the halo was calculated in minutes of arc. Normal halo size values are 111.6 ± 39.8 minutes of arc.[20] Because many patients had a halo size greater than the Vison Monitor could measure ($>$330 min of arc), a semiquantitative score was created to classify patients: glare score (GS) 0 for patients with halo size $<$150 minutes of arc, GS 1 for patients with halo size 150 to 300 minutes of arc, and GS 2 for halo size $>$300 minutes of arc.

Platforms and Navigational Courses

Mobility performance under photopic lighting conditions (P) and mesopic conditions with glare (M+G) were evaluated in 4 different mobility courses. The courses were 8-m indoor routes in the Streetlab platform according to previously validated protocols.[17,18] Illumination was controlled in intensity and color temperature (250 lx, 4350 K) by 9 LED panels and reproduced under the same conditions for all participants. The mobility courses were performed first under P lighting (235 lx) and then under M+G mesopic lighting (10 lx) with an additional spot in front of the patient to represent a dazzling condition (15% cobalt). Dazzling spotlights were placed in front of the subject at the bottom of the course and adjusted to the size of the subject.

Subjects were instructed to walk at their preferred walking speed following an established route among obstacles such as low contrast gray boxes, building cones, roadside nails, curbs and mannequins. One example of a mobility course is shown in Figure 1. One course was performed to familiarize subjects with the principle of the mobility course. Then, a total of 4 mobility courses with a similar level of complexity and number of obstacles were performed in random order for all participants.[17,18] The time to complete the path, defined as "mobility time" and the number of "mobility incidents" such as bumps, stumbling and stops were recorded. The number of trajectory segments and distance traveled were also recorded. Trajectory segmentation was modeled with the simplified Ramer-Douglas-Peucker algorithm (epsilon value 20 cm) to identify changes in direction using inflexion points.[21,22]

At the conclusion of the 4 mobility courses for each illumination condition, subjects were asked to walk an 8 m path. Each subject was instructed that the 8 m path was straight and unobstructed. They were asked to walk at their normal, comfortable pace. This walk was timed, and each subject's preferred walking speed (PWS) was determined for each lighting condition. A normalized walking speed was calculated by dividing a subject's walking speed (WS) from the mobility course by the speed while walking a straight unobstructed path (PWS),

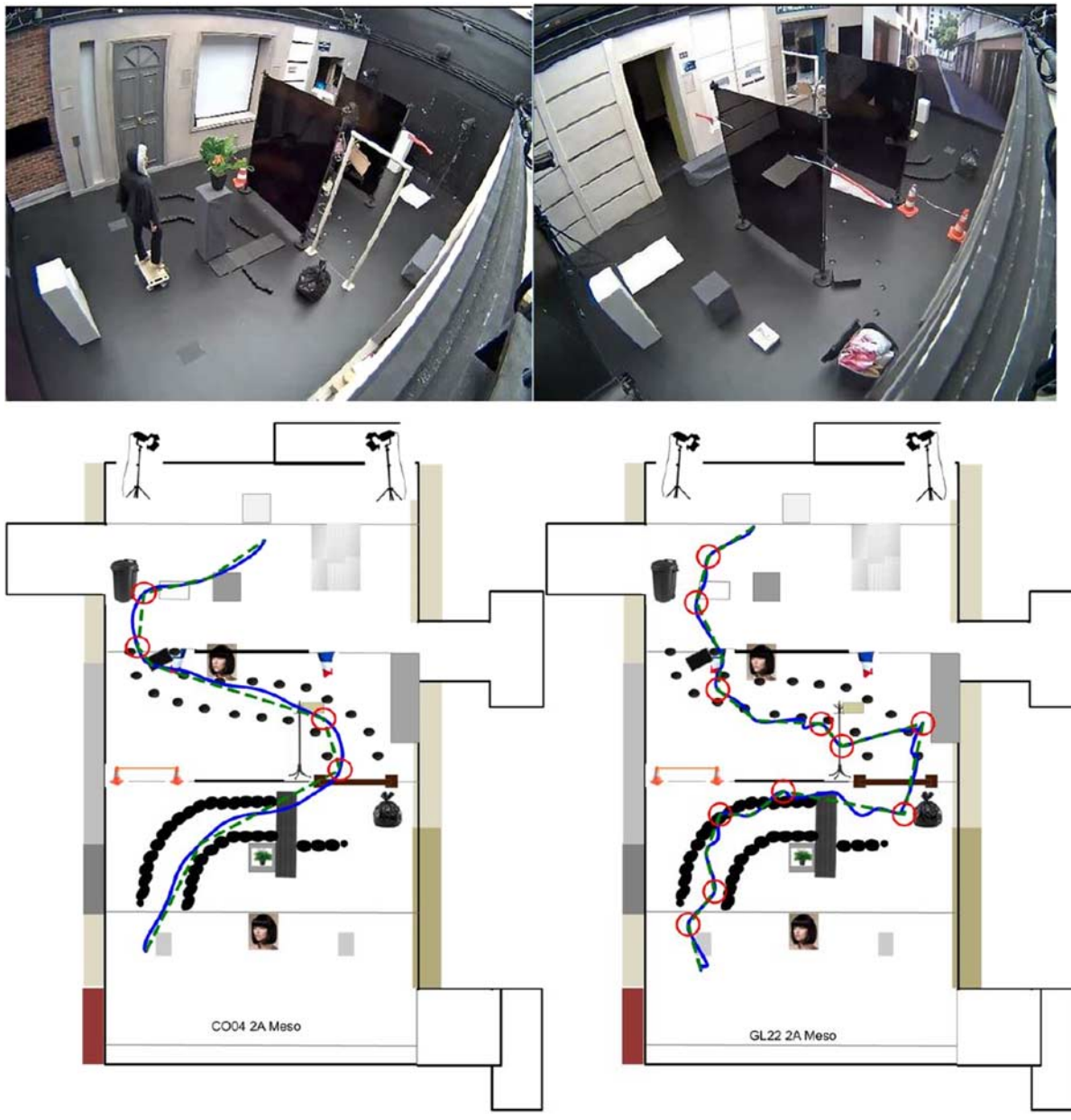

FIGURE 1. Example of a mobility course in the Streetlab environment. Upper pictures show an overhead view of the participant's trajectory during the trial. The lower left diagram represents trajectory segmentation of one control subject in mesopic conditions with glare. The lower right diagram represents trajectory segmentation of one glaucoma subject under the same lighting conditions. The blue line corresponds to the true trajectory of the torso tracked by the Vicon system. The red dot corresponds to a turning point, and the green line corresponds to one trajectory segment for each simplified trajectory. Figure 1 can be viewed in color online at www.glaucomajournal.com.

expressing the ratio as a percentage defined as "percentage of preferred walking speed" (PPWS).[23] PPWS offers the advantage of allowing subjects to act as their own controls, normalizing the data for age and physical factors.[24]

Self-reported Questionnaire: the NASA Task Load Index (NASA-TLX)

The NASA-TLX is a widely used, subjective, multidimensional assessment tool that rates perceived workload to assess a task, system, or team's effectiveness or other aspects of performance. The NASA-TLX has 6 subscales: mental demand, physical demand, temporal demand, overall performance, effort, and frustration level. The minimum score was 0 and the maximum score for each subscale was 100. The total NASA-TLX score was obtained by calculating the average of the 6 subscales. It was self-administered to each participant at the conclusion of the 4 mobility courses for each illumination condition.

Statistical Analysis

Statistical analysis was carried out with R 3.4.2 software (www.r-project.org/). Descriptive statistics were used

TABLE 1. Subject Characteristics

	Control	Glaucoma	Early	Moderate	Severe	*P*
Patients (n)	12	22	5	12	5	
Age (y)	56.7 (10.1)	56.4 (10.1)	56.2 (13.1)	59.4 (12.4)	49.4 (13.4)	0.953*
Sex (% male)	7 (58)	13 (59)	3 (60)	6 (50)	4 (80)	1†
VA-BE (LogMAR)	−0.03 (0.05)	0.018 (0.07)	0.02 (0.05)	0.00 (0.04)	0.06 (0.13)	0.073*
VA-WE (LogMAR)	−0.04 (0.09)	0.19 (0.24)	0.06 (0.08)	0.20 (0.18)	0.29 (0.42)	0.004*
Contrast (LogCS)	1.9 (0.0)	1.7 (0.2)	1.9 (0.0)	1.7 (0.2)	1.6 (0.2)	0.004*
MD-BE (dB)	0.6 (0.8)	12.9 (6.6)	4.0 (2.6)	13.7 (3.7)	19.9 (4.8)	< 0.001*
MD-WE (dB)	0.9 (1.2)	21.2 (8.0)	11.5 (4.8)	23.7 (6.9)	24.9 (5.6)	< 0.001*
IVF score	0	32.3 (22.3)	5.0 (3.1)	37.0 (13.7)	48.2 (27.8)	< 0.001*
Esterman score	116.1 (4.1)	91.2 (27.3)	113.2 (13.4)	91.7 (20.6)	68.2 (38.1)	0.004*

*t Test.
†Fisher exact test.
IVF indicates integrated binocular visual fields; MD-BE, mean deviation best eye; MD-WE, mean deviation worst eye; VA-BE, visual acuity of the best eye; VA-WE, visual acuity of the worst eye.

to analyze demographic data. The Kruskal-Wallis with Dunn test as appropriate with post hoc Bonferroni correction was used to evaluate the association between disability glare and glaucoma, and the association between disability glare and controls. The paired t test was used to evaluate the influence of different lighting conditions on locomotion tasks. The t test was also used to evaluate difference of mobility performances between glaucoma and control groups in the same lighting conditions. A value of $P < 0.05$ was considered significant.

RESULTS

Clinical Data

The mean visual acuity of the worst eye (VA-WE) in the glaucoma group was significantly lower than the control group (0.19 ± 0.24 and -0.04 ± 0.09 LogMAR, respectively, $P = 0.004$). The mean VAs of the best eye in the glaucoma and control groups were not significantly different (0.018 ± 0.07 and -0.03 ± 0.05 LogMAR, respectively, $P = 0.073$). Binocular CS was significantly lower in the glaucoma group (1.74 ± 0.18 and -0.042 ± 0.09 LogCS respectively, $P = 0.004$). Within the glaucoma group, the mean MD was -21.18 ± 8.01 for MD the worse eye and -12.92 ± 6.64 for MD the best eye. On VF analysis of the better eye, 5 patients (22.7%) had an early defect, 12 patients (54.6%) had a moderate defect, and 5 patients (22.7%) had an advanced or severe defect according to the Hodapp-Parrish-Anderson classification.[19] The mean IVF score was 32.27 ± 22.31, and the mean Esterman score was 91.23 ± 27.29. Demographic and baseline data are shown in Table 1.

GS

The glare score of the worse eye (GS-WE) was significantly higher in glaucoma patients than in the control group ($\chi^2 = 15.99$, $df = 3$, $P = 0.001$). It was also significantly higher between moderate glaucoma patients and controls ($P = 0.001$) and between severe glaucoma patients and controls ($P = 0.049$). GS-WE was not different between controls and early glaucoma or between moderate and severe glaucoma. The glare score of the best eye (GS-BE) was significantly higher in the glaucoma group compared with controls ($\chi^2 = 14.24$, $df = 3$, $P = 0.003$). GS-BE was also higher in moderate glaucoma patients than in controls ($P = 0.010$) and higher in severe glaucoma than in controls ($P = 0.016$). There was no difference between early glaucoma and controls or between moderate and severe glaucoma for GS-BE. GS results are shown in Table 2.

Mobility Performance

When comparing the performance of subjects between P and M+G conditions, the mobility time was 9.3% longer in the glaucoma group in M+G condition (20.51 ± 5.8 s in M+G and 18.76 ± 4.3 s in P, $P = 0.01$) and 5.5% longer in the control group in M+G condition(17.9 ± 3.6 s in M+G and 16.96 ± 3.2 s in P, $P = 0.017$). PPWS was 6.3% slower in the glaucoma group in M+G condition ($45.8\% \pm 7.6\%$ in M +G and $48.9\% \pm 6.7\%$ in P, $P = 0.006$) and 3.6% slower in the control group in M+G condition ($48.5\% \pm 5.9\%$ in M+G and $50.3\% \pm 5.8\%$ in P, $P = 0.008$). WS was not different for controls between M+G and P (0.58 ± 0.094 and 0.60 ± 0.086 m/s, respectively, $P = 0.495$). However, WS was 5.5% slower in the glaucoma group in M+G compared with P (0.52 ± 0.10 m/s in M+G and 0.55 ± 0.10 m/s in P, $P = 0.007$). Distance traveled was not different for controls between M+G and P, but it was 2.4% longer in the glaucoma group in M+G condition (10.08 ± 0.55 m in M+G and 9.84 ± 0.43 m in P, $P = 0.008$). The number of mobility incidents and trajectory segmentations were not different between M+G and P conditions for both groups. Results

TABLE 2. Study Population Divided Into Groups According to GS-BE and GS-WE

GS-BE	0 (n = 18)	1 (n = 9)	2 (n = 7)	GS-WE	0 (n = 12)	1 (n = 12)	2 (n = 10)
Control	11	1	0	Control	9	3	0
Glaucoma	7	8	7	Glaucoma	3	9	10
Early	3	2	0	Early	1	4	0
Moderate	3	5	4	Moderate	1	4	7
Severe	1	1	3	Severe	1	1	3

GS-BE indicates glare score of the best eye; GS-WE, glare score of the worse eye.

TABLE 3. Mobility Performances of Control and Glaucoma Groups Under P and M+G Conditions

	Control			Glaucoma		
	M+G	P	*P**	M+G	P	*P**
Nasa-TLX (score)	25.5 (6.20)	24.8 (8.40)	0.663	34.4 (14.80)	29.7 (11.30)	0.017
Mobility incident (n)	0.18 (0.23)	0.20 (0.29)	0.839	0.46 (0.91)	0.33 (0.33)	0.400
Trajectory segmentation (n)	6.0 (0.86)	5.5 (0.75)	0.159	6.3 (1.3)	5.7 (0.60)	0.062
Distance traveled (m)	9.99 (0.38)	9.83 (0.46)	0.293	10.08 (0.55)	9.84 (0.43)	0.008
Mobility time (s)	17.9 (3.60)	17.0 (3.20)	0.017	20.51 (5.80)	18.76 (4.30)	0.010
WS (m/s)	0.58 (0.09)	0.60 (0.09)	0.495	0.52 (0.10)	0.55 (0.10)	0.007
PPWS (%)	48.5 (5.90)	50.3 (5.80)	0.008	45.8 (7.60)	48.9 (6.70)	0.006

*Paired *t* test.
M+G indicates mesopic lighting conditions with glare; P, photopic lighting conditions; PPWS, percentage of preferred walking speed; WS, preferred walking speed on trial.

comparing mobility performance in P and M+G lighting conditions are shown in Table 3.

Comparing mobility performances between glaucoma patients and normal subjects, there was no significant difference between glaucoma and controls in P lighting (Table 4). However, under M+G conditions, WS and PPWS were significantly lower for glaucoma patients than controls ($P = 0.049$ and 0.038, respectively). Similarly, mobility time was significantly longer for glaucoma patients compared with controls ($P = 0.046$) under M+G conditions. The distance traveled, mobility incidents, and trajectory segmentations were not significantly different between glaucoma patients and control subjects under M+G lighting conditions (Table 4).

Comparing the NASA-TLX of subjects between P and M+G conditions, it was unchanged for controls (25.5 ± 6.2 in M+G and 24.8 ± 8.4 in P, $P = 0.663$), but it was significantly higher in the glaucoma group under M+G than under P conditions (34.4 ± 14.8 and 29.7 ± 11.3, respectively, $P = 0.017$) (Table 3).

Comparing the Nasa-TLX between the glaucoma group (29.7 ± 11.3) and control group (24.8 ± 8.4), there was no significant difference under P conditions ($P = 0.141$). However, under M+G conditions, the Nasa-TLX was significantly higher for the glaucoma group (34.4 ± 14.8) than the control group (25.5 ± 6.2) ($P = 0.006$) (Table 4).

DISCUSSION

Our findings reveal significant glare disability for moderate and severe glaucoma patients with a significant impact of glare disability on mobility performance. Our glaucoma patients had significantly higher GS-BE and GS-WE than control subjects, especially in the moderate and severe stages of glaucoma. These results are consistent with those of Nelson and colleagues, who evaluated self-reported visual disability in glaucoma patients by means of a questionnaire and their association with visual function. They found that glare disability as measured with the brightness acuity tester was the visual function test the most correlated to self-reported visual disabilities after VF loss. They also found a high correlation between self-reported glare and VF loss for moderate and severe glaucoma compared with controls. Patients with moderate and severe VF loss had similar scores, suggesting a threshold effect of the impact of glare disability in glaucoma patients.[25]

Evaluation of orientation and mobility courses under M+G and P lighting conditions showed that glaucoma patients' mobility was significantly altered under conditions of glare. The number of mobility incidents was not statistically different between M+G and P conditions for glaucoma patients. This result demonstrates adaptation of glaucoma patients, reducing their speed and modifying their course to prevent mobility incident. This adaptation to glare conditions requires a higher physical and mental workload, as shown by the higher NASA-TLX index under M+G conditions than under P conditions in the glaucoma group. Although the disturbance was less pronounced in the control group than for glaucoma patients, normal subjects also showed differences in performance under M+G and P conditions for mobility time and PPWS. Glare disability is a common symptom even in healthy patients, especially the elderly.[20,26] Glare disability increases with age, and the mean age in our study was relatively high. The reduction in

TABLE 4. Comparison of Mobility Performances of Glaucoma Patients and Controls in M+G and Glaucoma Patients and Controls in P

	M+G			P		
	Control	Glaucoma	*P**	Control	Glaucoma	*P**
Nasa-TLX (score)	25.5 (6.20)	34.4 (14.80)	0.006	24.8 (8.40)	29.7 (11.30)	0.141
Mobility incident (n)	0.18 (0.23)	0.46 (0.91)	0.136	0.20 (0.29)	0.33 (0.33)	0.328
Trajectory segmentation (n)	6.0 (0.86)	6.3 (1.30)	0.221	5.5 (0.75)	5.7 (0.60)	0.200
Distance traveled (m)	9.99 (0.38)	10.08 (0.55)	0.251	9.83 (0.46)	9.84 (0.43)	0.862
Mobility time (s)	17.9 (3.60)	20.51 (5.80)	0.046	17.0 (3.20)	18.76 (4.30)	0.065
WS (m/s)	0.58 (0.09)	0.52 (0.10)	0.038	0.60 (0.09)	0.55 (0.10)	0.056
PPWS (%)	48.5 (5.90)	45.8 (7.60)	0.049	50.3 (5.80)	48.9 (6.70)	0.134

**t* Test.
M+G indicates mesopic lighting conditions with glare; P, photopic lighting conditions; PPWS, percentage of preferred walking speed; WS, preferred walking speed on trial.

PPWS and increase in mobility time could be early consequences of glare disability—the first adaptation mechanism. Glaucoma patients seemed to react similarly to control subjects under glare conditions, but with more consequences on locomotion, with higher distance traveled and significantly increased NASA-TLX score. Although the mobility performance of glaucoma patients and controls was similar under P lighting conditions, performance was significantly different under glare conditions. This result confirms that, in situations with dazzling light, glare disability affects the performance of glaucoma patients more so than controls.

There are several hypotheses that may explain why glaucoma patients suffer from glare disability more than healthy patients. One hypothesis, first mentioned by Walls and Judd,[27] is related to macular pigment. It acts as a yellow filter and promote comfort by reducing glare and dazzle. In a study of 36 healthy subjects, Stringham and Hammond[28] showed that visual thresholds under glare conditions were strongly related to macular pigment density. The influence of macular pigment on glare disability is strongly dependent upon the specific spectral conditions of the stimulus: it will not reduce glare disability when the glare is not produced by light containing a significant proportion of short-wave energy.[28] Hammond et al[29] showed, in 150 healthy young subjects, that macular pigment density was significantly related to serum lutein and zeaxanthin concentrations, glare disability, chromatic contrast and photostress recovery. Igras et al[30] observed lower values for macular pigment density in the presence of glaucoma compared with controls. Siah and colleagues, evaluating the relationship between macular pigment and glare disability in open-angle glaucoma, found that low spatial frequency mesopic CS with glare was significantly correlated with macular pigment density. Glaucoma patients who reported glare symptoms had a significantly lower macular pigment density.[31]

Another hypothesis could arise from the recently discovered intrinsically photosensitive retinal ganglion cells (ipRGCs), also called melanopsin-expressing retinal ganglion cells (mRGCs). They contribute to the maintenance of pupil diameter and pupillary constriction in the pupillary light reflex and are responsible for the postillumination pupillary response.[32,33] In addition to attenuating retinal illumination, a light responsive pupil can reduce the visual effects of glare, diffraction and optical aberrations.[34] A small pupil diameter also reduces photoreceptor bleaching, allowing faster dark adaptation.[35] Reduced postillumination pupil response (PIPR) and dysfunctional suppression of pineal melatonin secretion after light exposure has been observed in glaucoma patients.[34,36,37] These observations in humans have been corroborated in vivo in animal glaucoma models, showing reduction in mRGC density.[38,39] Obara and colleagues, comparing paraffin-embedded human donor eyes with glaucoma patients (n = 11) and age-matched controls (n = 10), found that severe glaucoma patients had a significant loss in mRGC density compared with age-matched controls. Moreover, Feigel et al,[34] testing ipRGCs by measuring the sustained PIPR in 25 glaucoma patients compared with 16 healthy, age-matched control participants, found that moderate and severe glaucoma patients have a dysfunctional ipRGC-mediated PIPR. These dysfunctions and loss of ipRGCs in moderate and severe glaucoma, but not in early glaucoma, might explain why we found significantly higher glare in moderate and severe glaucoma patients but not in early glaucoma.

Glare disability can also be a consequence of changes in the ocular media. Light scattering in the optical media of the eye causes a veil of stray light over the retina. Stray light increases with age in healthy eyes, and the primary cause of glare disability causing straylight is cataract.[40,41] Cataract should not have influenced the results of the present study very much, since patients in the glaucoma group and the control group were of similar age, and visually significant cataract was an exclusion criteria. Disturbances in the optical media can also be due to ocular surface changes and dry eye. A large proportion of patients with open-angle glaucoma or ocular hypertension have signs or symptoms of ocular surface disease or changes in tear film osmolarity.[42,43] Koh et al[44] showed that, in dry eye, increased stray light results from tear film instability. Sherwood et al[45] found that glaucoma medications and previous surgeries correlated with self-reported glare disability and night vision problems. Since glaucoma patients use glaucoma eyedrops, this might be an important cause of glare disability in these patients.

There are several limitations to be considered in our study. First, there is no commonly accepted gold standard measurement for glare disability. However, in the present study, glare disability was measured objectively using the Vision Monitor (MonCv3, Metrovision, France). The repeatability, reliability and normal values of this method in healthy eyes of all ages was assessed by Puell et al.[20] Van den Berg et al[46] showed that stray light measurements with the C-Quant Straylight Meter (Oculus Optikgeräte, GmbH, Wetzlar, Germany) exhibit better repeatability and discriminative ability than glare tests. However, Palomo-Álvarez and Puell,[8] comparing the same Straylight Meter and the Vision Monitor, showed that both discriminated well between normal eyes and eyes with cataract, although the disk halo radius measured using the Vision Monitor showed better diagnostic capability. Second, we had to create a semiquantitative score based on the normal values found by Puell and colleagues, because the range of the halo size measurement was not large enough, and subjects with high glare could not be measured above 333 minutes arc. This semiquantitative score was based on normal values described by Puell et al[20] with regular intervals. The normal values were determined by Puell and colleagues on 147 healthy subjects with a mean age of 48.2 ± 16.2 years (range: 20 to 77 y) and halo size increases with age. In our study mean age was older but control and glaucoma group were age-related with no significant difference of age. Third, the sample size of our study was small. It can affect the reliability of results because of higher variability in small sample studies. Also, there is no guarantee that the population of our study is representative of the overall population of patients with glaucoma and healthy controls. Study involving a larger number of patients is needed to confirm our results.

This study is the first study showing that glare disability is significantly higher in moderate and severe glaucoma compared with age-matched and sex-matched healthy controls. It is also the first study showing impact of glare disability on mobility in glaucoma patients. Evaluating glare disability is important in understanding patients' mobility difficulties, and clinicians should be more aware of glare disability in their clinical management of glaucoma. Studying mobility under glare conditions is also important since mobility is the most manifest effect of glare disability. Although the impact of glare disability can be evaluated with questionnaires already in existence, there is a need for

an objective evaluation of the impact of this frequent symptom in glaucoma patients.[47] There are as yet no effective countermeasures to improve disability related to glare. Colored filters are often presented as countermeasures for glare disability, but in common situations, target and glare light sources have similar spectra, so colored filters decrease targets and glare sources proportionately, and retinal image contrast does not increase.[28,48–50] A mobility course in controlled environments and lighting conditions might be used to evaluate the efficacy of future antiglare devices and confirm whether these improve mobility performance in glaucoma patients.

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