

Exploring the effect of glaucomatous visual field defects of current drivers on a neuropsychological test battery

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ABSTRACT.

Purpose: This study explores the effect of glaucomatous visual field defects on several neuropsychological tests that are often used in research and in clinical settings.

Methods: Nineteen glaucoma patients and nineteen healthy participants, which are current drivers and older than 65 years old were included. All participants completed the Montreal Cognitive Assessment (MoCA), the Trail Making Test (TMT), the Benton Visual Retention Test (BVRT), the Snellgrove Maze Task (SMT) and the Digit Span Test (DST). All participants were also tested on contrast sensitivity and near and far visual acuity. For the glaucoma patients, visual field tests were downloaded from hospital servers.

Results: On the MoCA test, glaucoma patients scored lower than the healthy group, but not significantly. On the MoCA-Blind, the difference was statistically significant. Glaucoma patients also had lower percentile scores on the TMT, with a significant difference in the TMT-A, but this difference largely disappeared in the calculated TMT B-A index, which isolates the cognitive component. The BVRT and SMT showed no significant differences between both groups. In the only non-visual test, the DST, glaucoma patients outperformed the healthy group. Glaucoma severity did not influence results, except for the BVRT on which the moderate/severe group has better scores.

Conclusion: Using visual items might lead to conclusions about cognition when it should be one about vision. Therefore, careful selection of tests is needed when examining cognition in glaucoma patients.

Key words: neuropsychological testing – glaucoma – visual field defects – fitness to drive – vision

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Introduction

Neuropsychological test batteries that encompass several cognitive domains are commonly used to assess cognitive decline. However, one problem in assessing cognition in older people is comorbidity, such as visual impairment. Over 2.2 billion people worldwide have some form of visual impairment, caused by, for example, unaddressed refractive error, cataract or glaucoma (World Health Organization 2019). As screening instruments often use visual stimuli, this could interfere with the reliability of the assessment for those with visual impairment (Kempen et al. 1994). This means that conclusions could be made about cognition, when it should be one of vision. For example, both in Alzheimer's disease (Cronin-Golomb et al. 1995) and in Parkinson's disease, research has demonstrated that visual impairment can influence performance on cognitive tests (Toner et al. 2012).

Glaucoma

One example of an ocular disease that can cause visual impairment is glaucoma. In glaucoma, the optic nerve is damaged, which leads to prechiasmatic visual field loss. Usually, the periphery is affected first, but the centre of the visual field can also be affected in later stages of the disease, and sometimes even in the beginning (Aulhorn & Karmeyer 1977; Brusini & Johnson 2007). About 3% of all people between

40 and 80 years old have glaucoma (Tham et al. 2014). Glaucomatous visual field defects can be present in one eye but not in the other, or if it is in both eyes, the visual field defects can be in different locations (Huang et al. 2014), allowing compensation by the other eye. When the defects are in the same location in both eyes, the eyes cannot compensate. However, strategies such as head movements and additional or modified saccades might compensate for the defect (Wood et al. 2011; Smith et al. 2012; Kübler et al. 2015).

Neuropsychological tests

Visual impairment can influence performance on neuropsychological testing as both lowered contrast sensitivity and low visual acuity can have negative effects on neuropsychological test scores, and therefore overestimate the cognitive impairment (Cronin-Golomb et al. 1995; Toner et al. 2012). Even though glaucoma is not primarily a disease that affects central vision, it might influence performance in neuropsychological tests that utilize a larger part of the visual field. Defects in the visual field might slow down a participant's response because they have to compensate for the visual field defects by making additional head or eye movements. For example, Lee et al. (2020) found that older adults with mild-to-moderate glaucoma perform worse on tests of visual search and executive functioning. Next to the effect of visual field defects, glaucoma patients can have cognitive impairment as well, as cognitive impairment is common in the older population (Fukuoka et al. 2015). Glaucoma could not just be an ocular disease, but a more general neurodegenerative condition (Yochim et al. 2012; Danesh-Meyer & Levin 2015; Harrabi et al. 2015; Mancino et al. 2017).

Fitness to drive

Neuropsychological testing is often used in the assessments of fitness to drive when cognitive impairment can be expected (Bennett et al. 2016; Piersma et al. 2016) or for older drivers (Vaucher et al. 2014). Hence, it is of pivotal importance to know the influence of visual field defects on neuropsychological tests in order to be able to select tests appropriate tests.

A common screening test for mild cognitive impairment (MCI) is the Montreal Cognitive Assessment (MoCA) (Nasreddine et al. 2005). The MoCA consists of several tasks, assessing the most relevant cognitive domains. These domains include visuospatial skills, attention, memory, language and abstract reasoning. The sensitivity of the MoCA is high, around 90% for MCI patients and 100% for patients with Alzheimer's disease (Nasreddine et al. 2005; Wittich et al.). The MoCA is one of the few tests that has a version specifically for patients with lower vision. This MoCA-Blind test is the same as the MoCA, but the items with visual stimuli are removed from the analysis. This reduces the sensitivity of the test to about 44% for MCI and 87% for Alzheimer's disease but yields a better specificity of 98% instead of 87% than the original MoCA for detecting MCI. As the MoCA does not use the peripheral visual field and there is no time limit, it is not expected that glaucoma patients, will experience difficulties on this test due to visual field defects, and they can take longer to answer the visual items without lowering their score. In general, with glaucoma patients, the normal MoCA is used (McCoskey et al. 2018).

Next to a screening tool, specialized neuropsychological tests are needed to further assess cognitive impairment. The Trail Making Test (TMT) (Reitan 1958) is well-known and used both in clinics and in research to assess executive functioning, processing speed and (visual) attention. This test consists of part A, in which the participant connects numbers in ascending order, and part B, in which the participants alternate between connecting letters and numbers in ascending order. The TMT is a paper- and pen-based test on an A4 sized paper and is done at reading distance. This corresponds to a visual angle of at least 29° by 41° degrees, and more when the participant is leaning closer towards the paper. Research on the effects of simulated low visual acuity and cataract on TMT performance have demonstrated a negative impact on performance (Wood et al. 2010; de Haan et al. 2019), and the TMT has been associated scores in an on-road driving study in glaucoma patients (Bhorade et al. 2016). Glaucoma patients are significantly slower on the TMT-B compared with controls (Gangeddula et al.

2017). The Benton Visual Retention Test (BVRT) (Sivan 1992) is a test for visual perception and memory. In this test, the participant is allowed to see the figure for 10 seconds before it is removed and has to be reproduced from memory. A study that included glaucoma patients with and without cognitive impairment and a control group with and without cognitive impairment found that the BVRT shows an additional cognitive impairment in glaucoma patients, compared with those with cognitive impairment without glaucoma (Rosen et al. 2018). The Snellgrove Maze Task (SMT) (Snellgrove 2005) is a paper-based test in which the participant completes a maze without touching the walls or going into dead ends. Mazes are related to fitness to drive (Staplin et al. 2013), and cover a relatively large part of the visual field. Advanced glaucoma patients are significantly slower to complete the MST (Bhorade et al. 2016). The Digit Span Test (DST) is a test for working memory and is part of the Wechsler Adult Intelligence Scale (WAIS) (Kaufman & Lichtenberger 2005) test battery and uses no visual items.

In this paper, the effect of glaucomatous visual field defects on neuropsychological test scores is evaluated in a group of currently driving glaucoma patients over 65 years old. The goal was to evaluate whether it is warranted to use vision fair neuropsychological tests in this patient group, for example when assessing fitness to drive. Scores were compared with an age similar group of healthy participants who are also current drivers. Glaucoma patients and a control group completed several neuropsychological tests and a comprehensive visual examination, including visual acuity, contrast sensitivity and for glaucoma patients a visual field test. We hypothesize that visual field defects interfere with scores on neuropsychological tests that use visual items that are spread across the visual field. A second hypothesis is that more severe visual field defects are related to lower scores than mild visual field defects on these tests.

Materials and Methods

Participants

Participants were 19 glaucoma patients and 19 healthy participants. The glaucoma patients were recruited through

the University Medical Center Groningen (UMCG). Participants in the healthy group were recruited in two cities, Groningen and Leeuwarden, in the Netherlands, using flyers. Exclusion criteria were motor disorders and medication use that prohibits driving (ICADTS III). This study was conducted in accordance with the Medical Ethical Committee of the UMCG. Participants signed informed consent before starting the study. This study is in accordance with the Declaration of Helsinki.

The current study was part of a larger study on fitness to drive in glaucoma, for which the inclusion criteria were age over 65 years old, current drivers, a binocular visual acuity of 0.5 decimal or better (logMAR 0.3 or lower), and speaking Dutch. During testing, all participants wore their habitual correction. For the glaucoma group, all disease stages and visual field defect locations were included. Visual fields tests measured with the Humphrey Field Analyzer were downloaded from hospital servers. Visual fields measurements of both eyes were merged, taking the best value for sensitivity in each location, and plotted onto a visual field map (Figure S1). The severity of glaucoma is usually quantified with mean deviation (MD), which is the average difference in decibel (dB) from the expected value in all measured locations of the visual field (as a rule of thumb, 0 dB means intact, more than -6 dB is moderate/severe glaucoma and -30 dB means fully blind). The sample of 19 glaucoma patients included both patients with monocular visual field defects and patients with binocular visual field defects, as well as different stages of the disease. The glaucoma patients were stratified by disease severity of the better eye; the first group had an MD up to -6 dB (early glaucoma), and the second group had a MD of -6 dB or worse (moderate/severe glaucoma) in the better eye. The glaucoma patients classified as moderate/severe are underlined in Figure S1.

All participants filled in a questionnaire on driving experience and history of accidents. Participants were compared based on recent driving experience, defined as the number of days they usually drive per week in the last 6 months, total driving experience, defined as the number of years they hold a driver's license, and the number

of accidents in the past five years and fines in the past year.

Visual function tests

All participants completed vision tests on the Ocusweep (Ocusweep, Turku, Finland) for near and far visual acuity (background luminance 200 cd/m²) using a tablet with increasingly smaller Landolt C stimuli with their habitual correction (Ocusweep Oy. 2015). Contrast sensitivity (background luminance 150 cd/m²) was tested on the Ocusweep tablet using gratings (spatial frequency 1 cycle per degree) with increasingly lower contrast levels (Leinonen & Mäntysalo 2018, Ocusweep Oy 2015). While far visual acuity is the most common visual acuity measure, near visual acuity is the most relevant when reading or doing neuropsychological tests (Dupuis et al. 2015).

Neuropsychological tests

The Montreal Cognitive Assessment

In this study, the Dutch translated Montreal Cognitive Assessment (MoCA) (Nasreddine et al. 2005) was used. The maximum score on the MoCA is 30 points. Scores of 26 or higher are considered in the normal range, scores between 22 and 25 indicate the possibility of cognitive impairment and scores of 21 or below indicate the possibility of a more significant impairment (Nasreddine et al. 2005). The MoCA-Blind is a subset of items from the regular MoCA test. In this version, all tasks with a visual component have been deleted. These components are visuospatial skills, executive skills and naming. Together, these tasks are worth 8 out of 30 points. The MoCA-Blind, therefore, has a maximum score of 22. The suggested cut-off point for cognitive impairment in the MoCA-Blind is any score equal to or below 18 (Wittich et al. 2010). Scores on both versions of the test are corrected for education by adding one point for all participants with less than 12 years of education.

Trail Making Test

In the Trail Making Test (TMT) (Reitan 1958) part A, the participant has to connect all the numbers in ascending order, as fast as possible. The total time to complete the test and the number of errors are the outcome measures. In the

second part of the test, the TMT-B, both numbers and letters have to be connected in ascending order, where the numbers and letters have to be alternated. All scores are converted to percentile scores, which are age, sex and education corrected. To isolate a cognitive component and limit the effect of visual field defects, the TMT B - A (Corrigan & Hinkeldey 1987) index can be calculated.

Benton Visual Retention Test

In the BVRT (Sivan 1992), the participant looks at a set of images. Each image is presented for 10 seconds, after which it is taken away. Then, the participant has to draw the image from memory. There are 10 different images in this test, and the score depends on the number of correct drawings (max. 10) and the number of mistakes. Some images are made up of more than one object and the type of mistake (e.g. omission, distortion or rotation) is relevant for scoring as well. Therefore, the maximum number of mistakes is 40.

Snellgrove Maze Task

The Snellgrove Maze Task (Snellgrove 2005) is a paper-based test in which the participant is instructed to complete the maze as quickly as possible, but without making any errors. Errors could be either crossing a wall or entering a dead end. The outcome measures are the seconds it takes to complete the test and the number of errors.

Digit Span

In the Digit Span test (Kaufman & Lichtenberger 2005), the test leader reads out loud a series of numbers, after which the participant has to repeat them. There is a forward condition, with normal repetition, and a backwards condition, in which the participant has to say the numbers in reversed order. This is a test for working memory and does not require vision. Scores are converted to percentile scores, which are age, sex and education corrected.

Statistical analysis

First, the glaucoma group and the healthy group were compared on demographics, contrast sensitivity (CS), and near and far visual acuity (VA) and driving experience and history using Wilcoxon signed-rank tests and chi-

squared tests. Then, the neuropsychological test scores were compared between the glaucoma group and the healthy group using Wilcoxon signed-rank test and in boxplots. The percentage of agreement between the MoCA (cut-off 26) and MoCA-Blind (cut-off 19) was calculated to evaluate the effect of using the MoCA-Blind version in glaucoma patients. Spearman's correlations between age and visual and neuropsychological measures were calculated. Lastly, the effect of glaucoma severity was tested using non-parametric tests that compare the patients with none-to-mild visual field defects in the better eye to the patients with moderate-to-severe visual field defects in the better eye. The results in this study were not corrected for multiple comparisons, as this is an exploratory study (McDonald 2014). Analyses were done using R (version 4.0.2, R Core Team 2020) and RSTUDIO (version 1.3.1093, R Studio Team 2020).

Results

Visual function

In both groups, the majority of the participants were male and had received higher education (Table 1). There was no significant difference between both groups in terms of near visual acuity, measured at 40 cm distance ($W = 196$, $p = 0.66$) and far visual acuity, measured at 3 m distance ($W = 157$, $p = 0.50$). The cut-off point for normal CS (according to the manufacturer of the test) is logCS of 1.5. None of the participants scored below this value, and there was no significant difference between the groups ($W = 208.5$, $p = 0.42$). Of the participants with glaucoma, 79% had binocular visual field defects.

The glaucoma group and the healthy group had similar total driving experience, of 52 years for the glaucoma patients and 53 years for the healthy group. They both drove approximately 3 days per week. In the glaucoma group, 16% reported to have had a fine compared to 0% of the healthy group, but they were parking tickets and small speeding tickets (Table 1). In both groups, 11% of participants reported to have experienced an accident in the past 5 years.

Comparing neuropsychological test scores

Figure 1 shows the test scores for the various tests, for both groups. The

Table 1. Participant characteristics and visual function.

Participant characteristics	Glaucoma ($n = 19$) Median (IQR)	Healthy ($n = 19$) Median (IQR)	p-Value*
Age (years)	74 (72.0, 77.5)	72 (70.5, 75.0)	0.19
Gender (% male)	63%	74%	0.49
Education (years)	15 (15.0, 15.0)	15 (14.0, 15.5)	0.66
Near visual acuity (logMAR)	0.16 (0.11, 0.22)	0.19 (0.12, 0.22)	0.66
Far visual acuity (logMAR)	-0.05 (-0.07, 0.05)	-0.08 (-0.18, -0.00)	0.50
Contrast sensitivity (log(1/threshold contrast))	2.08 (1.93, 2.22)	2.15 (2.08, 2.18)	0.42
Better eye MD (dB)	-4.51 (-6.67, -1.05)	NA	NA
Worse eye MD (dB)	-11.96 (-16.22, -9.22)	NA	NA
Recent experience (days per week)	3 (1.5, 4.0)	3 (2.0, 5.0)	0.55
Total experience (years)	52 (50.0, 57.5)	53 (50.0, 55.5)	0.73
Fines (%)	16%	0%	0.07
Accidents (%)	11%	11%	1.00

* Wilcoxon signed-rank test and chi-squared test.

boxplots show that glaucoma patients have lower medians on both the MoCA and MoCA-Blind, the TMT-A and TMT-B test, and they have less items correct and more errors on the BVRT and more errors on the SMT. In both conditions of the Digit Span test, they have higher median percentile scores than the control group. Table 2 presents the corresponding medians, IQRs and univariable comparisons. In the MoCA test, the median score of the glaucoma patients was below the cut-off point of 26. Removal of the visual items did not improve the performance of the glaucoma group compared with the healthy group, but instead, they now performed significantly lower than the healthy group. The median score of the glaucoma patients on the MoCA-Blind was 18, which is the cut-off value. The agreement between the MoCA and MoCA-Blind is displayed in Table 3. A chi-square test of independence showed no significant difference between the number of participants classified as having cognitive impairment between the glaucoma group and the healthy group in the MoCA ($\chi^2(1, N = 59) = 1.69$, $p = 0.19$). Using a cut-off of 18/22, 21% of all participants together scored below the cut-off in the MoCA-Blind. A chi-square test of independence showed a significant difference between the glaucoma group (37% of participants below cut-off) and the healthy group (5% of participants below cut-off) in the number of participants qualified as cognitively impaired by the MoCA-Blind ($\chi^2(1, N = 59) = 5.7$, $p = 0.017$). There were no participants identified by the MoCA-Blind as cognitively impaired that were

not classified as cognitively impaired by the MoCA. The glaucoma patients had lower median percentile score compared with the healthy participants on both the TMT-A and TMT-B (Table 2 and Figure 1), but only for the TMT-A was the difference statistically significant. When eliminating the visual component by calculating the TMT-B – TMT-A, group scores were comparable.

Spearman's correlations were calculated between age and all visual and neuropsychological measures. Of all these measures, far VA ($r_s = 0.34$, $p = 0.038$) and the TMT-A ($r_s = 0.45$, $p = 0.004$) and TMT-B ($r_s = 0.46$, $p = 0.003$) were significantly correlated with age. The scores on the TMT were calculated percentile scores, already corrected for age.

The effect of glaucoma severity

The glaucoma patients were stratified by disease severity of the better eye; early glaucoma was defined as an MD up to -6 dB and moderate/severe glaucoma was defined as MD of -6 dB or worse. The location of the visual field defects of the merged visual field of moderate/severe glaucoma patients varied among the group, but all of them had vision left in at least part of the central 10 degrees of the visual field, aiding compensational mechanisms to complete the task.

When comparing performance on the neuropsychological tests between early and moderate/severe glaucoma, glaucoma patients in the more advanced phase of the disease score similar on most items, except for the BVRT. Glaucoma patients with more severe visual field defects had – counterintuitively – a statistically significant

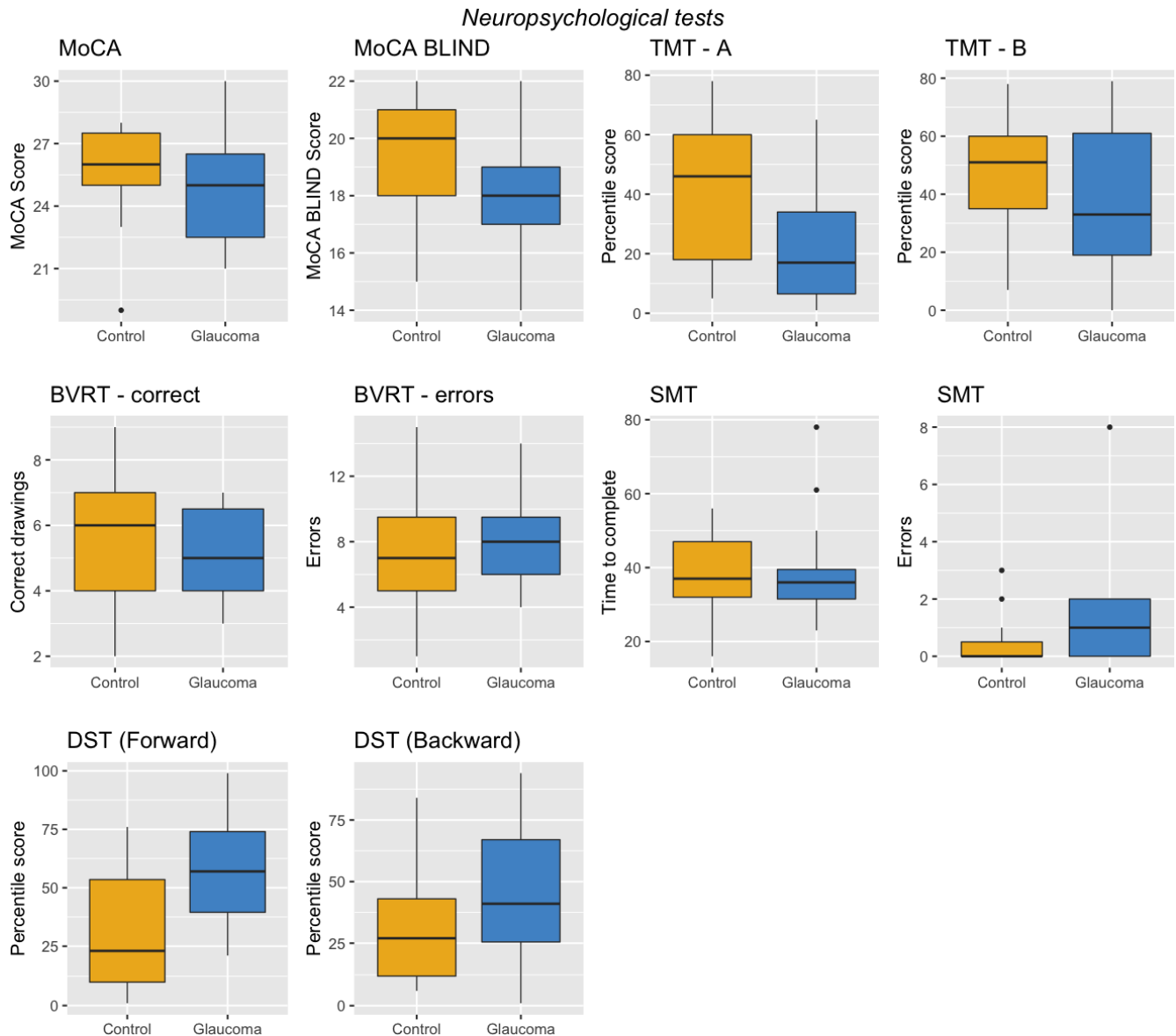


Figure 1. Neuropsychological test scores per group.

Table 2. Neuropsychological test scores.

	Glaucoma Median (IQR)	Healthy Median (IQR)	p-Value [†]
MoCA	25 (22.5, 26.5)	26 (25.0, 27.5)	0.21
MoCA-Blind	18 (17.0, 19.0)	20 (17.0, 19.0)	0.046*
TMT-A	17 (6.5, 34.0)	46 (18.0, 60.0)	0.038*
TMT-B	33 (19.0, 61.0)	51 (35.0, 60.0)	0.21
TMT B-A	13 (-7.0, 26.0)	14 (2.5, 27.0)	0.62
BVRT – correct	5 (4.0, 6.5)	6 (4.0, 7.0)	0.32
BVRT – error	8 (6.0, 9.5)	7 (5.0, 9.5)	0.67
SMT – seconds	36 (31.5, 39.5)	37 (32.0, 47.0)	0.56
SMT – error	1 (0.0, 2.0)	0 (0.0, 0.5)	0.078
DST – forward	57 (39.5, 74.0)	23 (10.0, 53.5)	0.002*
DST – backward	41 (25.5, 67.0)	27 (12.0, 43.0)	0.30

* Indicates a significant result.

† Wilcoxon signed-rank test.

higher number of drawings correct than those with moderate glaucoma and less errors (Table 4).

Discussion

The aim of this study was to evaluate whether it is needed to use vision fair testing in glaucoma patients, specifically in a population of current drivers. Although glaucoma patients score lower on most measures, these differences were statistically significant only for the MoCA-Blind and the TMT-A. On the only non-visual test, Digit Span Test, the glaucoma patients scored better than the healthy group.

Using the MoCA-Blind versus the MoCA did not improve the performance

Table 3. Correspondence between MoCA and MoCA-Blind.

Correspondence	All (%) (n = 38)	Glaucoma (%) (n = 19)	Healthy (%) (n = 19)
Agreement	68	74	63
Disagreement	32	26	37
<i>MoCA impaired, MoCA-Blind not impaired</i>			
Disagreement	0	0	0
<i>MoCA not impaired, MoCA-Blind impaired</i>			

Table 4. Neuropsychological test scores in glaucoma patients stratified by disease severity of the better eye.

	Early glaucoma (Median (IQR)) n = 13	Moderate and severe glaucoma (Median (IQR)) n = 6	p-Value
MoCA score	25.0 (22.0, 26.0)	25.5 (23.3, 27.0)	0.69
MoCA-Blind score	18.0 (17.0, 19.0)	18.5 (17.3, 19.8)	0.56
TMT-A percentile	20.0 (11.0, 36.0)	9.0 (6.0, 23.3)	0.54
TMT-B percentile	30.0 (14.0, 59.0)	38.0 (32.3, 64.8)	0.27
TMT B-A	10.0 (2.0, 19.0)	27.5 (19.5, 46.0)	0.09
BVRT – correct	4.0 (3.0, 5.0)	7.0 (7.0, 7.0)	<0.001*
BVRT – error	9.0 (8.0, 10.0)	5.5 (5.0, 6.8)	0.008*
SMT – seconds	36.0 (32.0, 38.0)	36.0 (31.3, 47.5)	0.86
SMT – error	1.0 (1.0, 2.0)	0.0 (0.0, 0.8)	0.32
DST – forward – percentile	50.0 (41.0, 75.0)	57.0 (42.8, 60.0)	0.83
DST – backward – percentile	37.0 (20.0, 56.0)	48.5 (41.3, 72.3)	0.51

* Indicates a significant result.

of the glaucoma patients compared with the healthy participants. Instead, the median score of the glaucoma patients was now on the cut-off and significantly lower than the median score of the healthy group. There were no participants identified by the MoCA-Blind as cognitively impaired that were not classified as cognitively impaired by the MoCA and the difference between the proportion of participants that scored below the cut-off was significantly different between both groups for the MoCA-Blind. The MoCA-Blind has reduced sensitivity for detecting MCI, most likely because items are removed from the MoCA but not replaced. The current study confirms the use of MoCA instead of MoCA-Blind in glaucoma patients, as no difficulties in tasks in the centre of the visual field without a time limit are expected.

In line with the hypothesis that neuropsychological tests with a large visual field component are most affected by glaucomatous visual field defects, glaucoma patients scored lower percentile scores than the healthy group on the TMT-A and TMT-B. Our findings are in line with literature that shows that glaucoma patients are slower on the TMT;

however, the previous work showed a significant difference in TMT-B, where the current study finds a significant result for the TMT-A (Gangeddula et al. 2017). However, in both the current study and the study by Gangeddula et al. (2017), glaucoma patients scored lower on both the TMT-A and TMT-B, and the differences between the groups were relatively large. When removing the visual component by calculating the TMT B-A index, the difference between both groups was very small. The TMT B-A index seems more robust for visual field defects in glaucoma patients, but more studies are needed to evaluate these results in larger groups. On the other hand, when assessing real-world functioning, for example driving, non-corrected scores like the TMT-A and TMT-B might be more relevant for the performance of glaucoma patients than non-visual measures. The TMT-A and TMT-B scores were significantly positively correlated with age, despite using age-, education- and gender-corrected percentile scores. The median age of the glaucoma group was two years older (74 years vs. 72 years), but the differences in

percentile scores were large, indicating that the difference between the groups can most likely not be attributed to age alone. Next to that, research on normative data for the TMT uses bins of 4 years, of which both the median age of the glaucoma patients and healthy group in the current study fall in the same bin (Tombaugh 2004).

In contrast, on the only test without visual items, the Digit Span Test, glaucoma patients performed better than the healthy group. As there is no visual component, it was expected that both groups would have a similar score. The overall pattern of scoring lower and having significantly higher scores on the DST might indicate that the glaucoma group had better cognitive resources overall but were negatively affected by the visual items of the tests. This, however, would need more research in larger groups. Summarizing all scores on the different tests, it seems that glaucoma patients do not have general cognitive decline, demonstrated by higher percentile scores on the DST, but caution is warranted when using the TMT.

When comparing mild-to-severe glaucoma, the only statistically significant difference was in the number of correct drawings and errors on the BVRT, in the advantage of the severe glaucoma group. This is a counter-intuitive finding and may be random. It could be that the location of the merged visual field defects of the moderate/severe glaucoma patients in this study did not obstruct the centre of the visual field to a degree that impairs performance. This type of visual field loss is characteristic of glaucoma. Therefore, it can be concluded that in this study, glaucoma severity, based on MD, is not related to performance on neuropsychological tests.

The participants from this study are part of a larger study on fitness to drive. Therefore, only current drivers with and without glaucoma are included in this study. This larger study also determined the sample size and in this group of participants, which are current drivers with a visual acuity of 0.5 or higher. Given the sample size, determined by the larger study, it is possible to find differences of 1 with a power of 0.83 using an alpha of 0.05. Therefore, this study is

of exploratory nature. One of the strengths of this study is that it assesses more than just (far) visual acuity. A full visual assessment was performed on all participants, including contrast sensitivity and visual field tests. The visual assessment was performed using Ocusweep, a relatively new device designed to measure functional vision. This device was chosen for the purpose of the larger study on driving with glaucoma. However, Ocusweep has not been extensively compared with traditional measures outside of the clinical validation study (Ocusweep Oy 2015). Next to the visual assessment, a complete neuropsychological test battery was used to compare performance, instead of separate tests, allowing comparison of performance between different tests and domains.

In general, when evaluating fitness to drive in glaucoma, this study indicates that the TMT might be affected by glaucomatous visual field defects, but other tests in the current study provide little evidence for the need for vision fair testing. Glaucoma severity did not influence performance on the neuropsychological tests in this group of current drivers, which might be explained by the location of the overlapping visual field defects. Non-visual neuropsychological tests are scarce and can be less reliable. In the case of glaucoma, the benefits do not outweigh the downsides. However, one must be careful when interpreting the results of tests that require a larger intact visual field.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. Overview of neuropsychological tests.

Figure S1. Merged binocular visual fields of all glaucoma patients.