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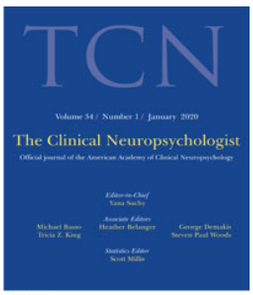

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Effects of low visual acuity on neuropsychological test scores: A simulation study

Gera A. de Haan[a,b], Oliver Tucha[a] and Joost Heutink[a,b]

[a]Department of Clinical and Developmental Neuropsychology, University of Groningen, Groningen, The Netherlands; [b]Royal Dutch Visio: Centre of Expertise for Blind and Partially Sighted People, Huizen, The Netherlands

ABSTRACT

Objective: To systematically examine the effect of low visual acuity (LVA) on a number of commonly used neuropsychological tests.

Method: In this study, the influence of LVA on a number of commonly used neuropsychological tests was examined in 238 healthy older adults (aged 50–80) without visual or neurological impairment. LVA was simulated using simulation glasses.

Results: It was found that a simulated LVA of ~0.2 (decimal acuity; Snellen 6/30 or 20/100, LogMAR 0.7) had a negative impact on test performance for the Trail Making Test, Complex Figure of Rey (copy score), and Visual Object and Space Perception battery subtest 3, but not for the Mini Mental State Examination and Balloons test. For some tests, the negative impact of LVA increased with age.

Conclusions: These results have important implications for the use of neuropsychological tests in the visually impaired population. More specifically, when administering the Trail Making Test, Complex Figure of Rey (copy score), and Visual Object and Space Perception Battery subtest 3 to older people with LVA, low test scores should be interpreted with great caution. Low test scores on the Mini Mental State Examination and Balloons Test are not likely to be caused by LVA and are more likely to reflect actual cognitive impairment. The results contribute to the validity of neuropsychological assessment of older people with visual impairment, leading to more effective and more patient-based rehabilitation.

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Low vision; neuropsychological assessment; validity; aging; diagnostics

Introduction

In the older population, both visual and cognitive impairments are more likely to occur. For the Dutch population for example, it is estimated that in 2020, 281,800 people (1.7%) will have low vision (defined as visual acuity between 20/400 and 20/60 or

CONTACT Gera A. de Haan G.A.de.Haan@rug.nl Department of Clinical and Developmental Neuropsychology, University of Groningen, Grote Kruisstraat 2/1, 9712 TS, Groningen, The Netherlands
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a visual field between 10° and 30° around the center). Of these people, 78.1% will be 50 years or older (Limburg & Keunen, 2009). The fact that cognitive impairment is common in older people is illustrated by the presence of mild cognitive impairment in 3–19% of people with age 65 or older (Limburg, 2007; Rait et al., 2005).

Accurate neuropsychological assessment is crucial to establish a match between the type and intensity of care and the cognitive capacities of an individual, for instance when older people are admitted to nursing homes or rehabilitation centers. Although most neuropsychological test norms are correct, when necessary, for age, gender, and education, the potential influence of visual impairment on test performance is not taken into account. Because it is not well established to what extent people with visual impairment may have problems seeing the test materials well enough to perform a particular test, low test scores are hard to interpret. This creates the risk that clinicians incorrectly attribute low test scores to cognitive impairment in visually impaired people, or that cognitive impairment is underestimated because low test scores are incorrectly attributed to visual impairment. Therefore, the validity of neuropsychological assessments for the older population with visual impairment may not be optimal, even more so because the majority of the neuropsychological tests rely on visually presented items.

A number of studies have examined the effect of visual impairment on several neuropsychological tests (Anstey, Dain, Andrews, & Drobny, 2002; Bertone, Bettinelli, & Faubert, 2007; Hunt & Bassi, 2010; Jefferis et al., 2012; Kempen, Kritchevsky, & Feldman, 1994; Killen et al., 2013; Lindenberger, Scherer, & Baltes, 2001; See, Anstey, & Wood, 2010; Skeel, Nagra, VanVoorst, & Olson, 2003; Skeel, Schutte, Van Voorst, & Nagra, 2006; Tay et al., 2006; Wood et al., 2009; Wood et al., 2010). Although the part of these studies that correlated real visual impairment with neuropsychological test scores (Anstey et al., 2002; Jefferis et al., 2012; Kempen et al., 1994; Killen et al., 2013; Skeel et al., 2003; Skeel et al., 2006; Tay et al., 2006) provides valuable information, it is not possible to conclude from these studies whether low test scores are caused by difficulty seeing the test material or, alternatively, whether low vision is associated with actual cognitive decline, as suggested by Lindenberger & Baltes (1994), for example. The effect of low visual acuity (LVA) can be examined in isolation by simulating LVA in healthy people with otherwise normal visual acuity (NVA). However, no studies have been performed that simulated LVA in a large sample ($n > 50$) of older people (50+). Therefore, the available literature is inconclusive about the effect of LVA on neuropsychological test performance of older people. Furthermore, Hill-Briggs, Dial, Morere, and Joyce (2007) concluded their review on factors influencing neuropsychological assessment stating that systematic research is necessary to develop reliable and valid assessments for people with sensory disabilities, such as visual impairment.

To systematically examine the effect of visual impairment on a number of commonly used neuropsychological tests, we simulated LVA in a relatively large group of older people (50–80 years of age). We chose to simulate a visual acuity of 0.2 (decimal acuity; Snellen 6/30 or 20/100, LogMAR 0.7). This level of visual acuity is considered as moderate visual impairment (World Health Organization, 1992) and although this level of acuity may cause hindrance (e.g. not being allowed to drive in European countries), people with this acuity are still capable of performing a wide range of activities without noticeable problems. Therefore, clinicians may not necessarily be aware of the LVA

being present when people with a visual acuity of 0.2 are performing neuropsychological tests. To clarify the implications for daily life, a visual acuity of 0.2 means that newspaper text needs to be enlarged two or three times to be read easily. However, a person with such visual acuity level is usually well able to navigate around obstacles when walking through a building. We did not attempt to simulate a specific visual disorder, although the simulation most closely matched cataract. Other eye diseases, such as macular degeneration and glaucoma, cause different levels of visual impairments across the visual field. To simulate such visual impairments (e.g. visual field defects), the simulation needs to be connected to the eye movements, which requires more complex techniques and falls beyond the interest of this study.

In this study, we focused on the older part of the population, as the risk of both cognitive and visual impairments increases with age, and therefore, the risk of a visual deficit influencing test performance is especially present in the older population. The prevalence of low vision, such as caused by cataract, is higher among the population of age 50 and older compared to younger age groups (Limburg & Keunen, 2009). Therefore, the inclusion criterion for minimal age of the participants in this study was set at age 50.

Because the participants in this study were free of visual or neurological impairments, the effect of LVA on neuropsychological tests could be examined without interference of potential cognitive decline that might be associated with real visual impairment (as suggested by Lindenberger & Baltes, 1994 for example). Besides examining which tests are sensitive to LVA and which are not, the chances of scoring below the cutoff value were compared between participants with LVA and participants with NVA. This forms an indication for the elevated risk of incorrectly concluding that a cognitive impairment is present for a person with LVA. Finally, it was investigated whether the effect of simulated LVA was moderated by age, gender, education level, or intelligence level. By providing information on the influence of LVA on test performance, this study contributes to an improved validity of neuropsychological assessments for visually impaired older people.

Materials and methods

Participants

Adults in the age range of 50–80 were recruited. Only people who reported to have no history of eye-related or neurological impairments were included. Participants were recruited by asking family, friends, and acquaintances (assuring that assessments were performed by researchers not related to the participants) and by placing public calls. Based on the answers on a short questionnaire, it was decided whether a person was eligible for participating in the study and an appointment was made for the assessment. All participants gave their informed written consent.

Design and procedure

Participants were randomly assigned to one of the two groups (group A or B; Figure 1), using stratified random sampling. During the entire assessment, participants wore their habitual glasses or contact lenses, as is usually the case in clinical practice. Participants were not allowed to change correction (e.g. use different glasses or take

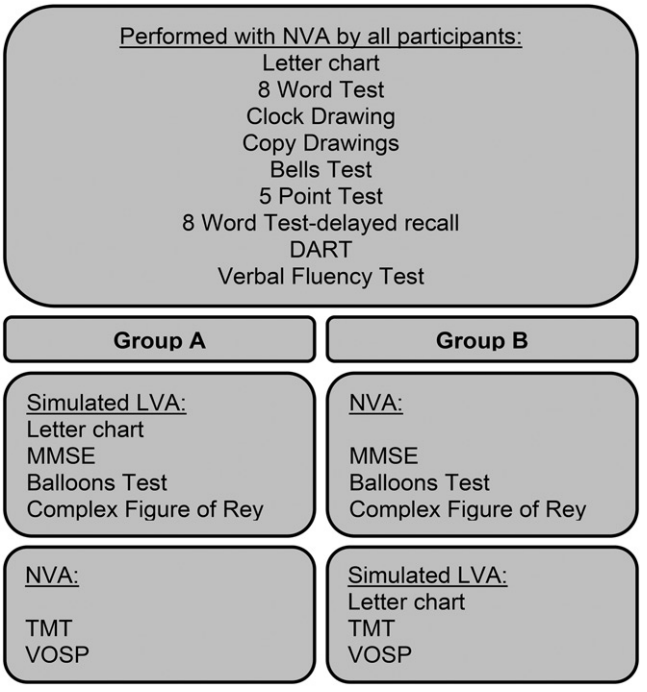

Figure 1. Test Battery in chronological order of administration. NVA = normal visual acuity; LVA = low visual acuity; DART = Dutch Adult Reading Test; MMSE = Mini Mental State Examination; TMT = Trail Making Test; VOSP = Visual Object and Space Perception Battery.

off glasses) once the assessment had started. Both groups performed the first part of the assessment with normal or corrected to NVA. The first part encompassed a set of tests to examine participants' own near visual acuity and their level of cognitive functioning. In the second part of the assessment, group A performed a set of tests with simulated LVA, while group B performed the same tests with NVA. Subsequently, group B performed two other tests with simulated LVA, while group A performed these tests with NVA. After putting on the simulation glasses, which were placed over the habitual glasses if the participant wore these during the assessment, participants were asked to take a good look around and to read a short text to get used to the glasses. Once participants were used to the glasses, near visual acuity was measured again for each participant while wearing the simulation glasses. No restrictions with regard to viewing distance were made, except during the visual acuity assessments. This way, participants were allowed to use spontaneous compensation methods when wearing the simulation glasses, as this is also allowed during assessments in clinical practice. Participants were tested individually in a quiet room. The assessments took place at the participants' homes or in a lab at the University of Groningen, whichever was preferred by the participant. The person scoring the tests was not aware of the experimental visual condition. The condition was also not mentioned on the test sheets, e.g. the drawings of the Complex Figure of Rey. The study followed the 2008 Declaration of Helsinki. The Ethical Committee of the Psychology department of the University of Groningen approved the study.

Materials

LVA was simulated using glasses covered with transparent but blurry foil. The glasses were designed to lower visual acuity to 0.2 (decimal acuity; Snellen 6/30 or 20/100, LogMAR 0.7), as tested in a participant who has a visual acuity of 1.0 (Snellen 6/6 or 20/20, LogMAR 0.0). It is impossible to simulate LVA in such a way that it truly matches real LVA, at least with current techniques. The blurry foil decreased the ability to distinguish small visual details, as is the case in cataract, although in a slightly different way. When participants wore glasses, the simulation glasses were placed over their own glasses.

To measure near visual acuity, the ETDRS letter chart was used (Ferris, Kassoff, Bresnick, & Bailey, 1982) at 40 cm viewing distance. Parallel versions were used for the assessments of participants' own normal or corrected to NVA and the simulated LVA. The neuropsychological tests both groups performed with their own normal or corrected to NVA consisted of the 8 Word Test: immediate recall, delayed recall, and delayed recognition (Lindeboom & Jonker, 1989), Clock Drawing (instructions and scoring as described by Elzen, Schmidt, & Bouma, 2004), Copy Drawings: items 28, 29, and 30 from the Beery VMI (Beery, Buktanica, & Beery, 2010), the Bells Test (Gauthier, Dehaut, & Joanette, 1989), 5 Point Test (test duration 3 min, administered as suggested by Goebel, Fischer, Ferstl, & Mehdorn, 2009), Verbal Fluency Test: animals and occupations from the GIT2 (Luteijn & van der Ploeg, 1983), and the Dutch Adult Reading Test (DART) to estimate intelligence (Schmand, Bakker, Saan, & Louman, 1991).

Five tests were selected to be performed with simulated LVA because of their frequent use in neuropsychological assessments. These were the Mini Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975); the Balloons Test, which is a paper–pencil cancellation test that screens for global and hemi-inattention by asking participants to cross out balloons among a larger number of circles (part A) or circles among a larger number of balloons (part B; Edgeworth, Robertson, & McMillan, 1998); the Complex Figure of Rey: copy and immediate recall (Meyers & Meyers, 1995); the Trail Making Test (TMT: part A and B; Reitan, 1992); and the Visual Object and Space Perception Battery (VOSP), which screens for disorders of visual perception. Subtests 1–4 of the VOSP were developed to measure object recognition and subtests 5–8 were developed to measure spatial perception (Warrington & James, 1991). With regard to the MMSE, Reischies and Geiselmann (1997) suggested a version in which all items with a visual component (naming two items, handling a sheet of paper, reading, writing, and copying) were omitted (i.e. the so-called MMblind). The full MMSE was administered in this study and, in addition to the total score, the MMblind score was calculated.

Statistical analysis

In the first step of the analysis, it was examined whether the two groups differed with regard to age, gender, education, visual acuity, and the scores on the neuropsychological tests that all participants performed with NVA. For visual acuity, statistics were performed on the LogMAR values. In the second step, the effects of simulated LVA were assessed by comparing scores on the MMSE, Balloons Test, Complex Figure of Rey, TMT, and VOSP between the NVA condition and LVA condition. The comparisons were performed using two-tailed independent samples *t* tests. In case equal variances could not

be assumed, as tested with Levene's test for equality of variances, the unequal-variance *t* test was performed. When the parametric assumptions were not met, as tested with the Kolmogorov–Smirnov and Shapiro–Wilk tests as well as by inspection of the data plots, the nonparametric Mann–Whitney *U* test was used. For the categorical variable gender, the Chi-square test was used to compare the two groups. As the main aim of this study was to find out which tests need to be interpreted with caution when administered to people with LVA, we deliberately did not correct for multiple comparisons, thus minimizing the chance of type II errors. In the context of this study, a type II error would mean an incorrect conclusion that LVA has no influence on test performance. Consequently, an adjusted *p* value would increase the risk of incorrectly ascribing a low test score to impaired cognitive functioning for an individual with actual (nonsimulated) LVA. Effect sizes were calculated according to Cohen (1988) for the *t*-test comparisons (Cohen's d). Effect sizes *r* were calculated for the Mann–Whitney *U* tests (Cohen, 1988) and Phi effect size for the Chi-square test (Fritz, Morris, & Richler, 2012). In case of missing data, the participant was excluded from the specific analysis.

To examine the risk of false interpretation of test scores for people with LVA, the percentage of participants scoring below the cutoff value (i.e. the cutoff value as presented in test manuals or papers providing norm data) was calculated for both the NVA and LVA condition. Furthermore, relative risk values were calculated (Sheskin, 2004). Relative risk here refers to the risk of scoring below the cutoff value when visual acuity is low compared to when visual acuity is around 1.0.

Finally, it was investigated whether the effect of simulated LVA on neuropsychological test scores was moderated by age, gender, education level, or intelligence level. These moderation effects were examined for those neuropsychological tests for which the effect of simulated LVA was significant, at least of medium effect size and with significantly high relative risk scores. The moderation effect of age was examined using regression analyses in which first age (centered) and vision condition (LVA vs NVA) were entered as independent variables. Then the interaction term of age by vision condition was added. The same was done for calculating the moderation effect of intelligence (DART scores). To examine whether the effect of simulated LVA was different for men and women, an ANOVA was performed in which gender, vision condition, and the interaction term were inserted as independent variables. A similar ANOVA was performed for examining the moderation effect of education, for which education scores were divided into two groups of approximately equal sample size. The higher level of education corresponded to at least a high-school degree that allows entry to a university of applied sciences (scores 6 and 7 from the classification of the Dutch education system according to Verhage (Duits & Kessels, 2006)).

Results

Participants

Of the 241 participants recruited, three participants were excluded from the study because of assumed early-stage eye disease (as mentioned by participants during the assessment). The characteristics of the 238 participants ($n = 117$ in group A, $n = 121$ in group B) are presented in Table 1. There were no significant differences between the

Table 1. Summary of participant characteristics, visual acuity, and scores on neuropsychological tests that all participants performed with normal or corrected to normal visual acuity.

		Group A ($n = 117$)	Group B ($n = 121$)	p value	Effect size
Age		64.4 ± 8.3 [50;79]	64.6 ± 8.6 [50;79]	0.856[b]	$r = 0.01$
Gender	Men (number)	56	61	0.694[c]	Phi = 0.03
	Women (number)	61	60		
Education[a]		5.4 ± 1.1 [2;7]	5.5 ± 0.9 [2;7]	0.547[b]	$r = 0.04$
Visual acuity	LogMAR	0.03 ± 0.09 [−0.16;0.24]	0.02 ± 0.10 [−0.18;0.30]	0.493[b]	$r = 0.04$
	Decimal notation	0.95 [0.58;1.45]	0.95 [0.50;1.51]		
Simulated visual acuity	LogMAR	0.75 ± 0.11 [0.52;0.96]	0.75 ± 0.10 [0.40;0.94]	0.611[b]	$r = 0.03$
	Decimal notation	0.18 [0.11;0.30]	0.18 [0.11;0.40]		
8-word test	Immediate recall total score (0–40)	32.1 ± 4.2 [22;40]	32.9 ± 4.0 [21;40]	0.202[b]	$r = 0.08$
	Delayed recall score (0–8)	6.0 ± 1.5 [1;8]	5.7 ± 1.8 [0;8]	0.184[b]	$r = 0.09$
	Recognition score (0–16)	15.5 ± 0.9 [12;16]	15.5 ± 1.0 [9;16]	0.581[b]	$r = 0.04$
Clock drawing	Score (0–14)	12.7 ± 1.4 [5;14]	12.6 ± 1.5 [3;14]	0.973[b]	$r = 0.00$
Copy drawings	Score (0–3)	1.5 ± 1.0 [0;3]	1.7 ± 1.0 [0;3]	0.183[b]	$r = 0.09$
Bells test	Targets (0–35)	32.7 ± 2.8 [21;35]	32.6 ± 2.5 [25;35]	0.278[b]	$r = 0.07$
	Time (s)	108.4 ± 40.6 [44;275]	104.7 ± 34.3 [54;273]	0.709[b]	$r = 0.02$
5 point test	Number of unique patterns (3 min)	28.6 ± 9.0 [12;55]	28.3 ± 8.6 [7;50]	0.779[d]	$d = 0.04$
DART	Estimated IQ score	102.9 ± 8.7 [81;124]	103.4 ± 9.2 [80;124]	0.701[d]	$d = 0.05$
Verbal fluency test	Number of animals	23.9 ± 6.8 [7;43]	24.8 ± 6.5 [10;42]	0.294[d]	$d = 0.14$
	Number of occupations	18.8 ± 4.9 [7;31]	19.1 ± 4.8 [6;31]	0.650[d]	$d = 0.06$

Notes: Values represent mean ± standard deviation [minimum;maximum], unless mentioned otherwise.
[a]Level of education according to Verhage (Duits & Kessels, 2006).
[b]Mann–Whitney U test.
[c]Chi-square test.
[d]Two-tailed independent samples t test.
r = effect size for Mann–Whitney U tests; Phi = effect size for Chi-square tests; d = Cohen's d effect size for t tests; DART = Dutch Adult Reading Test.

two groups in terms of age, gender, education level, visual acuity, and simulated LVA. Also, scores on the neuropsychological tests that all participants performed with NVA did not differ between the two groups (Table 1).

Effects of simulated LVA

Mini Mental State Examination

No evidence was found for an effect of simulated LVA on the MMSE total score nor was there an effect of simulated LVA on the subscore of the six items requiring vision (naming two items, handling a sheet of paper, reading, writing, and copying). All participants, including those with simulated LVA, made one error at maximum on the visual items. We checked the MMblind score, in which the visual items are omitted from the total score (Reischies & Geiselmann, 1997), and this revealed no significant effect of simulation glasses ($p = 0.229$). Effect sizes were negligible for each of these comparisons. A summary of the test scores is presented in Table 2.

Balloons Test

Participants with LVA needed significantly more time to find all targets in part A of the Balloons Test than participants with NVA. This effect was of medium, almost large,

Table 2. Summary of scores on neuropsychological tests.

		Group A ($n = 117$)	Group B ($n = 121$)	p value	Effect size
MMSE	Total score (0–30)	28.1 ± 1.6 [23;30]	28.4 ± 1.4 [23;30]	0.221[b]	$r = 0.08$
	Visual items (0–8)	7.9 ± 0.2 [7;8]	7.9 ± 0.3 [7;8]	0.187[b]	$r = 0.09$
Balloons Test	Total targets part A (0–20)	All scored 20	All scored 20		
	Time to complete part A	**47.8 ± 22.7 [18;142]**	**31.0 ± 18.0 [11;150]**	**<0.001[b]**	***r* = 0.48**
	Total targets part B (0–20)	19.8 ± 0.5 [18;20]	19.8 ± 0.6 [18;20]	0.750[b]	$r = 0.02$
Complex Figure of Rey	**Copy score (0–36)**	**25.9 ± 4.7 [7.5;34]**	**29.4 ± 4.3 [12;36]**	**<0.001[b]**	***r* = 0.40**
	Copy time	149.5 ± 65.4 [69;496]	153.5 ± 68.8 [45;500]	0.647[b]	$r = 0.03$
	Immediate recall score (0–36)	15.1 ± 6.6 [1;32]	15.2 ± 6.6 [0;29.5]	0.905[c]	$d = 0.02$
	Immediate recall time	103.2 ± 51.2 [24;363]	106.0 ± 42.1 [35;288]	0.195[b]	$r = 0.08$
TMT	**Time part A**	**35.0 ± 13.2 [14;97]**	**52.0 ± 24.9 [15;231]**	**<0.001[b]**	***r* = 0.46**
	Time part B	**88.7 ± 67.3 [29;600]**	**139.2 ± 103.6 [39;600]**	**<0.001[b]**	***r* = 0.39**
	B|A index	2.5 ± 1.1 [1.0;9.7]	2.7 ± 1.4 [0.9;9.5]	0.612[b]	$r = 0.03$
VOSP	**Screening (0–20)**	**19.1 ± 1.1 [15;20]**	**18.7 ± 1.1 [15;20]**	**<0.001[b]**	$r = 0.23$
	Subtest 1 (0–20): incomplete letters	**19.1 ± 1.0 [14;20]**	**18.5 ± 1.5 [11;20]**	**0.002[b]**	$r = 0.20$
	Subtest 2 (0–30): silhouettes	**21.8 ± 4.3 [9;29]**	**20.7 ± 4.3 [8;29]**	**0.045[b]**	$r = 0.13$
	Subtest 3 (0–20): object decision	**17.6 ± 1.6 [14;20]**	**15.4 ± 2.5 [10;20]**	**<0.001[b]**	***r* = 0.46**
	Subtest 4 (0–20): progressive silhouettes[a]	**10.9 ± 2.8 [4;19]**	**11.8 ± 2.7 [4;19]**	**0.014[b]**	$r = 0.16$
	Subtest 5 (0–10): dot counting	**9.9 ± 0.4 [8;10]**	**9.9 ± 0.3 [8;10]**	**0.042[b]**	$r = 0.13$
	Subtest 6 (0–20): position discrimination	19.7 ± 0.8 [15;20]	19.7 ± 0.6 [17;20]	0.857[b]	$r = 0.01$
	Subtest 7 (0–10): number location	9.2 ± 1.1 [6;10]	9.1 ± 1.2 [5;10]	0.995[b]	$r = 0.00$
	Subtest 8 (0–10): cube analysis	9.4 ± 1.1 [2;10]	9.2 ± 1.6 [0;10]	0.748[b]	$r = 0.02$

Notes: Values represent mean ± standard deviation [minimum;maximum]. The shaded areas represent the tests performed with simulated low visual acuity (LVA).
[a]For this subtest, a lower score means a better score.
[b]Mann–Whitney *U* test.
[c]Two-tailed independent samples *t* test.
r = effect size for Mann–Whitney *U* tests; d = Cohen's d effect size for *t* tests; p values < 0.05 and medium effect sizes printed in bold; MMSE = Mini Mental State Examination; TMT = Trail Making Test; VOSP = Visual Object and Space Perception Battery.

effect size. However, all participants with simulated LVA completed part A well within the maximally allowed time of 3 min. There was no effect of simulated LVA on the number of targets found in part B (negligible effect size). The number of participants who completed part B in time was similar for the two vision conditions (80% for the NVA condition and 81% for the LVA condition).

Complex Figure of Rey

Regarding the copy condition, participants with LVA scored on average 3.5 points lower than participants with NVA. This difference was significant and of moderate effect size. No effects of simulated LVA were observed for the score in the immediate recall condition or the time needed to complete the drawings in the copy or immediate recall condition (all negligible effect sizes).

Trail Making Test

Participants with LVA scored significantly lower on both TMT-A and TMT-B compared to participants with NVA (moderate effect sizes). Four participants ($n = 1$ in the NVA condition and $n = 3$ in the LVA condition) did not complete TMT-B within 10 min, at which point the test was aborted. The B|A index was not significantly affected by simulated LVA (negligible effect size).

Visual Object and Space Perception Battery

For the screening and subtests 1–5, participants with LVA scored significantly lower than participants with NVA (medium effect size for subtest 3—object decision, small effect sizes for the other subtests). However, for the screening and subtest 5, all participants in both the NVA condition and LVA condition scored above the 5% cutoff value as provided in the test manual (Warrington & James, 1991). For subtests 6–8, no effects of simulated LVA were found (all negligible effect sizes).

Potential risk of misinterpreting low scores

Table 3 shows the percentages of participants scoring below the cutoff values (i.e. the cutoff value as presented in test manuals or papers providing norm data) in the LVA condition and in the NVA condition, respectively. A significantly higher chance of scoring below the cutoff value in the LVA condition was revealed for the Rey Copy Score, TMT-A, TMT-B, and VOSP subtest 3 (VOSP-3, object decision). These were also the tests for which scores showed a significant difference of at least medium effect size between LVA and NVA (Table 2). In addition, a substantially higher chance of scoring below the cutoff value for LVA compared to NVA was also found for the VOSP subtest 1 (incomplete letters).

Moderating factors

Age

Table 4 shows the regression output for the moderating influence of age on the effects of vision condition. For the Complex Figure of Rey, age did not moderate the effect of simulated LVA on the copy score. For TMT-A, TMT-B, and VOSP-3, age did moderate the effect of simulated LVA, which is illustrated in Figures 2–4 by the predicted values from the model for age 55, 65, and 75.

Gender

No significant influence of gender was observed on the effect of simulated LVA on the Rey Copy Score ($F(1) = 1.398$, $p = 0.238$, $\eta = 0.006$). The same holds for the effect on TMT-A ($F(1) = 0.084$, $p = 0.772$, $\eta = 0.000$), TMT-B ($F(1) = 0.744$, $p = 0.389$, $\eta = 0.003$), and VOSP-3 ($F(1) = 0.248$, $p = 0.619$, $\eta = 0.001$).

Education

The effect of simulated LVA on the Rey Copy Score was found to be independent of the level of education ($F(1) = 0.113$, $p = 0.737$, $\eta = 0.000$). The same holds for the

Table 3. Chances of scoring below the cutoff value.

			% participants with score below cutoff value		Relative risk of scoring below the cutoff value[b]
		Cutoff value[a]	Normal visual acuity (NVA)	Low visual acuity (LVA)	
MMSE	Total score (0–30)	<24	1.7	1.7	1.0 ($p = 0.973$)
Balloons Test	Total targets part B (0–20)	<17	0	0	1.0 ($p = 0.987$)
Complex Figure of Rey	**Copy score (0–36)**	≤5% cutoff value (Fastenau, Denburg, & Hufford, 1999)	**9.9**	**23.3**	**2.3 ($p = 0.008$)**
	Immediate recall score (0–36)		9.1	11.2	1.2 ($p = 0.590$)
TMT	**Time part A**	<5% cutoff value (de Vent et al., 2016)	**1.7**	**14.1**	**8.2 ($p = 0.004$)**
	Time part B		**5.1**	**20.7**	**4.0 ($p = 0.001$)**
VOSP	Screening (0–20)	<15[c]	0	0	1.0 ($p = 0.987$)
		≤15	0.9	1.7	1.9 ($p = 0.588$)
	Subtest 1 (0–20)	<16	1.7	4.1	2.4 ($p = 0.286$)
		≤16	**2.6**	**9.1**	**3.5 ($p = 0.047$)**
	Subtest 2 (0–30)	<15	6.0	9.1	1.5 ($p = 0.369$)
		≤15	8.5	13.2	1.5 ($p = 0.253$)
	Subtest 3 (0–20)	<14	**0**	**24.8**	**59.0 ($p = 0.004$)**
		≤14	**5.1**	**36.4**	**7.1 ($p < 0.001$)**
	Subtest 4 (0–20)	>15	5.1	5.0	1.0 ($p = 0.952$)
		≥15	8.5	13.2	1.5 ($p = 0.253$)
	Subtest 5 (0–10)	<8	0	0	1.0 ($p = 0.987$)
		≤8	0.9	0.8	1.0 ($p = 0.981$)
	Subtest 6 (0–20)	<18	2.6	1.7	0.6 ($p = 0.627$)
		≤18	6.0	5.8	1.0 ($p = 0.948$)
	Subtest 7 (0–10)	<7	2.6	4.1	1.6 ($p = 0.507$)
		≤7	7.7	10.7	1.4 ($p = 0.419$)
	Subtest 8 (0–10)	<6	1.7	4.1	2.4 ($p = 0.286$)
		≤6	2.6	5.8	2.3 ($p = 0.230$)

Notes: Relative risks with $p < 0.1$ printed in bold. Sample size NVA: $n = 121$ for Mini Mental State Examination, Balloons Test, and Complex Figure of Rey and $n = 117$ for Trail Making Test and Visual Object and Space Perception Battery; Sample size LVA: $n = 117$ for Mini Mental State Examination, Balloons Test, and Complex Figure of Rey and $n = 121$ for Trail Making Test and Visual Object and Space Perception Battery.

[a]Cutoff values as presented in test manuals or papers providing norm data.

[b]Relative risk is calculated by dividing the proportion of participants scoring below the cutoff value in the LVA condition by the proportion of participants scoring below the cutoff value in the NVA condition. The corresponding p value is calculated as described by Sheskin (2004, p. 542).

[c]The Visual Object and Space Perception Battery manual (Warrington & James, 1991) is not clear about the use of the cutoff values. Therefore, results are presented for both < and ≤ the cutoff values.

MMSE = Mini Mental State Examination; TMT = Trail Making Test; VOSP = Visual Object and Space Perception Battery.

effect on TMT-A ($F(1) = 0.051$, $p = 0.822$, $\eta = 0.000$), TMT-B ($F(1) = 1.995$, $p = 0.159$, $\eta = 0.008$), and VOSP-3 ($F(1) = 0.012$, $p = 0.913$, $\eta = 0.000$).

Intelligence

The estimated IQ score from the DART did not moderate the effect of simulated LVA on the Rey Copy Score ($t = -0.468$, $p = 0.640$), TMT-A ($t = 0.597$, $p = 0.551$), TMT-B ($t = -1.117$, $p = 0.265$), or the VOSP-3 ($t = 0.968$, $p = 0.334$).

Discussion

In this study, the effect of simulated LVA on a number of commonly used neuropsychological tests was examined in a group of healthy older people (aged 50–80).

Table 4. Regression output for the total group ($n = 238$). Age, vision condition, and age × vision condition entered as independent variables.

Dependent variables	Independent variables	*B*	*t*	*p* value	R^2
Rey Copy Score	(Constant)	25.900	63.118	<0.001	0.163
	Age	−0.137	−2.753	0.006	
	Vision condition	3.461	6.027	<0.001	
	Age × vision condition	0.074	1.080	0.281	
TMT-A	(Constant)	35.058	21.873	<0.001	0.370
	Age	0.754	3.880	<0.001	
	Vision condition	16.775	7.462	<0.001	
	Age × vision condition	0.741	2.762	0.006	
TMT-B	(Constant)	88.942	12.126	<0.001	0.251
	Age	2.937	3.305	0.001	
	Vision condition	49.716	4.833	<0.001	
	Age × vision condition	2.635	2.147	0.033	
VOSP-3	(Constant)	17.546	93.938	<0.001	0.273
	Age	−0.011	−0.479	0.632	
	Vision condition	−2.182	−8.329	<0.001	
	Age × vision condition	−0.080	−2.565	0.011	

Notes: Age = centered age variable. Vision condition is a dummy variable: normal visual acuity condition = 0; low visual acuity condition = 1 for TMT-A; TMT-B and VOSP-3; low visual acuity condition = 0; normal visual acuity condition = 1 for Rey Copy Score. TMT-A = Trail Making Test part A; TMT-B = Trail Making Test part B; VOSP-3 = Visual Object and Space Perception Battery subtest 3.

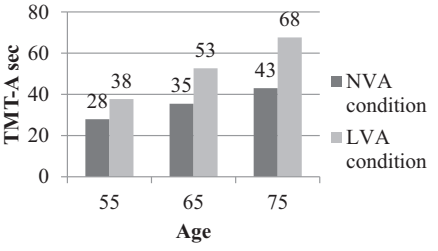

Figure 2. Predicted scores on the Trail Making Test part A for ages 55, 65, and 75 based on the regression model. NVA = normal visual acuity; LVA = low visual acuity; TMT-A = Trail Making Test part A.

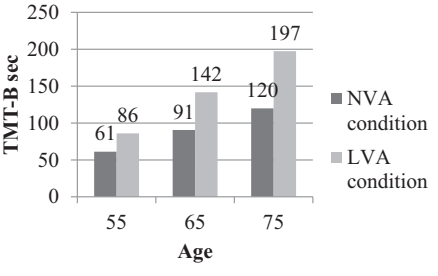

Figure 3. Predicted scores on the Trail Making Test part B for ages 55, 65, and 75 based on the regression model. NVA = normal visual acuity; LVA = low visual acuity; TMT-B = Trail Making Test part B.

Test performance with NVA was compared to performance with simulated LVA, while controlling for age, sex, education, and cognitive functioning. This revealed that simulated LVA had a meaningful negative impact on the performance in the TMT (A and B), Complex Figure of Rey (copy score), and VOSP (especially subtest 3), but not in the MMSE and the Balloons Test. A significant increase in the risk of scoring below the

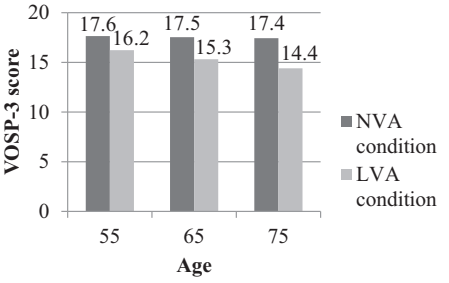

Figure 4. Predicted scores on the Visual Object and Space Perception Battery subtest 3 for ages 55, 65, and 75 based on the regression model. NVA = normal visual acuity; LVA = low visual acuity; VOSP-3 = Visual Object and Space Perception Battery subtest 3.

cutoff value in the LVA condition compared to the NVA condition was found for the Rey Copy Score, TMT-A, TMT-B, and VOSP-3. This suggests that for these tests, there is a substantial risk of incorrectly concluding that a cognitive impairment may be present while test performance is in fact impaired by LVA. This risk was not found to be moderated by gender, education, or intelligence level. For the TMT-A, TMT-B, and VOSP-3, the negative impact of simulated LVA increased with age. The findings for each individual test will be discussed below.

MMSE: Our study suggests that the MMSE can be used for assessment of people with a visual acuity as low as 0.2 without significant risk of overestimating cognitive impairment. No effect of simulated LVA was observed with regard to the MMSE items that rely on vision. All participants with simulated LVA made only one mistake at maximum on these items. Previous studies examining people with visual impairment however showed that visually impaired older people (age 60+) scored significantly lower on the visual MMSE items then older people without visual impairment (Jefferis et al., 2012; Killen et al., 2013). These dissimilar outcomes are likely to be explained by a difference in visual acuity of the participants compared to our study, as severely sight impaired people were included in previous studies (Jefferis et al., 2012; Killen et al., 2013). Based on the present findings, it is recommended to administer the full MMSE to people with visual acuity of 0.2 and above, and in addition, to calculate the MMblind score (i.e. excluding the items with a visual component from the total score). Busse et al. (2002) provided norms for the MMblind, which provide additional information next to the MMSE full score. It is not recommended to just leave the visual items out when administering the test and estimate the full MMSE score based on the MMblind score. There is evidence that the visual MMSE items are easier than the items without a visual component as measured in the general population (Busse et al., 2002). Consequently, a transformation of MMblind scores to full MMSE scores is difficult.

Balloons Test: Although participants with simulated LVA needed on average 54% more time to complete the Balloons A than participants with NVA, all participants finished well within the given time. For Balloons B, simulated LVA had no effect on the amount of targets found within the given time. Balloons A and B therefore seem safe to be administered to people with visual acuity of 0.2 or higher. The present findings indicate that for older people with LVA, test scores below the cutoff value are not likely to be caused by their visual acuity deficit.

TMT: Participants with simulated LVA needed on average 49% more time on part A and 57% more time on part B compared to participants with NVA. The finding that with simulated LVA, search tasks such as the Balloons A, TMT-A, and TMT-B all take on average around 50% longer to complete, demonstrates that even when targets are large enough to be perceived with LVA, test performance is negatively influenced. Even though a person with LVA is able to identify a target, this may take additional cognitive effort compared to seeing with NVA. This effort may come at a cost of decreased task performance. For example, fewer resources may remain for attentional or motor aspects of the task. A number of other studies have also looked at the effect of LVA on the TMT. The current findings are in line with the findings of Wood et al. (2009, 2010). These authors concluded that cataract simulation goggles negatively affected the time needed to complete TMT-A and TMT-B in both older (aged 65–82) (Wood et al., 2010) and younger (aged 18–33) (Wood et al., 2009) participants. Another simulation study found a negative influence of simulated LVA on subtests of the D-KEFS that are similar to TMT-A, but no effect on the switching subtest similar to TMT-B (Bertone et al., 2007). When LVA was simulated by blurring the testing sheets, no effect of this manipulation was revealed for TMT-A and TMT-B (Hunt & Bassi, 2010). In a study of Skeel et al. (2006), older participants (aged 70+) with real LVA did not score significantly worse on the TMT-A or TMT-B than participants with intact visual acuity. However, in a younger group of people (mean age 20), participants with real LVA performed worse on the TMT-B, but not on the TMT-A compared to participants with intact visual acuity (Skeel et al., 2003). The inconsistent results among these studies are likely to be explained by the variety of both participant characteristics and LVA values. This study indicates that for the TMT, the currently available norm data (de Vent et al., 2016) should not be applied in people with LVA. In clinical practice, this means that for individuals with LVA, the current norm data of the TMT can only be used to state that a test score is in the normal range, but they cannot be applied to conclude that the cognitive abilities measured by the test are impaired.

Complex Figure of Rey: In this study, simulated LVA impaired performance in the copy condition, while no effect of simulated LVA was found in the immediate recall condition. This means that compared to the copy score, the recall score is proportionally higher for participants with simulated LVA than for participants with NVA. It may be that more attention is required to complete the copy task when wearing simulation glasses and that additional attention enhances the encoding of the figure and storage in memory. For the copy score, as for the TMT, current data indicate that abnormal scores may arise from LVA alone. Future research could examine to what extent people with LVA reach higher copy scores when they are encouraged to take more time to complete the test. However, for now, the present findings suggest that the ratio between copy score and immediate recall score is different for people with LVA than for people with NVA. Copying the figure seems harder for people with LVA than for people with NVA while performance in the immediate recall condition is relatively better (i.e. compared to the copying) for people with LVA than for people with NVA. This makes it difficult to interpret the immediate recall score with the current norms in case of LVA, in particular as the current norms do not provide data for the immediate recall score that are corrected for the copy score.

VOSP: The results indicate that low scores on subtest 1, 2, 3, and 4 should be interpreted with caution for older people with LVA. Especially for subtest 3 (object decision), there is a higher risk of scoring below the cutoff value because of LVA. In subtest 3, four black figures printed on white paper are presented. One of these is the silhouette of a real object, presented from a slightly odd visual angle. The other three figures are not showing real objects. Participants are asked to indicate which figure represents the real object. The participants with simulated LVA had more problems with this subtest in particular, but also with the other object subtests of the VOSP, compared to the spatial subtests. Interestingly, the figures presented in the object subtests are relatively large in size so that one might assume that participants with LVA would be able to recognize them without problems. However, it appears that recognition of the figures is more dependent on visual acuity than one would assume. Perhaps interpretation of the figures is partly dependent on the perception of subtle curves in the outline of the silhouettes, which may be more difficult for people with LVA. The finding that the spatial subtests were not found to be affected by simulated LVA may possibly be explained by intact perception of the stimulus location despite the stimulus being blurred. Based on these findings, the advice for clinical practice is to administer additional tests measuring object perception when an individual with LVA performs badly on subtest 1–4, to find out if visual object perception is really disturbed.

Some limitations of this study and ideas for future studies should be mentioned. In this study, binocular visual acuity of 0.2 was simulated. LVA in this article does not refer to the full range of low vision and results may be different for other levels of low vision. Also, it might be that the influence of visual impairment on test performance is different for people with a real visual acuity of 0.2. On one hand, it is possible that the influence of LVA is less when people have had LVA for a longer period of time, as they may have learnt to compensate. On the other hand, eye diseases frequently cause visual impairment other than acuity deficits, such as image distortion, visual field defects, or reduced contrast sensitivity. These impairments of visual function may have an additional impact on test performance, for example, on tests for spatial cognition. Therefore, additional research is needed to examine the effect of other types of visual impairment, such as other levels of visual acuity, image distortion, or visual field defects. Ideally, new norms are gathered for different types of visual impairment. However, because most neuropsychological tests are sensitive to factors such as age, level of education, and gender, very large sample sizes are required to get a sufficient set of normative data. As it is very hard to identify large groups of patients that are homogenous in terms of their visual impairment and comorbidity, large homogenous groups are easier to obtain when simulating visual impairment by means of simulation glasses as used in this study. In conclusion, adapted norms based on different types of simulated visual impairment would be a very welcome addition to the current norms should emerging evidence indicate a need.

Another aspect related to the generalizability of the present findings concerns age. As participants in this study were between 50 and 80 years of age, it is not clear to what extent the results can be applied to younger people. It seems unlikely that a visual acuity of 0.2 has an impact on the MMSE and Balloons Test for younger people, considering that no impact was found on the older people who participated in this

study. The currently available norms for the TMT, Complex Figure of Rey, and VOSP, however, correct for age and it could be that healthy young people perform so well on these tests, that LVA has an even higher relative impact on test performance of younger people than it has in the older population. Although the current results do not suggest such an effect (Figures 2–4), future research is needed to provide a conclusive answer.

As this study examined healthy and neurologically normal participants only, the results do not provide information on the contribution of LVA to a low test score if a person is actually cognitively impaired. It is possible that LVA interacts with actual cognitive impairment, which results in even greater adverse effects of LVA on neuropsychological test performance.

A last suggestion for future studies regarding the generalizability of the present findings is to examine the effect of LVA on other neuropsychological or intelligence tests, such as the Montreal Cognitive Assessment (Julayanont et al, 2015).

In conclusion, the results suggest that the MMSE and Balloons Test can be administered without adjustments when visual acuity is 0.2. Low test scores in these tests are not likely to be caused by LVA in older people. This indicates that there is no need to switch to the blind version of the MMSE (MMblind) (Busse et al., 2002; Jefferis et al., 2012; Reischies & Geiselmann, 1997) as long as visual acuity is 0.2 or higher. However, the MMblind score may provide additional information and could therefore be calculated in addition to the total score after administering the full MMSE (norms provided by Busse et al., 2002). For the TMT, Complex Figure of Rey (copy score), and VOSP (subtests 1–4, but especially subtest 3), low test scores should be interpreted with great caution when older people with LVA are assessed. Further testing is then recommended to find out whether cognition is actually impaired. The same may hold for tests that include visual search for specific targets among distractors, as simulated LVA increased search time on both search tests as performed in this study by ∼50%. Object perception seems to be more impaired by LVA, even when large objects are presented with high contrast. A recommendation for clinicians is never to assume that test performance is not affected by LVA when an individual is able to identify small visual targets. Even though identification is still possible, people with LVA may need more time and effort and this may negatively affect test performance. A last recommendation to examiners is to be aware that the risk of incorrectly concluding that a cognitive impairment is present in adults with limited visual acuity increases with age (at least for TMT-A, TMT-B, and VOSP-3).

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ORCID

Oliver Tucha http://orcid.org/0000-0001-8427-5279
Joost Heutink http://orcid.org/0000-0002-4811-968X

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