1040-5488/10/8712-1037/0 VOL. 87, NO. 12, PP. 1037–1043
OPTOMETRY AND VISION SCIENCE

ORIGINAL ARTICLE

Simulated Visual Impairment Leads to Cognitive Slowing in Older Adults

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ABSTRACT
Purpose. To investigate the impact of different levels of simulated visual impairment on the cognitive test performance of older adults and to compare this with previous findings in younger adults.
Methods. Cognitive performance was assessed in 30 visually normal, community-dwelling older adults (mean = 70.2 ± 3.9 years). Four standard cognitive tests were used including the Digit Symbol Substitution Test, Trail Making Tests A and B, and the Stroop Color Word Test under three visual conditions: normal baseline vision and two levels of cataract simulating filters (Vistech), which were administered in a random order. Distance high-contrast visual acuity and Pelli-Robson letter contrast sensitivity were also assessed for all three visual conditions.
Results. Simulated cataract significantly impaired performance across all cognitive test performance measures. In addition, the impact of simulated cataract was significantly greater in this older cohort than in a younger cohort previously investigated. Individual differences in contrast sensitivity better predicted cognitive test performance than did visual acuity.
Conclusions. Visual impairment can lead to slowing of cognitive performance in older adults; these effects are greater than those observed in younger participants. This has important implications for neuropsychological testing of older populations who have a high prevalence of cataract.
(Optom Vis Sci 2010;87:1037–1043)

Key Words: aging, contrast sensitivity, cataract, cognitive function, visual impairment

The visual world is complex; efficient integration and processing of complex information from a variety of sources is necessary to successfully complete most everyday tasks. Age-related changes in sensory abilities, such as visual impairment, can potentially compound this process and influence not only the ability to undertake visual tasks but also the ability to quickly apprehend and process sensory information. Research suggests that degraded visual input can lead to problems in processing information, even when simulated in otherwise visually normal young persons.[1–3] In visually impaired older adults, visual impairment may coexist with cognitive decline, which can potentially compound deficits in performance on complex visual tasks.

Cataracts are the leading cause of visual impairment.[4] In a recent study of adults aged 49 years and older, 72% had cataracts or had had cataract surgery over a 10-year follow-up period.[5] As the population continues to age, the proportion with cataracts is likely to increase further, given that the prevalence of cataracts increases significantly with age.[6] Importantly, Reidy et al.[7] found in a United Kingdom study that 88% of persons with cataracts were not under regular eye care, so it is likely that a significant proportion of the older population and their healthcare providers remain unaware of their visual impairment.

Although the effects of cataracts on visual function are well established, there is a growing body of evidence demonstrating that cataracts can also have a significant detrimental impact on a range of everyday activities including balance and falls risk,[8,9] mobility,[10] and driving.[11–13] A series of recent studies have also explored the relationship between cataracts and cognitive performance, with mixed findings. McGwin et al.[14] compared the cognitive status of a group of older adults with cataract with that of age-matched control participants using the Mattis Organic Mental Syndrome Screening Examination and found no between group differences, concluding that cataract and cognitive status were not related. Another study compared the cognitive performance of a group of women who had had cataract extraction with a control group who

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had never had cataracts and reported no difference in cognitive test performance.[15] However, the cognitive tests were administered by telephone and, hence, were not presented visually.

A number of recent studies have compared cognitive test performance, pre- and post-cataract surgery.[16–18] Hall et al.[18] reported improvements in cognitive performance after cataract surgery, but improvements were also observed in the control group, which suggests that the improvements may be attributable to practice effects. Other studies have failed to find improvements in cognitive performance after cataract surgery, both in small sample randomized controlled trials,[19] and in nursing home residents.[20] However, in our recent study,[1] we found that inducing visual changes similar to cataract produced large declines in performance on cognitive tests in otherwise visually normal, young adults.

The aim of the current study was to determine whether simulated cataracts similarly affected the cognitive test performance of older visually normal adults and whether the effects of simulated cataracts on this older cohort was greater than that for the younger participant group tested previously.[1] The influence of cataract was simulated using Vistech filters (Vistech consultants, OH) which, like real cataracts, have a greater effect on contrast sensitivity than visual acuity (VA),[21] and commonly used, commercially available cognitive tests were selected to explore these effects. These cognitive tests are widely used as measures of overall cognitive processing speed and accuracy and are intended to be representative of higher-order tasks in everyday life. To rule out other potentially confounding factors, visual function was manipulated as a repeated-measures variable, so that each participant's performance under the simulated cataract condition could be compared with their baseline performance.

METHODS

Participants

Thirty visually normal older adults aged 65 years and older were recruited from the School of Optometry clinic at Queensland University of Technology to participate in this study. Participants included 20 men and 10 women (mean age = 70.2 ± 3.9 years; age range = 65 to 82 years). All participants reported that they were in good general health and were free of neurological or psychiatric conditions; none of the participants reported taking any medications relating to dementia or any other neurological condition. All participants were required to be visually normal and free of ocular disease as determined through their clinical records and a screening eye examination before inclusion in the study, which involved assessment of VA, direct ophthalmoscopy, and slitlamp biomicroscopy.

The study was conducted in accordance with the requirements of the Queensland University of Technology Human Research Ethics Committee and followed the tenets of the Declaration of Helsinki. All participants were given a full explanation of the experimental procedures, and written informed consent was obtained, with the option to withdraw from the study at any time.

Simulated Visual Impairment

The visual degradation resulting from age-related cataracts was simulated using Vistech light scattering filters that have been used to simulate the effect of cataracts on a variety of functional outcomes.[8,21,22] The filters produce a wide-angle light scatter (light scatter between 5 and 20°) with a similar angular distribution to that of normal eyes, and those with cataracts, they increase intraocular light scatter and glare sensitivity and have a greater effect on contrast sensitivity than VA as do real cataracts.[21] The filters were mounted in a full aperture trial frame, with two levels of simulated visual impairment: one with a single Vistech filter (88% light transmission), another with two filters mounted together (75% transmission), and a baseline condition with no filter in place; the filters had a negligible effect on color (<0.01 on both x and y CIE 1931 chromaticity coordinates).

Vision Assessment

All vision and cognitive testing was undertaken with the participants' optimal refractive correction (appropriate for the working distance of the tests) for the three conditions (no filter, one filter, and two filters). All testing was conducted in one session at the Optometry Clinic at Queensland University of Technology, and the order of the visual conditions was randomized for all participants. For each visual condition, the cognitive tests were conducted before the vision tests to minimize any expectations a participant might have regarding the effect of a given filter on performance.

Static VA

VA was tested binocularly using a high-contrast (90%) Bailey-Lovie (logMAR) chart at a working distance of 3 m under the recommended illumination conditions. Participants were instructed to read the letters from left to right on the chart and were encouraged to guess letters when unsure. VA was scored on a letter by letter basis, where each correctly identified letter represented a score of 0.02 log units.

Pelli-Robson Letter Contrast Sensitivity

Letter contrast sensitivity was measured binocularly using the Pelli-Robson chart under the recommended viewing conditions.[23] Participants were asked to report each line of letters and to guess the letter when they were unsure; each letter reported correctly was scored as 0.05 log units.

Cognitive Tests

Three commonly used, standard pen-and-paper cognitive tests were selected for inclusion in the study and were administered under binocular viewing conditions. The order of the tests was randomized between participants to avoid sequencing effects.

Digit Symbol Substitution Test

The Digit Symbol Substitution Test (DSST) is used clinically and has been widely used as a measure of general information processing speed in studies of cognitive aging.[24,25] Test scores correlate highly with general intelligence and chronological age.[26,27]

Participants are presented with a rectangular grid of high-contrast symbols. For each of these symbols, participants are instructed to substitute the appropriate digit according to a code that appears at the top of the page. Both speed and accuracy are equally emphasized in the instructions to ensure consistency.[28] The DSST score is recorded as the number of correct symbols drawn in 90 s.

Trails A and B Tests

The Trail Making Test (TMT) from the Halstead-Reitan Neuropsychology Test Battery[24] is widely used as a measure of executive function and for processing speed, attention, and mental flexibility.[29,30] The test consists of two parts. In part A, participants are asked to draw a line joining a series of high-contrast dots that are numbered from 1 to 25. In part B, the participant joins a series of numbers and letters in the sequence 1-A-2-B and so on. Any errors made by the subjects are pointed out by the examiner immediately and corrected before continuing the sequence. A participant's score is taken as the time to complete the test to the nearest tenth of a second.

Stroop Color Word Test

The Stroop Color Word Test has been found to effectively discriminate cognitive processing ability among the elderly and is widely used as a measure of selective attention and speed of information processing.[24,31,32] The test consists of three sections. In section 1 (Stroop D), the participant is presented with 24 colored dots (red, green, yellow, or blue), arranged in a pseudorandom order within the array. The participant is required to report the color of the dots as quickly as possible. In section 2 (Stroop W), participants view an array of color words where the ink matches the printed words and are instructed to read the words as quickly as possible. In the final section (Stroop C), color words and ink are presented incongruously, e.g., the word yellow is printed in blue ink, and participants are asked to name the color of the ink. The time to complete each of the Stroop D and W tasks measures overall processing speed, whereas the difference between the Stroop C and the Stroop D condition is a measure of response inhibition, as the participant inhibits their habitual response of reading the printed words. The Stroop Color Word Test has been found to be highly sensitive to age-related changes in cognitive processing speed.[33,34]

Statistical Analyses

Multivariate analysis of variance (MANOVA) was conducted examining differences in cognitive test performance between the different visual conditions for this older cohort. The results were then compared with previously presented results for a younger cohort of participants,[1] using a two-way mixed MANOVA with age group as a between-subjects factor and vision condition as a repeated measures factor. Follow-up comparisons for the vision conditions were conducted using the Fisher LSD test, which is known to maintain family-wise error at the nominal alpha level (0.05) when there are three or fewer conditions. Significant interactions in the mixed MANOVA were followed up using interaction contrasts to ascertain whether each pairwise difference between vision conditions depended on age. Two-way ANOVAs were conducted comparing the effects of the filters on the visual function of participants between age cohorts.

Because the visual changes resulting from the filters affected both contrast sensitivity and VA, it was of interest to determine which measure of visual function related most highly to the changes in performance for each condition. To compare this, the variables were standardized and analyzed using a series of linear mixed effects models with participant identity as a random factor, vision condition as a repeated measures factor with unstructured covariances, and VA and contrast sensitivity within each condition as independent variables. Because the two visual function measures were inextricably related to one another, each independent variable was tested in a separate model to reduce collinearity. Participant age was also included as a covariate in each model to control for potential confounding effects.

RESULTS

The simulated cataract filters impaired participants' performance on both measures of visual function compared with the baseline condition. Group mean VA for the baseline condition was -0.03 ± 0.05 log units (Snellen equivalent ~20/20) and was significantly worse in the presence of the filters ($F_{(2,58)} = 406.28$; $p < 0.001$), with significant differences between each of the vision conditions and baseline, and between one and two filters. For the one-filter condition, mean VA was reduced to 0.22 ± 0.11 log units (Snellen equivalent ~20/32, representing a relatively moderate level of cataract), whereas with two filters, the mean VA was reduced to 0.47 ± 0.10 log units (Snellen equivalent ~20/63), which represents a more severe cataract level. Group mean contrast sensitivity with the Pelli-Robson chart was 1.79 ± 0.04 log units at baseline, which was also significantly reduced by the filters ($F_{(2,58)} = 607.4$; $p < 0.001$), with all vision conditions being significantly different from one another and from baseline. Contrast sensitivity was reduced to 1.32 ± 0.15 log units with the one-filter condition and 0.77 ± 0.20 log units with the two-filter condition, representing moderate and more severe levels of degradation respectively. The effect of the filters was greater for this older cohort than for the previously reported group of younger participants for both VA (0 filter: −0.09, 1 filter: 0.00, and 2 filters: 0.15 log units) and contrast sensitivity (0 filter: 1.98, 1 filter: 1.57, and 2 filters: 1.12 log units).

Importantly, VA for all filter conditions at a working distance of about 40 cm for all participants was calculated to be at least four lines better than the visual requirements calculated for these versions of either the DSST (logMAR = 0.97), and the TMTA and TMTB (logMAR = 0.84). That is, the printed targets used in the DSST and TMT were about 2.5 times larger than the size required for recognition with the VA levels achieved with the filters; thus, it is not merely the ability to resolve the target that changed the speed of processing.

Group mean data for the cognitive tests for the three visual vision conditions are given in Table 1 and demonstrate that cognitive test performance became worse as the level of filters was increased. There was a significant overall effect of vision condition on performance across tests (Wilks $\lambda = 0.205$, $F_{(12,18)} = 5.805$, $p < 0.001$). Table 1 shows the results of the individual ANOVAs

TABLE 1.
Mean cognitive performance for older adults in this study

Measure	Mean performance (SE)			ANOVA	
	0 Filter	1 Filter	2 Filters	df (2,58), F	p
DSST (correct in 90 s)[a]	46.73 (1.94)	44 (1.61)	36.07 (1.73)	26.29	<0.001
TMTA (s)[b]	37.56 (1.97)	48.61 (3.31)	149.12 (16.8)	40.12	<0.001
TMTB (s)[b]	103.42 (6.81)	122.72 (9.54)	267.52 (18.43)	71.84	<0.001
Stroop D (s)[b]	12.17 (0.33)	12.76 (0.65)	13.57 (0.46)	3.87	0.026
Stroop W (s)[b]	17.97 (0.65)	19.26 (0.96)	28.79 (2.54)	16.31	<0.001
Stroop C (s)[b]	31.23 (1.29)	31.02 (1.78)	40.62 (3.01)	9.87	<0.001
Stroop C-D (s)[b]	19.06 (1.2)	18.26 (1.55)	27.05 (2.83)	8.22	0.001

[a]Higher scores indicate better performance.
[b]Higher scores indicate poorer performance.

TABLE 2.
Two-way ANOVA of the effect of the filters according to the age cohort

Measures	Vision, F (p)[a]	Age-group, F (p)[b]	Filter × Age-group, F (p)
VA (logMAR)	657.88 (<0.001)	140.72 (<0.001)	81.21 (<0.001)
Contrast sensitivity (logCS)	1194.77 (<0.001)	98.96 (<0.001)	8.65 (<0.001)
DSST (correct in 90 s)	67.19 (<0.001)	105 (<0.001)	0.02 (0.981)
TMTA (s)	43.74 (<0.001)	79.69 (<0.001)	33.57 (<0.001)
TMTB (s)	83.83 (<0.001)	141.34 (<0.001)	52.87 (<0.001)
Stroop D (s)	12.82 (<0.001)	9.8 (0.003)	0.44 (0.647)
Stroop W (s)	19.13 (<0.001)	67.06 (<0.001)	11.71 (<0.001)
Stroop C (s)	11.74 (<0.001)	100.92 (<0.001)	6.01 (0.003)
Stroop C-D (s)	7.5 (0.001)	107.53 (<0.001)	6.8 (0.002)

[a]$F_{(2,112)}$.
[b]$F_{(1,56)}$.

for each cognitive test. For each of the DSST, TMTA, and TMTB, all pairwise differences between the means are significant. For the Stroop C, W, and C-D (interference) scores, all differences are significant with the exception of the baseline and the single filter condition, which did not differ significantly from one another. For the Stroop color naming test (Stroop D), the only significant difference was between the two-filter condition and baseline.

A second MANOVA, comparing the current cohort with a younger cohort described previously who undertook the same cognitive tests with the same filter conditions,[1] again found a significant overall main effect of vision condition (Wilks $\lambda = 0.231$, $F_{(12,46)} = 12.8$, $p < 0.001$), as well as a significant difference between the age cohorts in terms of overall performance (Wilks $\lambda = 0.195$, $F_{(6,52)} = 35.78$, $p < 0.001$). There was also a two-way interaction between the effect of the filters and the age of the participants (Wilks $\lambda = 0.335$, $F_{(12,46)} = 7.6$, $p < 0.001$).

Table 2 presents the two-way repeated-measures ANOVAs for each of the cognitive tests, according to vision condition and age group. Overall, there was a trend of poorer performance with increasing filter strength for both age groups, and overall, the older cohort performed more poorly than did the younger cohort (Fig. 1). In addition, for all tests except the DSST and the Stroop D, there was a significant interaction, wherein the effects of the filters were considerably greater for the older cohort than for the younger one. Post hoc simple interaction comparisons for the significant variables revealed that the difference in performance between the one- and two-filter conditions was significantly greater for older than younger participants for each test, as was the difference between the no-filter and two-filter conditions. For the TMTA and TMTB tests, the difference between the one-filter and no-filter conditions was also significantly larger for the older than the younger participants.

Two-way ANOVAs conducted on each of the vision measures revealed a significant main effect of vision condition, a significant main effect of age group, and also a significant two-way interaction between the factors (Table 2). Overall, both VA and contrast sensitivity declined with increasing filter strength, and the older adults scored worse on both measures. The effect of the filters was also greater for older than for younger participants. Notably, however, the interactions were qualitatively very different from the interactions on the cognitive measures. For the vision measures, there was a relatively monotonic change in visual function as a function of the visual degradation, whereas for the cognitive measures, there was an abrupt decrease in performance with the two-filter condition.

Linear mixed effects models showing the relationship between visual function measures and performance on each cognitive test, controlling for age, are given in Table 3. The magnitude of the regression coefficients shows that for all tests, contrast sensitivity

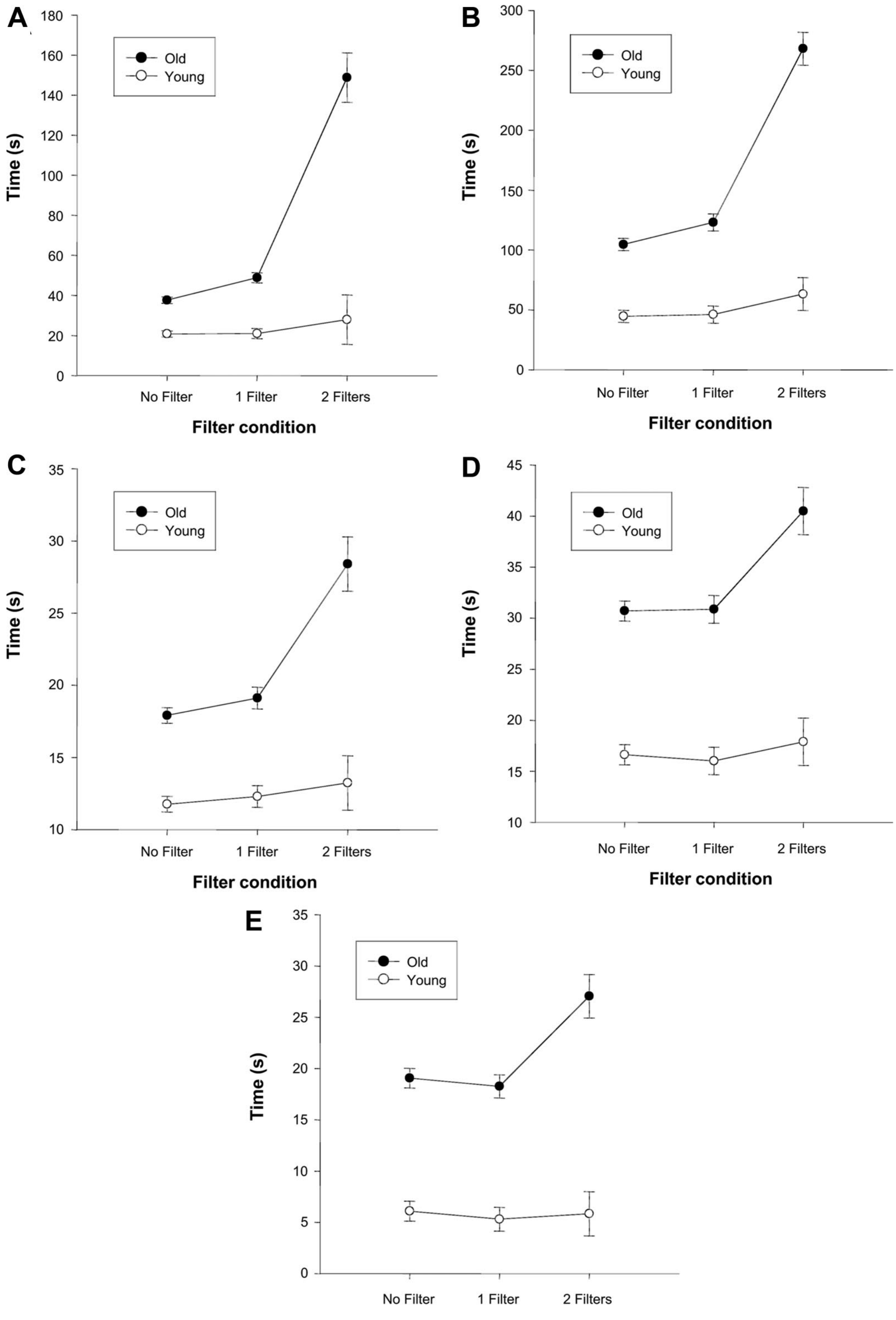

FIGURE 1.
Significant two-way interactions of filter strength and age group for TMTA (A), TMTB (B), Stroop W (C), Stroop C (D) and Stroop C-D (E).

with each filter condition was a stronger predictor of cognitive test performance than was VA.

DISCUSSION

In this study, we found that simulated cataracts had a significant impact on cognitive test performance for a range of commonly used tests in a group of visually normal older adults and that these effects were greater than those found previously in young adults.[1] Importantly, contrast sensitivity, rather than VA, predicted the decrements in cognitive test performance.

Contrast sensitivity was shown to be a better predictor of the differences in performance on the cognitive tests between vision

TABLE 3.
Partial regression coefficients (β) and significance from linear mixed effects models predicting performance on each cognitive test from visual function measures (VA and contrast sensitivity) controlling for participant age

	Cognitive test						
Vision measure	DSST, β (p)	TMTA, β (p)	TMTB, β (p)	Stroop D, β (p)	Stroop W, β (p)	Stroop C, β (p)	Stroop C-D, β (p)
VA	−0.238 (0.001)	0.174 (<0.001)	0.323 (0.002)	0.203 (0.006)	0.221 (0.005)	0.132 (0.071)	0.118 (0.114)
Contrast sensitivity	0.239 (0.004)	−0.239 (<0.001)	−0.425 (<0.001)	−0.237 (0.003)	−0.245 (0.005)	−0.154 (0.057)	−0.122 (0.133)

conditions for the older participants in this study, which reflects the associations found previously for younger adults.[1] Although previous studies in cognitive ageing have suggested a relationship between sensory visual function and cognition,[35,36] the majority of these studies have focused on VA as their index of visual function. It is important to note that contrast sensitivity is also significantly affected by the aging process[37] and, thus, is potentially important in cognitive testing. Our findings are in accord with a previous study[38] that reported that differences in contrast sensitivity accounted for substantial levels of unique variance in neuropsychological test performance, even when the effects of age were controlled for. Anstey et al.[39] also found that contrast sensitivity was associated with processing speed in older adults and that performance on measures of perceptual matching, processing speed, and associative memory was slower when the visual contrast of the test stimuli was reduced. Importantly, the effects of the filters on cognitive processing cannot merely be explained in terms of a difference in legibility of the pencil-and-paper tests, as performance was similarly degraded in the color naming component of the Stroop D, which does not require reading.

The finding that the filters had a greater impact on the visual function of the older than younger participants may be the result of an interaction between light scatter already present in the older eye and additional light scatter produced by the Vistech filters. Importantly, the corresponding deterioration in cognitive function was over and above that level which could be predicted by the visual deterioration. This suggests an interaction between the visual effects of the filters and another, possibly cognitive effect on higher level identification, indicating that the older cohort were more susceptible to disturbance of visual input than their younger counterparts. This may be explained by a cognitive resource model whereby degraded sensory input puts greater demand on higher cognitive resources, reaching a threshold where performance on cognitive tests is affected. As older adults have a reduction in overall processing resources, performance deficits caused by the simulated cataract are more dramatic. This suggests that in later life, when eye disease becomes more prevalent, the additional burden imposed at a lower sensory stage leaves older adults with fewer cognitive resources to compensate for the impact of visual deficits on cognitive processing. A similar explanation has been offered for the effects of hearing impairment on the cognitive test performance of older adults.[40]

An advantage of the approach taken in this study is that the only factor that varied between tests was the visual status of the participants as manipulated by the filters. In studies that have compared cognitive performance between participants with cataracts and those without cataracts, there are many other variables that might differ between groups such as cognitive status, education levels, premorbid intellectual ability, and neurological disease. In studies that have compared cognitive status before and after cataract surgery, performance may also be influenced by the length of time between tests and by practice effects, as it is not possible to randomize the order of testing pre- and post-cataract surgery. In the approach adopted here, it was possible to minimize the effects of practice on the tests by randomizing the order in which the filters were applied. However, there are inherent limitations in simulating the effects of cataracts or any other type of visual impairment, in that although the use of simulated visual impairments allowed us to partial out the effects of vision alone, without introducing variations in experience, it is recognized that the effects observed may be greater than for people with true vision impairment who have adapted to their condition. The simulation that involved the two cataract filters also presents a relatively severe reduction in both VA and contrast sensitivity; nevertheless, they do serve to demonstrate that visual impairment affects performance on commonly used cognitive tests and that these effects interact with participant age.

In summary, this study demonstrates that the visual status of older participants can lead to slowing of cognitive test performance. Differences in contrast sensitivity rather than VA are better predictors of these changes. This has significant clinical implications for older populations and suggests that interventions to improve vision may have important implications in terms of reducing cognitive slowing in this group. Future studies should be directed at identifying the cutoff level of contrast sensitivity at which cognitive performance is impaired to provide clinical guidelines for test protocols.

Received June 1, 2010; accepted August 23, 2010.

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