Association between Higher Order Visual Processing Abilities and a History of Motor Vehicle Collision Involvement by Drivers Ages 70 and Over

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Purpose. To examine in a population-based sample of 2000 drivers aged 70 years and older, the independent association between higher order visual processing impairment and motor vehicle collision (MVC) rate during the prior 5 years.

Methods. Three higher order visual processing screening tests were administered since previous research found associations between impaired performance on these screens and MVC involvement. They included an estimate of visual processing speed under divided attention conditions (useful field of view [UFOV] subset 2); Trails B, a paper and pencil test of visual processing speed also involving problem solving, executive function, and working memory; and the visual closure subtest of the Motor Free Visual Perception Test (MVPT) examining the ability to recognize objects only partially visible. Potentially confounding variables were also assessed including demographics, general cognitive status, visual acuity, and contrast sensitivity. MVC involvement was determined by accident reports from the Alabama Department of Public Safety, and driving exposure was estimated from the Driving Habits Questionnaire.

Results. MVC rates (for at fault and all MVCs) were significantly higher for those older drivers with impairments in any of the three visual processing screening tests. After adjustment for potentially confounding influences, the association between MVC rate and Trails B remained significant, whereas the association with MVPT and UFOV did not.

Conclusions. This population-based study of drivers aged 70 years and older suggests that a paper and pencil test assessing higher order visual processing skills is independently associated with a recent history of MVC involvement. (*Invest Ophthalmol Vis Sci.* 2013;54:778–782) DOI:10.1167/iovs.12-11249

Concerns about older driver safety continue to receive considerable public and media attention.[1–3] Older adults have a higher rate of driving errors and motor vehicle collisions (MVCs) (both fatal and nonfatal) than do middle-aged adults.[4,5] Older drivers are also more likely to die or sustain serious injuries once involved in a MVC.[6,7] Added to these concerns is the fact that older drivers are a rapidly growing segment of the population and are continuing to drive for more years into late adulthood than did previous generations.[8] Concerns about safety must be balanced against the personal need for community mobility and the negative consequences of driving cessation.[9] Driving cessation in older adults is associated with an increased risk for depression,[10–12] placement into long-term care,[13] and decreased physical activity level and health status.[14,15]

There is strong interest in examining risk factors for MVCs among older drivers since risk factor identification can be used to guide the development of screening approaches for high-risk older drivers, which could ultimately improve public safety. Deficits in certain higher order visual processing abilities in older adults have emerged from previous research as among the strongest and consistently reported functional risk factors for MVC involvement. They typically exhibit stronger associations with MVC than do visual sensory functions (e.g., contrast sensitivity, visual acuity).[16] These deficits include slowed visual processing speed under divided attention conditions as measured by the useful field of view (UFOV) subtest 2, a computerized test,[17–22] and also as measured by Trails B, a paper and pencil test.[18,20,23–25] There have also been several reports that impairment in visuospatial processing ability as measured by the Visual Closure Subtest of the Motor-Free Visual Perception Test is related to older drivers' MVC involvement and impaired driving performance.[20,26,27] These visual processing impairments have been associated with MVC involvement in both cross-sectional[18,23] and prospective studies.[19,21,22,25] While the previous work has gone far in establishing the association between these impairments and MVC involvement in older adults, with two exceptions[20,21] population-based estimates are lacking. Therefore, we examined these relationships in a large population-based ($N = 2000$) sample of older drivers ages 70-years-old and older residing in Alabama, who were legally licensed to drive, and were also currently driving. Our approach allows for population-based estimates of the association between a recent history of MVC involvement and slowed visually processing speed and impaired spatial ability, while also adjusting for other factors known to impact MVC rates in older drivers.

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Methods

The study was approved by the institutional review board of the University of Alabama at Birmingham and was consistent with the Declaration of Helsinki. The sample was assembled for the purposes of a population-based study of older drivers ($N = 2000$) aged 70 years and older who resided in Jefferson County, Alabama or the border areas of contiguous counties.[28] We began with a list of persons residing in this geographic area obtained from a direct marketing company (Pinpoint Technologies, Tustin, CA). We then confirmed driver's license status through the Alabama Department of Public Safety (AL DPS), and eliminated those from the target population who did not hold Alabama licenses. From this target population of licensed drivers, we randomly selected potential participants who were mailed a letter about the study, which was then followed by a telephone call from study personnel to confirm eligibility; if eligible, the person was invited to participate. The inclusion criteria were: (1) age 70 or older, (2) held a current Alabama driver's license, (3) had driven within the last 3 months, (4) did not reside in a nursing home or other institution where comprehensive care was provided and/or community access and driving opportunity were controlled, and (5) spoke English. For those individuals who were eligible and agreed to participate, an appointment was scheduled at the Clinical Research Unit in the Department of Ophthalmology, University of Alabama at Birmingham. For those who declined to participate, basic demographic information (age, race/ethnicity, sex) and driving status were obtained. All study personnel who interacted with participants were masked with respect to each participant's MVC history.

A trained interviewer administered several questionnaires to participants. These included a review of demographic characteristics (age, race, sex, education completed) and a medical condition questionnaire that asked about the presence versus absence of 15 chronic medical conditions in the form of "Has a doctor ever told you that you have . . . ." The Driving Habits Questionnaire[29] was used to obtain an estimate of annual mileage.

Three higher order visual processing screening tests were selected for administration since previous research has demonstrated significant associations between impaired performance on these tests and MVC involvement,[17–27] as discussed earlier. Visual processing speed under divided attention conditions was examined by the UFOV subtest 2 (Visual Awareness Research Group, Punta Gorda, FL).[30,31] This screening test, administered on a computer with a touch screen, estimates the amount of time in milliseconds that a person needs to discriminate which of two test targets is presented at fixation in central vision, while simultaneously identifying the location of a peripheral target in the 10° radius field. Scores can range from 16 to 500 ms. Impaired UFOV subtest 2 performance was defined in terms of moderate impairment (scores 150–350 ms) and severe impairment (scores > 350 ms).[20] Visual processing speed while dividing attention was also assessed using the Trails B test,[32] a paper and pencil test that not only relies on processing speed and divided attention but also on problem solving, executive function, and working memory.[33] It is a connect the dots task that includes two sets of dots, one labeled from 1 to 25 and the other labeled A to Z. The participant connects the dots by alternating between numbers and letters (i.e., 1, A, 2, B, 3, C etc.). Performance is expressed in terms of the time (expressed in minutes) needed to complete the test. Impaired performance on Trails B was defined as scores greater than or equal to 2.47 minutes.[20,23] Spatial ability was assessed by the Visual Closure Subtest of the Motor-free Visual Perception (MVPT)[34]; this test examines one's ability to recognize incompletely drawn objects by matching them to completely drawn versions of the object. A total of 11 test cards are shown, so scores can range from 0 to 11 correct. Impaired MVPT performance was defined as less than eight cards correct.[20]

Contrast sensitivity and general cognitive status were also assessed. They have been previously associated with MVC involvement by older drivers[35–38] and also can impact higher visual processing skills,[18,39] and, thus, could serve as potentially confounding factors in examining the relationship between higher order visual processing skills and MVC involvement. Contrast sensitivity was estimated using the Pelli-Robson contrast sensitivity chart[40] under binocular conditions; it was scored by the letter-by-letter scoring method[41] and expressed as log sensitivity. General cognitive status was assessed by the Mini-Mental State Exam, with potential scores ranging from 0 to 30 (perfect performance).[42] We also measured habitual, binocular visual acuity using the Electronic Visual Acuity (EVA) tester,[43] which was expressed as logarithm of the minimum angle resolvable (logMAR).

Accident reports for the 5 years prior to each participant's enrollment date were provided by the AL DPS, the state agency that maintains these records. These reports provided information about the MVCs incurred in the previous 5 years in which the participant was the driver, and whether or not the participant was deemed at fault by the police officer who came to the scene. This information was used together with driving exposure obtained through the Driving Habits Questionnaire[29] to calculate the crash rate per million miles driven for each group in the study.

Drivers with and without impaired performance on the three visual processing tests were compared with respect to demographic, health, and driving characteristics using *t*- and χ^2 tests for continuous and categorical variables, respectively. Poisson regression was used to estimate rate ratios (RRs) and associated 95% confidence intervals (CIs) for the association between overall and at fault MVC involvement and MVPT, Trails B, and UFOV. Age, sex, race, education level, mental status, contrast sensitivity, visual acuity, and the number of comorbid health problems were considered potential confounders, and, thus, adjusted RRs are also reported. P values of less than or equal to 0.05 (two-sided) were considered statistically significant.

Results

Table 1 presents descriptive statistics for the sample with respect to demographic variables, contrast sensitivity, visual acuity, mental status, the number of medical comorbidities, and annual mileage. Participants with impaired scores on the visual closure subtest of the MVPT, Trails B, and UFOV subtest 2 were more likely to be older, African American, and have completed less education; they were also more likely to have worse contrast sensitivity, visual acuity, and mental status scores, and their annual mileage was lower. Men were more likely to have impairments on Trails B and UFOV than were women, but this sex difference was not significant on the MVPT. Annual mileage was lower for those with impairments on Trails B, UFOV, and the MVPT.

Table 2 presents the number of MVCs incurred (overall and at fault) in the 5 years prior to enrollment and the MVC rate (per million miles of travel) for impaired and nonimpaired drivers on each visual processing test. Also presented are both crude and adjusted RRs that examine associations between impairment on each visual processing screening test and MVC rate. These associations are presented for all MVCs as well as for at fault MVCs only. Focusing first on the analysis on all MVCs, regardless of visual processing test, the rate of MVC involvement was higher for those with impairment on any of the visual processing tests, as revealed by significant RRs. After adjustment for potentially confounding factors, the association between MVC rate and Trails B remained significant. However the association with MVPT and UFOV was no longer significant.

With respect to at fault MVCs, a similar picture emerged. MVC rates were higher for those with visual processing impairment as defined by MVPT, Trails B, or UFOV subtest 2. These rate increases were significant when unadjusted, yet when adjusted, only Trails B was significantly associated with MVC rate.

TABLE 1. Demographic Characteristics, Contrast Sensitivity, Visual Acuity, Mental Status, Number of Comorbid Medical Conditions, and Annual Mileage Stratified by Nonimpaired and Impaired Performance on the Visual Processing Screening Tests (MVPT Visual Closure Subtest, Trails B, UFOV Subtest 2)

	MVPT Visual Closure Subtest			Trails B			UFOV Subtest 2			
	>7	≤7		<2.47	≥2.47		<150	150–350	>350	
	n = 1,700	*n* = 300	*P* Value	*n* = 1241	*n* = 754	*P* Value	*n* = 1,125	*n* = 653	*n* = 221	*P* Value
Age, mean (SD)	76.9 (4.8)	78.6 (5.6)	<0.0001	76.2 (4.2)	78.8 (5.7)	<0.0001	76.2 (4.4)	77.7 (4.8)	80.5 (6.2)	<0.0001
Sex, *n* (%)										
Male	971 (57.1)	159 (53.0)	0.18	679 (54.7)	447 (59.3)	0.05	661 (58.7)	344 (52.7)	125 (56.6)	0.04
Female	729 (42.9)	141 (47.0)		562 (45.3)	307 (40.7)		464 (41.2)	309 (47.3)	96 (43.4)	
Race, *n* (%)										
White	1466 (86.2)	1466 (58.0)	<0.0001	1130 (91.1)	505 (67.0)	<0.0001	1010 (89.8)	500 (76.6)	129 (58.4)	<0.0001
Black	226 (13.3)	125 (41.7)		107 (8.6)	244 (32.4)		110 (9.8)	149 (22.8)	92 (41.6)	
Other	8 (0.5)	1 (0.3)		4 (0.3)	5 (0.7)		5 (0.4)	4 (0.6)	0 (0.0)	
Education, *n* (%)										
Less than high school	503 (29.6)	129 (43.1)	<0.0001	292 (23.5)	340 (45.2)	<0.0001	292 (26.0)	237 (36.4)	103 (46.6)	<0.0001
High school grad or GED	38 (2.2)	13 (4.4)		21 (1.7)	30 (4.0)		24 (2.1)	20 (3.1)	7 (3.2)	
1–4 y of college	893 (52.5)	125 (41.8)		712 (57.4)	303 (40.2)		629 (55.9)	294 (45.1)	94 (42.5)	
Postgraduate degree	266 (15.7)	32 (10.7)		216 (17.4)	216 (10.6)		180 (16.0)	101 (15.5)	17 (7.7)	
Contrast sensitivity, mean (SD)	1.7 (.13)	1.6 (.13)	<0.0001	1.70 (0.12)	1.63 (0.14)	<0.0001	1.7 (0.12)	1.7 (0.13)	1.6 (0.14)	<0.0001
Visual acuity, mean (SD)	0.05 (0.13)	0.09 (0.14)	<0.0001	0.04 (0.12)	0.09 (0.15)	<0.0001	0.03 (0.12)	0.07 (0.14)	0.10 (0.15)	<0.0001
MMSE, mean (SD)	28.4 (1.7)	26.8 (2.6)	<0.0001	28.8 (1.2)	27.1 (2.4)	<0.0001	28.8 (1.2)	27.9 (3.0)	26.0 (3.0)	<0.0001
Comorbid conditions, mean (SD)	3.4 (1.8)	3.4 (1.8)	0.88	3.3 (1.8)	3.6 (1.9)	<0.0003	3.3 (1.8)	3.6 (1.8)	3.6 (1.8)	0.0006
Annual mileage, mean (SD)	9845 (9657)	7724 (7717)	0.0003	10,380 (9812)	8124 (8583)	<0.0001	10,288 (9974)	8964 (8546)	7345 (8533)	<0.0001

DISCUSSION

This study found that older drivers, aged 70 years and older, with deficits in higher order visual processing had higher rates of MVC involvement than those with no such deficits, specifically, those with slowed visual processing speed under divided attention conditions and impaired visuospatial ability to visualize information not present, were more likely to be crash involved in the previous 5 years. This population-based study is in agreement with several previous studies,[17–22] both cross-sectional and prospective in design, in highlighting the importance of visual processing speed and spatial abilities in understanding collision involvement among older drivers. However, in the present study, several potentially confounding factors that were correlated with both visual processing abilities and crash rates were also measured; when associations between MVC involvement and visual processing abilities were adjusted for these factors, only impaired performance on Trails B remained significant. Trails B relies on many types of skills.[33] In addition to visual processing speed and divided attention, Trails B also involves problem solving, executive function, and working memory, as well as visual scanning, and eye–hand motor control. It could be that because it taps into either a wider array of relevant skills than the UFOV and the MVPT, or a

TABLE 2. Associations between Performance in Visual Processing Screening Tests and MVC Rate in the Previous 5 Years (Both Unadjusted and Adjusted Rate Ratios)

		All MVCs				At Fault MVCs			
	N	*N* MVCs	MVC Rate*	RR (95% CI)	RR (95% CI)†	*N* MVCs	MVC Rate*	RR (95% CI)	RR (95% CI)†
MVPT visual closure subtest									
>7 correct	1,700	566	5.16	Reference	Reference	253	2.31	Reference	Reference
≤7 correct	300	115	7.62	1.48 (1.21–1.80)	0.97 (0.78–1.21)	55	3.64	1.58 (0.18–2.11)	0.93 (0.67–1.27)
Trails B									
<2.47 minutes	1,241	382	4.53	Reference	Reference	160	1.90	Reference	Reference
≥2.47 minutes	754	298	7.43	1.64 (1.41–1.91)	1.23 (1.02–1.49)	148	3.67	1.94 (1.55–2.43)	1.39 (1.05–1.83)
UFOV subtest 2									
<150 ms	1,125	362	4.78	Reference	Reference	160	2.11	Reference	Reference
150–350 ms	653	228	5.97	1.25 (1.06–1.48)	0.98 (0.82–1.17)	96	2.51	1.19 (0.93–1.54)	0.88 (0.67–1.15)
>350 ms	221	91	8.60	1.80 (1.43–2.27)	0.99 (0.75–1.31)	52	4.91	2.33 (1.71–3.19)	1.09 (0.73–1.61)

* Motor vehicle collision rate per million miles of travel.

† Rate ratio (RR) adjusted for age, sex, race, education, contrast sensitivity, visual acuity, MMSE, and number of comorbid medical conditions.

set of skills more relevant or fundamental to controlling a vehicle, Trails B emerges as having an independent association with a history of MVC involvement.

Unlike the majority of previous studies, this study did not find that visual processing speed as measured by UFOV subtest 2 was independently associated with a history of MVC involvement after adjustment for potentially confounding factors. That the results from the current study are inconsistent with prior work is surprising, given the robustness of the association across various study designs. Some previous studies reporting associations between UFOV and MVCs have been based on small samples,[17] samples pooled across studies,[22] convenience samples,[44,45] those with a disproportionate representation of multiple crash involved drivers,[18,19] and/or addressed the relationship between baseline visual processing abilities and incident (prospective), not retrospective, MVCs.[19–21] In a population-based study based in a driver licensing office in Maryland,[20] UFOV subtest 2 (the same screening test as used in the present study) was associated with incident MVC involvement after adjustment for many other factors; however, associations were not adjusted for contrast sensitivity impairment as was the case in the present study. Contrast sensitivity is known to elevate MVC risk in older drivers and also known to impact UFOV test performance.[35–37] Yet when contrast sensitivity was removed from our multivariable analysis, there still was no association with UFOV impairment; thus, this does not explain the difference in results between the two studies.

In another population-based, prospective study of older adults in Salisbury, Maryland (SEE Project),[21] UFOV was measured in a sample of study participants who were approximately 2.1 times more likely to have an incident crash in subsequent years after adjustment for demographic variables, mental status, and medical comorbities; however associations in the SEE Project were not adjusted for contrast sensitivity. As mentioned above, in the present study, even when contrast sensitivity was not adjusted for, there still was no association between UFOV and MVC rate. It is important to consider design differences between the SEE Project and the current study, given the difference in the results. The present study used the current UFOV software where performance is defined as a duration threshold and peripheral targets are presented at approximately 10° eccentricity only, whereas the SEE project used the original version of the UFOV test where targets are presented out to 30° and performance is expressed as a spatial area within the 30° field where a criterion level of performance could be met. Yet previous research indicates good agreement between the two versions of the test.[31] The age distribution in the two studies was different; approximately one-third of the Maryland sample were in the 60 age group at baseline, whereas all drivers in the present study were age 70 and over. Only half the participants took the UFOV test in the SEE project, whereas the test was administered to all participants in the present study.

Another major reason for differences between our study and the two Maryland studies[20,21] could be that the Maryland studies had a prospective design, whereas the present study did not. The lack of an association in the current study might be attributable to survival bias. Despite the use of retrospective MVCs, our study design is inherently cross-sectional in nature and as a result, individuals in this older age group with UFOV impairment who were particularly at risk for MVCs may have died. This is supported by previous work suggesting that older drivers with UFOV impairment have a higher mortality risk than those without UFOV impairment.[15] Our older driver sample in the present study is now being followed prospectively for MVC involvement, which will eventually constitute a more appropriate direct comparison with the two Maryland studies.

Strengths and limitations of this study should be considered. This study had a large sample, population-based design. The age range focused on was older drivers aged 70 and over, the age range in later adulthood where MVC rates in the United States dramatically increase, especially rates of fatal collisions.[46] Many potentially confounding factors were measured and taken into account when evaluating RRs. The visual processing screening tests subjected to evaluation were selected based on numerous previous studies suggesting their relevance to understanding driver safety in older adults.[17–27] In preliminary analyses, we explored a variety of cutpoints for impairment definitions for the visual processing tests studied here, with no noteworthy change in the main results of the study. A limitation is that the visual processing abilities of nonparticipants could not be ascertained and, thus, their impact on our measures of association remains unknown. The generalizability of our findings to ethnic/racial groups other than whites of non-Hispanic origin and African Americans and to other geographic regions of the United States is unknown.

In conclusion, this study suggests that impaired visual processing speed under divided attention conditions in drivers aged 70 years and older as assessed by a simple paper and pencil test, which also relies on problem solving, executive function, and working memory, is independently associated with an elevated MVC rate during the previous 5 years of driving. This large sample of older drivers is being followed prospectively to assess whether incident MVCs are associated with the higher order visual processing tests examined here, as well as with visual sensory tests (contrast sensitivity, visual field sensitivity). The prospective portion of this population-based Alabama study will be instructive in whether it confirms the results of the two Maryland population-based, prospective studies[20,21] that found that UFOV subtest 2 is a significant independent marker for incident MVC involvement. It is firmly established that visual acuity testing, the standard vision screening approach at initial licensure or renewal in the United States and many other jurisdictions is inadequate as a screening tool for identifying crash prone drivers because of its poor sensitivity and specificity.[16] Thus, there is a pressing public safety need to investigate alternative visual screening strategies so that licensure decisions are evidence-based, fair, and effective at enhancing safety.

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