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Motion Perception as a Risk Factor for Motor Vehicle Collision Involvement in Drivers ≥ 70 Years

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Abstract

Purpose: To evaluate the relationship between visual function and a five-year history of motor vehicle collision rates in older adults. Motion perception impairment was explored as a risk factor for motor vehicle collisions for the first time in this study.

Materials and Methods: Participants were licensed drivers ≥70 years old enrolled in the Alabama VIP Older Driver Study who underwent functional assessments for motion perception, distance visual acuity, contrast sensitivity, visual field sensitivity, and visual processing speed. Participants were recruited based on their being patients in an ophthalmology clinic in the year prior to enrollment or had participated in an earlier driving study. Crash reports were obtained from the Alabama Law Enforcement Agency for the 5 years prior to enrollment and mileage estimated using the Driving Habits Questionnaire. Crude and age-adjusted rate ratios (RRs) and 95% confidence intervals (95% CIs) were calculated using Poisson regression.

Results: 159 participants enrolled with a mean age of 79 years. The age-adjusted crash rate was higher among those with worse motion perception (RR: 2.7, 95% CI: 1.4–5.2), severe slowing in visual processing speed (RR: 3.6, 95% CI: 1.5–8.5), and impaired peripheral visual field sensitivity (RR: 2.4, 95% CI: 1.3–4.4).

Conclusions: Among a sample of older drivers, crash rates were higher for those with impaired motion perception, severely slowed visual processing speed, and impaired peripheral visual field sensitivity. The association between motion perception and crash risk in older drivers has not been

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previously reported. Prospective analysis of the Alabama VIP Older Driver Study will examine these risk factors for future collision involvement based on naturalistic driving data.

Keywords

driving; older drivers; vision; motor vehicle collisions; motion perception

1. INTRODUCTION

Older drivers constitute the population of drivers with the largest growth rate in the United States (Federal Highway Administration 2017). Older drivers aged ≥ 80 years have a crash rate per vehicle miles driven that is higher than middle-aged adults and approaches that of young adults (Tefft, 2017). Previous research on older driver safety has established that several aspects of visual function increase the risk for on-road motor vehicle collision involvement as recorded by governmental jurisdictions (i.e., through accident reports) (Ball *et al.* 1993, Owsley *et al.* 1998a, Owsley *et al.* 1998b, Rubin *et al.* 2007, Green *et al.* 2013a). Epidemiological studies on older drivers have shown that impairments in contrast sensitivity, peripheral vision (visual fields), and slowed visual processing speed are also associated with both a history of collisions and future collisions (Johnson and Keltner 1983, Ball *et al.* 1993, Owsley *et al.* 1998a, Ball *et al.* 2006, Rubin *et al.* 2007, Friedman *et al.* 2013, Green *et al.* 2013b, Huisingh *et al.* 2015, Huisingh *et al.* 2017, Owsley *et al.* 2020).

Visual motion perception is important for many daily tasks such as perceiving events, driving, walking, and social interactions (Sepulveda *et al.* 2020). As a visual ability it involves different levels of processing including detecting spatial changes in objects over time, perceiving contrast changes, and higher order processing involving integration of spatial and temporal motion information. Research has shown that aging negatively impacts several aspects of motion perception both in central and peripheral vision (Sepulveda *et al.* 2020). Many of the motion perception problems experienced by older adults depend on early levels of visual processing, arising at a retinal level and the first stages of cortical processing, and involve detection of minimum levels of speed, contrast or displacement of targets (Owsley *et al.* 1983, Wood and Bullimore 1995, Sepulveda *et al.* 2020). Despite the fact that driving involves a constantly moving visual array, and that several studies have indicated an association between motion sensitivity and various aspects of driving performance (Wood 2002, Wood *et al.* 2008, Lacherez *et al.* 2014, Wood *et al.* 2014, Wood *et al.* 2018), no study to date has used real-world collision information to examine whether impaired motion perception increases risk for collision involvement in older drivers.

Identifying and confirming visual components associated with motor vehicle collisions, particularly among an increasing population of those at greater risk of a collision, is essential to inform future research, public policy, and healthcare so older drivers can independently operate a motor vehicle as long as it is safe. Therefore, in the present study on drivers aged 70 years and over, we explore the association of motion perception and 5-year history of crash rate, not addressed previously in the literature, and also examine the association of other visual risk factors.

2. MATERIALS AND METHODS

2.1 Study design and sample

Data from the Alabama VIP Older Driver Study were used in this cross-sectional assessment of baseline visual functions and their association with motor vehicle collision rates in the five years prior to enrollment. The study design has been previously described (Owsley *et al.* 2018). Participants aged ≥70 years were recruited based on their participation in a previous population-based study on older drivers in Alabama (Owsley *et al.* 2013), or from eye clinics of the Callahan Eye Hospital at the University of Alabama at Birmingham (UAB) who were seen during the previous year. Prior to enrollment, a screening interview was completed to confirm those who enrolled were aged ≥70 years of age, had a valid State of Alabama driver's license, drove at least 4 days per week, spoke English, and owned or had permission to use a motor vehicle. The study required that drivers have a minimum of 4 days of driving per week because the purpose of the study is to focus on the association between visual function and crash rate. Requiring that they drive at least 4 days per work increased the likelihood of increased driving exposure (mileage). All participants, regardless of their five-year collision history, were included. UAB's Institutional Review Board approved this study, written informed consent was obtained from all participants, and this study adhered to the Declaration of Helsinki.

2.2 Data collection

On the day of enrollment, participants completed questionnaires through interviewer administration to collect information on baseline demographics, education, general health, driving habits (Driving Habits Questionnaire (DHQ) (Owsley *et al.* 1999)), depressive symptoms (Center for Epidemiology Studies Depression Scale (CES-D) (Radloff 1977)), and general cognitive status (Mini-Mental Status Examination (MMSE) (Folstein *et al.* 1975)). The DHQ assess six domains: current driving status and miscellaneous items (e.g., seat belt use, spectacle use), dependence on other drivers, driving difficulty, driving space, and self-reported crashes and citations (Owsley *et al.* 1999). In this study, the DHQ was used to estimate miles driven and was used in statistical models; the test-retest reliability for exposure assessment has been shown to be high (r = 0.83) (Owsley *et al.* 1999). The CES-D asses four factors including depressed affect, positive affect, somatic activity or inactivity, and interpersonal changes (Radloff 1977). The CES-D's test-retest reliability is moderate (r = 0.57) and the internal consistency is strong (Brown-Spearman coefficient = 0.85) (Radloff 1977). Persons at risk of depression have scores greater than 16 (Lewinsohn *et al.* 1997). The MMSE is a screening tool that evaluates general cognitive function including items on orientation, attention, memory, language, and visual-spatial skills; it has strong test-retest reliability (r = 0.89) (Folstein *et al.* 1975). MMSE scores greater than or equal to 24 indicate cognitive impairment (Folstein *et al.* 1975). The most recent electronic health records for participants were obtained (within one year of enrollment) to ascertain the eye diagnoses common in older age (i.e., glaucoma, diabetic retinopathy or macular edema, age-related macular degeneration, cataract, pseudophakia). All visual function tests were performed under photopic conditions ("daylight conditions"), and testing was binocular unless otherwise mentioned. Habitual distance visual acuity, which assesses spatial resolution in central vision, was measured using the Electronic Visual Acuity (EVA) (Beck *et al.* 2003) device with its standard protocol. Impaired acuity was defined as logMAR > 0.3 (worse than 20/40), the visual acuity standard used by many governmental jurisdictions for driving licensure. Contrast sensitivity, which measures the ability to discern objects between the foreground and background, was assessed using the Pelli-Robson chart (Pelli *et al.* 1988) scored using the letter-by-letter method (Elliott *et al.* 1991). Impaired contrast sensitivity was defined as log sensitivity <1.5, a cut-point in many older driver crash studies (Huisingh *et al.* 2015).

Visual field sensitivity (decibels) was assessed monocularly using the Humphrey Field Analyzer (HFA) Model II-I with a custom test of 20 white stimulus-size III targets using a full-threshold procedure (Carl Zeiss Meditec, Dublin, CA, USA). Visual field sensitivity measures the ability to detect targets of different brightness levels throughout the visual field. As previously described by Huisingh et al. (2015), test target location selections were based on the visual field area relevant to the roadway environment and viewed through the windshield (Vargas-Martin and Garcia-Perez 2005) or at the vehicle's dashboard. Test target locations in the HFA extended up to 60° horizontally for each eye, which is the most extreme horizontal field position testable in the HFA, and included test locations out to 15° superiorly and 30° inferiorly. The monocular visual fields from each participant were measured and combined to form a binocular field (Nelson-Quigg *et al.* 2000) of 21 points within the area described above. To create the binocular field, the sensitivity at each test location was defined by the most sensitive point (highest level of visual field sensitivity) of the two eyes. For instances where sensitivity was tested in only one eye (which was the case for each eye at 60° temporal on the horizontal meridian), the sensitivity of that eye defined the binocular visual field. Visual field sensitivities were grouped into the following regions: overall (all test targets), superior (targets above the horizontal meridian), inferior (targets below the horizontal meridian), left (targets to the left of the vertical meridian), right (targets to the right of the vertical meridian), and peripheral (targets at or temporal to ±45°). All sensitivities at test locations within each region were averaged to calculate the regional sensitivity. Better visual field sensitivities were defined as the top three quartiles and worse as the lowest quartile, following prior convention (Huisingh *et al.* 2015).

Visual processing speed under divided attention conditions was estimated using the useful field of view (UFOV) subtest 2 (Edwards *et al.* 2005, Edwards *et al.* 2006). This test estimates the amount of time (milliseconds (ms)) it takes a person to determine which of two targets is shown in central vision while concurrently identifying the location of a target in the peripheral 10° radius field. UFOV scores range from 16 to 500 ms, with scores 150–350 ms categorized as moderately impaired, and scores greater than 350 considered severely impaired (Owsley *et al.* 2013).

Motion perception in central vision was assessed using a drifting Gabor test, which has been used in prior evaluations of hazard perception (Lacherez *et al.* 2014). This test presented a 3 cycle/degree vertical sinusoidal grating filtered with a Gaussian envelope. Participants were asked to identify the drifting direction (right versus left) of the grating, with the drift rate (Hz) varying during a 2-down/1-up staircase with 8 reversals. Thresholds were defined as the average of the last 6 reversals. Previous cut-points for motion perception impairment in crash risk studies have not been reported. Thus, we defined impaired motion perception as thresholds worse than or equal to the median value.

Information on state-reported motor vehicle collisions for all participants was obtained from crash reports provided by the Alabama Law Enforcement Agency for the period between the enrollment date and five years prior to that date.

2.3 Statistical analysis

Demographic, visual function, cognitive function, and eye condition information collected were summarized for all participants. Crude and adjusted rate ratios (RRs), defined as the ratio of the incidence rate in the exposed group and the unexposed group, and 95% confidence intervals (95% CIs) for the association between any crash and visual function were calculated using Poisson regression models. Deviance was assessed but models did not require correction for dispersion. Regression models used a log link function and an offset for the natural log of miles driven. Models were adjusted for age at enrollment. Poisson regression assumptions were met as the response variable was the count of crashes per mile driven, observations are independent, and the mean was equal to the variance. To further assess the association of motion perception and crash risk, further adjustment for visual acuity and contrast sensitivity was completed. This was the only model adjusted for other visual function measure(s). The following were not confounders and thus were not adjusted for: sex, race, number of medical conditions, CES-D score, MMSE score, and years of education. The level of significance was set to $p < 0.05$.

3. RESULTS

There were 159 participants who enrolled, with 54.7% aged 70–79 years, 43.4% aged 80–89, and 1.9% aged 90–99 (Table 1). There were slightly more men (55.4%) than women (44.7%). The sample consisted of 18.2% African Americans and 81.8% whites of European descent. Cognitive function was not impaired in the majority of drivers (98.7%), and the vast majority were not depressed (98.1%). Most participants had visual acuity ≤0.3 logMAR (20/40 or better) (97.5%) (Table 1); only 4 drivers had visual acuity worse than 20/40, and thus with this low number of participants, visual acuity impairment's association with crash involvement was not evaluated. With respect to impaired contrast sensitivity, 10.7% of participants had deficits (< 1.5 log sensitivity) (Table 2). About half of participants had slowed visual processing speed (≥150 ms). The average overall binocular visual field light sensitivity was 23.8 dB (standard deviation 3.0 dB). The median value for motion perception was 0.14, so participants with that value or higher were defined as impaired. Participants self-reported they drove an average of 8,679 ± 12,180 miles annually generating an estimate of 6,900,022 miles driven in the sample for the five years prior to enrollment. In all, there were 47 crashes in the 5-year period prior to enrollment with 18.2% of participants having 1 crash, 3.8% having 2 crashes, and 1.3% having 3 crashes. The overall crash rate was 6.8 per 1,000,000 person-miles.

As shown in Table 3, a history of higher crash rate was associated with severe slowing in visual processing speed (RR: 3.6, 95% CI: 1.5–8.5), impairment in the peripheral visual field sensitivity (RR: 2.4, 95% CI 1.3–4.4), and impaired motion perception (RR: 2.7, 95% CI:

1.4–5.2) compared to those without impaired function. Impairment in the left visual field was significant in the crude model, (RR: 1.9, 95% CI: 1.1–3.6); however, the association was attenuated after adjusting for age (RR: 1.7, 95% CI: 0.9–3.2). Like our measure of motion perception, visual acuity and contrast sensitivity are also measures of central vision; after adjusting for acuity and contrast sensitivity, the association between motion perception and a history of collisions remained significant (RR: 2.6, 95% CI: 1.3–5.2). Contrast sensitivity and impairments in other sections of the visual field were not associated with increased collision rates.

4. DISCUSSION

This study suggests that impaired motion perception in older adults is associated with a history of motor vehicle collision involvement during the previous five years, with those with worse motion perception being 2.6 times as likely to have had a crash per mile driven compared to those with better motion perception, adjusting for age, visual acuity, and contrast sensitivity (RR: 2.6, 95% CI: 1.3–5.2). To our knowledge, this is the first report that motion perception is a risk factor for crash involvement in older drivers. Several studies by Wood and colleagues (Wood 2002, Wood *et al.* 2008, Wood *et al.* 2018) have found that various characteristics of on-road driving performance in older drivers are related to their motion perception abilities. Drivers with impaired motion sensitivity, minimum displacement threshold (D_{min}), assessed using random dot kinematograms were more likely to exhibit poorer performance on specific aspects of driving assessed on a closed road circuit (e.g., time-sensitive tasks, avoiding road hazards, dividing attention while driving) (Wood 2002), as well as on their overall driving performance skills under on-road conditions (Wood *et al.* 2008). Drivers with AMD with impaired motion sensitivity (D_{min}) had the lowest on-road driving performance measures (Wood *et al.* 2018). In addition, older drivers' impairments in motion perception were associated with problems in pedestrian detection at night (Wood *et al.* 2014) and in hazard detection in videos from the Hazard Perception Test (Lacherez *et al.* 2014), a screening tool used for licensure in the United Kingdom and Australia. Simulator studies have also underscored the role of motion perception in simulated driving tasks. Drivers with Alzheimer's disease who were more likely to crash in a simulator had deficits in seeing structure from motion (Rizzo *et al.* 2001). Wilkins et al. (2013) also showed that motion sensitivity was associated with emergency braking in a simulator by young drivers. Given the many driving performance maneuvers in on-road and simulator studies related to motion sensitivity, further work should explore motion perception as a risk factor for unsafe driving and collision involvement in older adults.

The findings from this study also support previously reported associations between a history of collisions by older drivers and visual field impairment (Johnson and Keltner 1983, Rubin *et al.* 2007, Huisingh *et al.* 2015, Huisingh *et al.* 2017) and slowed visual processing speed (Ball *et al.* 1993, Owsley *et al.* 1998a, Ball *et al.* 2006, Friedman *et al.* 2013). While the association between crash and left visual field was attenuated when adjusting for age in the current study, there is evidence from this small sample that the left portion of the visual field is particularly vulnerable to collision risk in older drivers as has been shown previously (Huisingh *et al.* 2015, Kwon *et al.* 2016); in the US the oncoming lane is to the left of the driver and thus presents vehicle control challenges from the opposing traffic.

Of the 159 participants in the study, only 4 fell into the impaired acuity category, with one participant having 3 crashes and another having 1 crash in the five years before enrollment. Both of these persons had advanced age-related macular degeneration (AMD) in one eye (geographic atrophy or a history of choroidal neovascularization) and intermediate AMD in the fellow eye. Owing to the small number of drivers with visual acuity impairment in the study, we did not evaluate the association between acuity and prior collision involvement. Future studies should devise strategies to identify these drivers as candidates for study since in some states the visual acuity standard extends to 20/60, and to 20/100 under certain circumstances.

A strength of this study is the inclusion of motion perception, previously ignored in studies on driver safety, in spite of the fact that older driver performance studies have indicated that on-road driving skills rely on motion sensitivity (Wood 2002, Wood *et al.* 2008, Lacherez *et al.* 2014, Wood *et al.* 2014, Wood *et al.* 2018). As in other epidemiological studies, findings support associations between a history of crash rate and slowed visual processing and impairments in peripheral vision. Information regarding crashes was obtained from our governmental jurisdiction and not by participant self-report which can be unreliable. Weaknesses must also be acknowledged. The study design is cross-sectional and, as such, the temporal relationship between measures of visual function and crash involvement is unknown. Additionally, inherent to cross-sectional study designs, selection bias is also possible. The study sample is relatively small compared to our previous work (Owsley *et al.* 2013) so statistical power was not high. Our earlier work on contrast sensitivity impairment in older drivers was on drivers with cataracts, where we found associations between contrast sensitivity deficits and crash involvement (Owsley et al., 1999, Owsley et al., 2001). However, many of the drivers in the current study had intraocular lenses and thus were less likely to have contrast sensitivity impairment, which may have minimized our ability to find an association between contrast deficits and crash involvement. There are many types of motion perception (Sepulveda *et al.* 2020) yet we only measured one aspect, a drifting grating Gabor test. The majority of the sample did not have cognitive impairment or signs of depression, and thus volunteer bias may exist when compared to the general population. A limitation of the study is that driving exposure (mileage) was self-reported, which could make rate ratios less accurate compared to reality. Future research on crash risk and motion perception should seek to differentiate the roles of different levels of motion processing in older driver safety, including those from early stages of the motion pathway and more complex, higher-order motion perception functions. These studies should also include prospective study designs, including the use of naturalistic driving, to explore the relationship between motion perception and future crash involvement.

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Highlights

- Visual function and association with rate of 5-year history of motor vehicle collision (MVC) among drivers 70 years and older was assessed
- For the first time impaired motion perception was shown to be a MVC risk factor in real-world settings
- Risk of MVC increases for impaired peripheral visual field sensitivity and visual acuity
- Severely impaired visual processing speed is associated with MVC

Table 1.

Demographic and health characteristics of sample (N = 159)

Characteristic	Mean (standard deviation) or n (%)
Age, years	79.3 (5.1)
Age group, years	
70–79	87 (54.7)
80–89	69 (43.4)
90–99	3 (1.9)
Sex	
Women	71 (44.7)
Men	88 (55.4)
Race	
Black	29 (18.2)
White	130 (81.8)
Education, years	15.0 (2.8)
Education category	
Less than high school graduate	6(3.8)
High school graduate	78 (49.1)
College graduate	62 (39.0)
Professional or graduate school	13 (8.2)
MMSE, total score	27.8 (1.8)
MMSE	
≥ 24 (not impaired)	157 (98.7)
< 24 (impaired)	2 (1.3)
Medical conditions, number	
0–1	21 (13.2)
2–3	45 (28.3)
4–5	62 (40.0)
≥6	31 (19.5)
CES-D, total score	3.7 (4.2)
CES-D	
≤ 16 (not depressed)	156 (98.1)
> 16 (depressed)	3 (1.9)
Eye diagnoses (in at least one eye)[1]	
Glaucoma	43 (27.7)
Diabetic retinopathy or macular edema	10 (6.5)
Age-related macular degeneration	29 (18.7)
Cataract	63 (40.7)
Pseudophakia	97 (62.6)

Characteristic	Mean (standard deviation) or n (%)

[1] No eye medical record available, N = 4.

Table 2.

Visual function of the sample (N = 159)

Visual function	n (%)
Visual acuity, logMAR	
≤ 0.3 (better)	155 (97.5)
> 0.3 (worse)	4(2.5)
Contrast sensitivity, log sensitivity	
≥ 1.5 (better)	142 (89.3)
< 1.5 (worse)	17 (10.7)
UFOV subtest 2[1], ms	
< 150 (better)	65 (50.0)
150–350	50 (38.5)
> 350 (worse)	15 (11.5)
Visual field sensitivity, dB, 3 upper quartiles vs. lowest quartile	
Overall	
> 22.4 (better)	119 (74.8)
≤ 22.4 (worse)	40 (25.2)
Peripheral (≥ 45°)	
> 19.2 (better)	118 (74.2)
≤ 19.2 (worse)	41 (25.8)
Superior	
> 22.0 (better)	118 (74.2)
≤ 22.0 (worse)	41 (25.8)
Inferior	
> 22.1 (better)	118 (74.2)
≤ 22.1 (worse)	41 (25.8)
Left	
> 21.6 (better)	119 (74.8)
≤ 21.6 (worse)	40 (25.2)
Right	
> 21.8 (better)	118 (74.2)
≤ 21.8 (worse)	41 (25.8)
Gabor drifting grating, Hz	
< 0.14 (better)	79 (49.7)
≥ 0.14 (worse)	80 (50.3)

[1]N = 130 participants completed this test.

Table 3.

Crude and age-adjusted rate ratios (RR) and 95% confidence intervals (CI) for association between visual function and crash involvement for five years prior to enrollment

Visual function	Crude RR (95% CI)	Age-adjusted RR (95% CI)
Contrast sensitivity, log sensitivity		
≥ 1.5 (better)	REF	REF
< 1.5 (worse)	1.6 (0.8–3.2)	1.5 (0.8–3.2)
UFOV subtest 2, ms		
< 150 (better)	REF	REF
150–350	1.3 (0.7–2.6)	1.1 (0.5–2.2)
> 350 (worse)	4.3 (1.8–10.0)	3.6 (1.5–8.5)
Overall visual field sensitivity, dB		
> 22.4 (better)	REF	REF
≤ 22.4 (worse)	1.6 (0.8–3.1)	1.4 (0.7–5.2)
Peripheral visual field sensitivity, dB		
> 19.2 (better)	REF	REF
≤ 19.2 (worse)	2.5 (1.4–4.6)	2.4 (1.3–4.4)
Superior visual field sensitivity, dB		
> 22.0 (better)	REF	REF
≤ 22.0 (worse)	0.8 (0.4–1.6)	0.7 (0.4–1.5)
Inferior visual field sensitivity, dB		
> 22.1 (better)	REF	REF
≤ 22.1 (worse)	1.8 (1.0–3.2)	1.7 (0.9–3.0)
Left visual field sensitivity, dB		
> 21.6 (better)	REF	REF
≤ 21.6 (worse)	1.9 (1.1–3.6)	1.7 (0.9–3.2)
Right visual field sensitivity, dB		
> 21.8 (better)	REF	REF
≤ 21.8 (worse)	1.7 (0.9–3.1)	1.6 (0.9–3.0)
Gabor drifting grating threshold, Hz		
< 0.14 (better)	REF	REF
≥ 0.14 (worse)	2.9 (1.5–5.6)	2.7 (1.4–5.2)