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The Association between Visual Abilities and Objectively-Measured Driving Space, Exposure, and Avoidance among Older Drivers: A Preliminary Analysis

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Key Findings

- Study participants had mostly good visual function at the time of their enrollment.
- Poorer visual acuity and perception were related to a smaller driving space.
- Poorer visual acuity and perception were related to a lower driving exposure.
- Poorer visual acuity and perception were related to greater driving avoidance.

Abstract

The objective of the study was to determine if there is a relationship between objective measures of visual function and objective measures of driving habits. The study used data from 2,131 drivers aged 65-79 enrolled in the United States based Longitudinal Research on Aging Drivers (LongROAD) study. Correlational analysis were conducted of three measures of visual function at baseline and six GPS-derived measures of driving averaged over the subsequent year. Results showed that participants had generally good visual function at the time of their enrollment. Analyses found that lower visual acuity and poorer visual perception abilities were related to a smaller driving space, lower driving exposure, and greater driving avoidance, although not for every measure. Poorer contrast sensitivity was associated with avoidance of nighttime driving and driving on high-speed roads, but was not related to driving space or exposure. This study provides evidence about how poor visual abilities can impact subsequent yearly driving. These results support other research evidence that the lower than expected crash-involvement of people with declining visual function may be related to the fact these drivers self-regulate their driving. A limitation of the study was that all significant correlations were relatively small, suggesting that other variables in addition to the ones analyzed may also be important for understanding the relationship between driving habits and visual function scores.

Keywords

Traffic Safety, Mobility, Visual Acuity, Contrast Sensitivity, Visual Perception.

Introduction

The populations of most countries are aging. In the United States (US) for example, the population of older adults (age 65 or older) is expected to grow by 27%, from 431 million older adults in 2012 to a projected 727 million in 2030 (Ortman, Velkoff, & Hogan, 2014). Older adults will also account for a larger percentage of the total population, increasing from 13.7% in 2012 to 20.3% in 2030. It is expected that a large majority of older adults will also retain their driver licenses (Sivak & Schoettle, 2011). At the same time, research has established that visual functioning declines in older adulthood (see Owsley, 2011 for a review) and that many vision-related diseases are more common as one ages (Charlton et al., 2010; Dobbs, 2005).

Good visual function is important for safe driving. Indeed, 100 years ago, researchers were discussing the relationship between visual function and traffic crashes (see e.g., Bonner, 1923; Clements, 1906), yet studies have found mixed results about the effects of visual function declines on crash risk among older adults (see Owsley & McGwin, 1999, 2010 for reviews). For example, in a study of age-related macular degeneration (AMD) researchers found that people with AMD performed worse on driving tasks compared to controls, yet they had fewer crashes than controls (Szlyk, Pizzimenti, & Fishman, 1995). The researchers surmised that this finding resulted from people with AMD restricting their driving and thereby managing their exposure to crashes. There is other evidence in the scientific literature that older adults with certain visual conditions, such as cataracts (Owsley et al., 1999), glaucoma (van Landingham et al., 2013; Ramulu et al., 2009), central vision loss (Sengupta et al., 2014), and maculopathy (DeCarlo et al., 2003) report that they restrict their driving relative to those with normal vision. The literature also shows that people who have documented declines in visual function, such as in visuospatial perception, contrast sensitivity, and acuity, report restricted driving space, reduced driving exposure, and increased driving avoidance (e.g., Baldock et al., 2006; Ball et al., 1998; Brabyn et al., 2005; Freeman et al., 2006; Keay et al., 2009; Lotfipour et al., 2010; Ross et al., 2009; Sandlin, McGwin, & Owsley, 2014; Satariano et al., 2004; Stutts, 1998; West et al., 2003).

Nearly all of these studies, however, rely on participants' self-reporting their driving habits. Recent work with older drivers has found that when subjective estimates of driving over one week were compared to actual driving measured by a global positioning system (GPS) device installed in their vehicles and by driver-completed trip logs, older drivers were inaccurate at estimating their amount of driving and the number of trips they had taken (Blanchard, Myers, & Porter, 2010). There is a lack of research investigating the relationship between objectively measured visual abilities and objectively measured driving habits among older drivers. A study in Maryland explored the relationship among several functional abilities, including several measures of visual function, and driving at night as measured by an in-vehicle monitoring system (Kaleem, et al., 2012). The 990 participants in the study (age 67-87) had a custom data acquisition system installed in their vehicles, and they drove as they normally would for five days. Nighttime driving was defined as any part of a trip occurring during specific hours, and video of the drivers' face was used to determine who was driving the car. Using multivariate analyses, the study found that older drivers with better visual acuity and better contrast sensitivity were more likely to be driving at night when nighttime driving was measured objectively over a 5-day period. The purpose of the present study was to conduct a preliminary examination of an extensive data set of the relationship between measures of visual function at baseline and objective measures of driving habits (space, exposure, and avoidance) averaged over a long period of time among older drivers at five locations in the US.

Methods

The study utilized data from the multi-site Longitudinal Research on Aging Drivers (LongROAD) study. The LongROAD study was designed to explore several areas of older driver safety and mobility, including: protective and risk factors; medications; medical conditions; self-regulation; in-vehicle technologies and aftermarket adaptations; and cessation of driving. Study participants were enrolled in and around five cities across the US (Ann Arbor, MI; Baltimore, MD; Cooperstown, NY; Denver, CO; and San Diego, CA). Participant inclusion criteria were: aged 65-79 years; held a valid driver licence; drove on average at least once per week; had no significant cognitive impairment as determined by a score ≥4 on the Six Item Screener (Callahan et al., 2002) and medical record review; drove a primary vehicle at least 80% of the time that was model year 1996 or newer; planned to reside in the study area 10 months per year; and had no plans to move outside of study area in next five years. Eligible and interested individuals were scheduled for an in-person baseline session. All study protocols were approved by each site's Institutional Review Board.

Data used for this study were baseline measurements of visual function and objective driving data averaged over 12 months following baseline assessment. At baseline, participants completed a set of in-person functional assessments, including vision.

To record objective driving behavior data, a small device called a datalogger was installed in each participant's primary vehicle by plugging it into the on-board diagnostic (OBDII) port. The datalogger recorded GPS information (10 Hz), accelerometer data (4 Hz), and other vehicle data whenever the vehicle ignition was turned on. The datalogger had a built-in cellular system that was used to transmit data at the end of each trip, when the vehicle ignition was turned off. This cellular system was also used to "ping" the datalogger each day to ensure its proper operation. A Bluetooth receiver was used to detect when the study participant was the driver of the vehicle. The receiver detected and recorded the codes and signal strengths of all Bluetooth tags carried by the study participant and any other regular user of the participant's primary vehicle once per minute. This allowed us to determine the driver of the vehicle and remove any trips made by a non-participant. Further details of the data collection system, study methods, and power analysis to determine sample size can be found elsewhere (Li et al., 2017).

Driving data were filtered to identify participants who had been in the study for at least a 12 full months of participation at the time of analysis (n=2,131) and the remaining participants were excluded. For participants with more than 1 year of participation, only the first 12 months were analyzed. The objective driving habit measures were based on previous work (Molnar et al., 2013) and were conceptualized based on three components of the Driving Habits Questionnaire (DHQ, Owsley et al., 1999): driving space, driving exposure, and driving avoidance. The objective driving habit measures used were similar to the self-reported topics addressed in the DHQ, but derived from data recorded from the datalogger device installed in each participant's vehicle. The driving habit measures used in this study were: two measures of driving space (percent of trips within 15 miles [24 km] of home; percent of trips within 25 miles [40 km] of home); two measures of driving exposure (average miles driving per month; average days driving per month); and two measures of driving avoidance (average percent of trips at night; average percent of trips on high speed roads). Definitions of these measures are shown in Table 1. The monthly driving habit measures were averaged for each participant's year of data to obtain a mean and standard deviation (sd) for each measure.

The baseline assessment data for three measures of visual function were extracted for these participants from the LongROAD data. Visual function was measured with glasses or contact lenses being worn if they were used for driving. The measures of visual function were: Tumbling E (visual acuity), Pelli-Robson (contrast sensitivity; Pelli et al., 1988), and the Motor Free Visual Perception Test (MVPT-3) (overall visual perception ability, Colarusso & Hammill, 2003). The visual acuity analyses used measures for both eyes. Because of a problem with measuring visual acuity at one of the data collection sites, visual acuity data from this site are excluded from analysis. Tumbling E scores were converted to logarithm of the Minimum Angle of Resolution (logMAR). Scores could range from -0.10 to 0.70, with a score of 0 being average, scores greater than 0 representing increasingly worse acuity relative to average, and scores less than 0 being acuity that was increasingly better than average. The World Health Organization (WHO) and others (Dandona & Dandona, 206; WHO, 2012; West et al., 1997) define mild vision loss as logMAR scores in the range of 0.18 to 0.48 in the better eye. Visual acuity was converted to a binary variable that consisted of non-impaired acuity (scores of -0.10 to 0.18, n=1,949) and impaired acuity (scores of 0.30 or greater, n=168). This cut-off was selected in order to have a large enough sample of people with vision loss while still being in the range of mild vision loss or worse defined by the WHO. This binary variable was used in analyses. The analyses of contrast sensitivity used results from only the better eye. Scores on this test could range from 0 to 2.2 with higher scores indicating better contrast sensitivity. Scores on the overall measure of visual perception were based on the number of correct answers for test items 22-34 of the MVPT-3. Scores, therefore, could range from 0-13, with higher scores indicating better visual perception. Spearman correlations were calculated to compare driving habits and visual function measures.

Results

The 2,131 participants included in these analyses were 48.6% male, 85.7% White Non-Hispanic (6.8% Black Non-Hispanic, 2.6% Hispanic, and 2.3% Asian), and had a mean age of 71.2 years. Participants were well educated: 13.3% had a high school/trade degree or less, 21.2% had some college or an associate degree, 23.8% had a bachelor degree, and 41.7% had an advanced college degree. Annual household incomes were relatively high: 4.3% reported less than $20,000, 21.0% reported $20,000-$49.999,

Table 1. Means, standard deviations, definitions, and categories for each driving habit measure

Driving Habit Measure	Mean Median (sd)	Definition for the Monthly Variable (Trip is defined as ignition-on to ignition-off)	Category
Average monthly % trips within 15 miles (24 km) of home	64.1 67.2 (22.4)	Percent of trips traveled in month within 15 miles (24 km) of home.	Driving Space
Average monthly % trips within 25 (40 km) miles of home	75.8 80.8 (18.9)	Percent of trips traveled in month within 25 miles (40 km) of home.	Driving Space
Average miles [km] per month	791.4 [1273.6] 705.4 [1135.2] (444.2) [714.9]	Total number of miles driven in month.	Driving Exposure
Average days driving per month	22.5 23.3 (5.0)	Total number of days in month with at least one trip.	Driving Exposure
Average monthly % of trips at night	6.7 5.6 (5.1)	Percent of trips in month during which at least 80% of trip was during nighttime, with nighttime defined as end of evening civil twilight to beginning of morning civil twilight or a solar angle greater than 96 degrees.	Driving Avoidance
Average monthly % of trips on high speed roads	12.9 9.9 (10.9)	Percent of trips in month during which at least 20% of distance travelled was at a speed of 60 MPH (97 km/h) or greater (a proxy for travel on high speed roads).	Driving Avoidance

24.8% reported \$50,000-\$79,999, 15.0% reported \$80,000-\$99,999, and 31.4% reported \$100,000 or more.

The means, medians, and standard deviations of the six driving habit outcomes measures are shown in Table 1. The means scores, standard deviations (sd), and number of participants (n) for the visual function measures were: visual acuity (0.09, sd=0.12, n=1,509), contrast sensitivity (1.61, sd=0.14, n=2,117), and visual perception (11.6, sd=1.7, n=2,127). Figures 1-3 show the distributions of scores across the participants for visual acuity (Figure 1), contrast sensitivity (Figure 2), and visual perception (Figure 3).

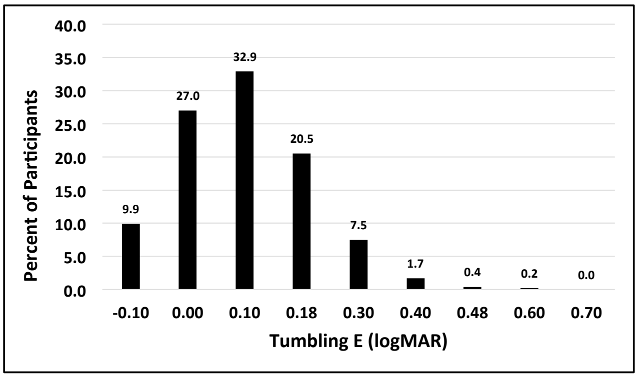

Figure 1. Distribution of logMAR scores for the Tumbling E test of visual acuity

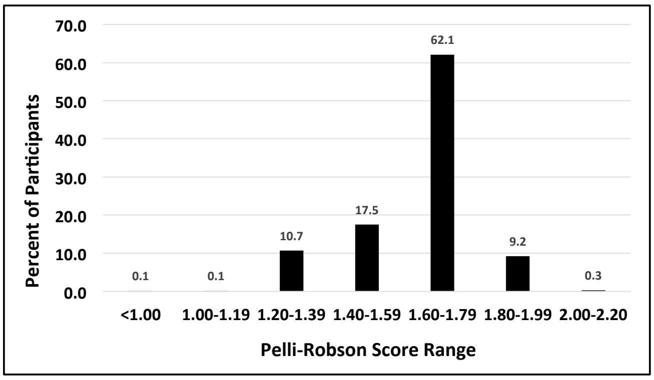

Figure 2. Distribution of scores for the Pelli-Robson test of contrast sensitivity (best eye)

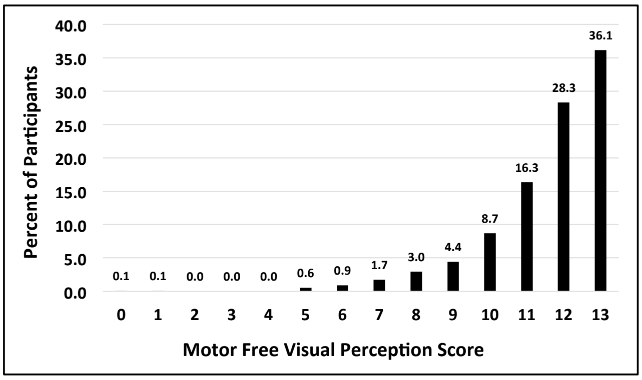

Figure 3. Distribution of scores for the Motor Free Visual Perception Test

Table 2 shows results of the correlation analysis (coefficient and p-value) across each driving habit/visual function comparison. The study found that both measures of driving space were significantly associated with visual acuity and visual perception scores, with worse scores being associated with a higher percentage of trips close to home: average monthly % trips within 15 miles (24 km) of home (67.2% for acuity impaired vs 73.5% for acuity not impaired; and 81.2% for the worse visual perception to 63.7% for the best visual perception); average monthly % trips within 25 (40 km) miles of home (78.0% for acuity impaired vs 83.0% for acuity not impaired; and 87.9% for the worse visual perception to 75.0% for the best visual perception). Contrast sensitivity was not associated with these measures of driving space. Analysis of the two driving exposure measures showed that average miles driven per month was significantly lower in the group with impaired acuity (765.3 miles [1231.6 km] vs 650.1 miles [1046.2 km]). Contrast sensitivity and visual perception scores were not statistically associated with this measure, but lower visual perception scores were associated with greater average number of days driving per month (number of days ranged from 23.8 for the worst visual perception to 22.4 for the best). To explore this finding further, we divided the average monthly days of driving scores into quartiles and determined the average MVPT-3 scores for each quartile. The results showed the following average scores by quartile from least days driving per month to the most: 11.6, 11.8, 11.5, and 11.4. These averages showed that there was little difference from the overall mean of 11.6 for any quartile and that there was no evident trend that explained the significant but small correlation. Both driving avoidance measures were associated with all three visual function measures, except that percentage of trips on high speed roads was not associated with visual acuity. For all statistically significant correlations, better visual function scores were associated with increasing average percentages of trips at night and on high speed roads: average monthly % trips at night (7.2% not impaired acuity vs 6.3% impaired acuity; percentages on contrast sensitivity ranged from 5.3% for the worse to 10.6% for the best; percentages on visual perception ranged from 5.7% for the worst to 7.2% for the best); and average monthly % of trips on high speed roads (percentages on contrast sensitivity ranged from 5.7% for the worse to 13.1% for the best and percentages on visual perception ranged from 11.1% for the worst to 14.6% for the best).

Discussion

This study sought to answer the question of whether there was a significant relationship between baseline measures of visual function and objective measures of driving habits averaged over a 1-year follow-up period after visual function assessment. The study found that, in general, lower visual acuity and poorer visual perception abilities among this cohort of older drivers were related to a smaller driving space, lower driving exposure, and greater driving avoidance. Poorer contrast sensitivity, which is related to one's ability to see in low light conditions, was associated with avoidance of night time driving (in agreement with the results reported by Kaleem, et al., 2012) and driving on

Table 2. Spearman correlations and p-values across each driving space/visual function comparison, with statistically significant differences shown in bold

Driving Habit Measure	**Visual Acuity** (Tumbling E, LogMAR) n=1,509	**Contrast Sensitivity** (Pelli-Robson) n=2,117	**Visual Perception** (MVPT-3) n=2,127
Average monthly % trips within 15 miles (24 km) of home	**0.09138 p=.0002**	0.01242 p=.5679	**-0.05029 p=.0204**
Average monthly % trips within 25 miles (40 km) of home	**0.08536 p<.0005**	0.00232 p=.9149	**-0.08076 p=.0002**
Average miles driven per month	**-0.09121 p=.0002**	-0.00684 p=0.7532	0.02556 p=.2397
Average days driving per month	-0.01305 p=.5937	-0.00159 p=.9416	**-0.04550 p=.0360**
Average monthly % of trips at night	-0.07812 p=.0014	.07880 p=.0003	0.08199 p=.0002
Average monthly % of trips on high speed roads	-0.04368 p=.0741	**0.12199 p<.0001**	**0.14885 p<.0001**

high speed roads, but was not related to measures of driving space or exposure. Thus, at least among the LongROAD cohort of older drivers, poorer visual function was generally related to the three categories of driving habits investigated in the study, as measured over a full year post visual function measurement.

Study results showed that most LongROAD participants included in these analyses had relatively good visual function at the time of their enrollment in the study, yet some had poor visual function. A binocular visual acuity score of 0 or less is considered normal or better than normal visual acuity, while mild visual impairment is considered to occur starting at a score of 0.18 or worse (see e.g., WHO, 2012). As shown in Figure 1, about 70% of the participants had scores better (lower) than 0.18 on the test of visual acuity. Older adult population norms for contrast sensitivity measured by the Pelli-Robson test average about 1.85 and range from about 1.70 -2.00 (see e.g., Mäntyjävi & Laitinen, 2001). The average score in the present study was 1.61, with about 90% of the sample scoring better (lower) than 1.80. No published norms for MVPT-3 scores (test items 22-34) for older adults could be found to which to compare the present study results. However, three large samples of healthy older drivers (787 adults age 55 and older, Ross et al., 2009; 697 older adults age 55-92, Vance et al., 2006; 1,910 adults age 55 and older, Ball et al., 2005) found average numbers of incorrect responses of 1.4, 1.5, and 1.7 (non-crash involved adults)/2.2 (crash-involved adults), respectively. The average number of incorrect items among the LongROAD participants in this study was 1.4, which is the same or better than these other studies. The high visual functioning of the LongROAD cohort is likely related to the inclusion criteria used for the study which required people to be active drivers and to be willing to have their driving monitored over several years (Li et al., 2017). We anticipate that visual function measures will show overall declines compared to the present results in the second in-person assessment, taking place between late 2017 and early 2019.

This study provides further evidence about how poor visual abilities can impact driving in the year following assessment when objective measures of driving, rather than self-reported driving, are considered. Scores on the MVPT-3 test, in particular, were related to restricted driving for all but one of the driving habit measures. These results also provide further evidence that the lower than expected crash involvement of people with declining visual function may be related to the fact the these drivers self-regulate their driving. By reducing their driving space and exposure, and avoiding challenging driving situations, older drivers may be able to lower their risk of a crash.

The strengths of this study include the use of a large sample of older drivers recruited from five distinct geographic locations in the US, and the use of objective driving data collected over an entire year. A limitation of the study was that all significant correlations were relatively small, suggesting that other variables in addition to the ones analyzed may also be important for understanding the relationship between driving habits and visual function scores. Nevertheless, we believe that the practical significance of these results is high. For example, the study found that those with impaired visual acuity drove an average of 14% less distance per month as compared to those with non-impaired acuity (a difference of nearly 100 miles [161 km]). Over the course of 12 months, this equates to an important reduction in exposure. As this longitudinal study continues, and the visual function of a greater number of participants declines, multivariate analyses will explore in greater depth the effects of visual function loss on driving space, exposure, and avoidance. Finally, the LongROAD cohort is relatively well-educated with high household incomes and, therefore, not necessarily representative of all older adult drivers. As such, these results may not generalize to all older driver populations.

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References

Baldock, M.R.J., Mathias, J.L., McLean, J., Berndt, A. (2006). Self-regulation of driving and older drivers' functional abilities. *Clinical Gerontologist*, **30(1)**, 53-70. https://doi.org/10.1300/J018v30n01_05

Ball, K., Owsley, C., Stalvey, B., Roenker, D.L., Sloane, M.E., & Graves, M. (1998). Driving avoidance and functional impairment in older drivers. *Accident Analysis & Prevention*, **30(3)**, 313-322. https://doi.org/10.1016/S0001-4575(97)00102-4

Ball, K.K., Roenker, D.L., Wadley, V.G., Edwards, J.D., Roth, D.L., McGwin, G. Jr., Raleigh, R., Joyce, J.J., Cissell, G.M., & Dube, T. (2005). Can high-risk older drivers be identified through performance-based measures in a Department of Motor Vehicles setting? *The American Geriatrics Society*, **54**, 77-84. https://doi.org/10.1111/j.1532-5415.2005.00568.x

Bonner, W.F. (1923). Visual requirements of automobile drivers. *Journal of the American Medical Association*, **81(19)**, 1628. https://doi.org/10.1001/jama.1923.02650190058035

Blanchard, R.A., Myers, A.M., & Porter, M.M. (2010). Correspondence between self-reported and objective measures of driving exposure and patterns in older drivers. *Accident Analysis & Preventio*n, **42(2)**, 523-529. https://doi.org/10.1016/j.aap.2009.09.018

Brabyn, J.A., Schneck, M.E., Lott, L.A., & Haegerström-Portnoy, G. (2005). Night driving self-restriction: Vision function and gender differences. *Optometry and Vision Science*, **82(8)**, 755-764. https://doi.org/10.1097/01.opx.0000174723.64798.2b

Callahan, C.M., Unverzagt, F.W., Hui, S.L., Perkins, A.J., & Hendrie HC. (2002). Six-item screener to identify cognitive impairment among potential subjects for clinical research. *Medical Care*, **40**, 771-781. https://doi.org/10.1097/00005650-200209000-00007

Charlton, J., Koppel, S., Odell, M., Devlin, A., Langford, J., O'Hare, M., Kopinathan, C., Andrea, D., Smith, G., Khodr, B.N., Edquist, J., Muir, C., & Scully, M. (2010). *Influence of Chronic Illness on Crash Involvement of Motor Vehicle Drivers, 2nd Edition*. Report No. 300. Clayton, Victoria, Australia: Monash University Accident Research Centre.

Clements, C. (1906). Errors of vision as a factor in motor car accidents. *The British Medical Journal*, **2**, 1636. https://doi.org/10.1136/bmj.2.2397.1636

Colarusso, R.P. & Hammill, D.D. (2003) *Motor-Free Visual Perception Test –Third Edition.* Novato, CA: Academic Therapy Publications.

Dandona, L. & Dandona, R. (2006). Revision of visual impairment definitions in the International Statistical Classification of Diseases. *BMC Medicine*, **4**, 7.

DeCarlo, D., Scilley, K., Wells, J. & Owsley, C. (2003). Driving habits and health-related quality of life in patients with age-related maculopathy. *Optometry and Vision Science*, **80(3)**, 207-213. https://doi.org/10.1097/00006324-200303000-00010

Dobbs, B. (2005). *Medical Conditions and Driving: A Review of the Scientific Literature (1960 - 2000)*. Report No. DOT HS 809 690. Washington, DC: National Highway Traffic Safety Administration. http://dx.doi.org/10.1037/e729552011-001

Freeman, E.E., Muñoz, B., Turano, K.A., & West, S.K. (2006). Measures of visual function and their association with driving modification in older adults. *Investigative Ophthalmology and Visual Science*, **47(2)**, 514-520. https://doi.org/10.1167/iovs.05-0934

Kaleem, M.A., Munoz, B.E., Munro, C.A., Gower, E., & West, S.K. (2012). Visual characteristics of elderly night drivers in the Salisbury Eye Evaluation driving study. *Investigative Ophthalmology and Visual Science*, **53(9)**, 5161-5167. https://doi.org/10.1167/iovs.12-9866

Keay, L., Munoz, B., Turano, K.A., Hassan, S.E., Munro, C.A., Duncan, D.D., Baldwin, K., Jasti, S., Gower, E.W., & West, S.K. (2009). Visual and cognitive deficits predict stopping or restricting driving: The Salisbury Eye Evaluation Driving Study (SEEDS). Investigative *Ophthalmology and Visual Science*, **50(1)**, 107-113. https://doi.org/10.1167/iovs.08-2367

Li, G., Eby, D.W., Santos, R., Mielenz, T.J., Molnar, L.J., Strogatz, D., Betz, M., DiGuiseppi, C., Ryan, L.H., Jones, V., Pitts, S.I., Hill, L.L., DiMaggio, C., LeBlanc, D., & Andrews, H.F. for the LongROAD Research Team. (2017). Longitudinal Research on Aging Drivers (LongROAD): Study design and methods. *Injury Epidemiology*, **4**, 22. https://doi.org/10.1186/s40621-017-0121-z

Lotfipour, S., Patel, B.H., Grotsky, T.A., Anderson, C.L., Carr, E.M., Ahmed, S.S., Chaakravarthy, B., Fox, J.C., & Vaca, F.E. (2010). Comparison of the Visual Function Index to the Snellen Visual Acuity Test in predicting older adult self-restricted driving. *Traffic Injury Prevention*, **11**, 503-507. https://doi.org/10.1080/15389588.2010.488494

Mäntyjävi, M. & Laitinen, T. (2001). Normal values for the Pelli-Robson contrast sensitivity test. *Journal of Cataract and Refractive Surgery*, **27**, 261-266. http://dx.doi.org/10.1016/S0886-3350(00)00562-9

Molnar, L.J., Charlton, J.L., Eby, D.W., Bogard, S.E., Langford, J., Koppel, S., Kolenic, G., Marshall, S., Man-Son-Hing, M. (2013). Self-regulation of driving by older adults: Comparison of self-report and objective driving data. *Transportation Research Part F*, **20**, 29-38. https://doi.org/10.1016/j.trf.2013.05.001

Ortman, J.M., Velkoff, V.A. & Hogan, H. (2014). *An Aging Nation: The Older Population in the United States*. Report No. P25-1140. Washington DC: US Census Bureau.

Owsley, C. (2011). Aging and vision. *Vision Research*, **51(3)**, 1610-1622. https://doi.org/10.1016/j.visres.2010.10.020.

Owsley, C. & McGwin, G. (1999). Vision impairment and driving. *Survey of Ophthalmology*, **43(6)**, 535-550. http://dx.doi.org/10.1016/S0039-6257(99)00035-1

Owsley, C. & McGwin, G. (2010). Vision and driving. *Vision Research*, **50(23)**, 2348–2361. https://doi.org/10.1016/j.visres.2010.05.021

Owsley, C., Stalvey, B., Wells, J., & Sloane, M.E. (1999). Older drivers and cataract: Driving habits and crash risk. *Journal of Gerontology: Medical Sciences*, **54A(4)**, M203-M211. https://doi.org/10.1093/gerona/54.4.M203

Pelli, D.G., Robson. J.G. & Wilkins, A.J. (1988). The design of a new letter chart for measuring contrast sensitivity. *Clinical Vision Sciences*, **2(3)**, 187-199.

Ramulu, P.Y., West, S.K., Munoz, B., Jampel, H.D., & Friedman, D.S. (2009). Driving cessation and driving limitation in glaucoma: The Salisbury Eye Evaluation Project. *Ophthalmology*, **116**, 1846-1853. http://dx.doi.org/10.1016/j.ophtha.2009.03.033

Ross, L.A., Clay, O.J., Edwards, J.D., Ball, K.K., Wadley, V.G., Vance, D.E., Cissell, G.M., Roenker, D.L., & Joyce, J.J. (2009). Do older drivers at-risk of crash modify their driving over time? *Journal of Gerontology: Psychological Sciences*, **64B(2)**, 163-170. https://doi.org/10.1093/geronb/gbn034

Sandlin, D., McGwin, G. Jr., & Owsley, C. (2014). Association between vision impairment and driving exposure in older adults aged 70 years and over: A population-based examination. *Acta Ophthalmologica*, **92(3)**, e207-e212. https://doi.org/10.1111/aos.12050

Satariano, W.A., MacLeod, K.E., Cohn, T.E., & Ragland, D.R. (2004). Problems with vision associated with limitations or avoidance of driving in older populations. *Journal of Gerontology: Social Sciences*, **59B(5)**, S281-S286. https://doi.org/10.1093/geronb/59.5.S281

Sengupta, S., van Landingham, S.W., Solomon, S.D., Do, D.V., Friedman, D.S., & Ramulu, P.Y. (2014). Driving habits in older patients with central vision loss. *Ophthalmology*, **121(3)**, 727-732. http://dx.doi.org/10.1016/j.ophtha.2013.09.042

Sivak, M. & Schoettle, B. (2011). Recent changes in the age composition of drivers in 15 countries. *Traffic Injury Prevention*, **13(2)**, 126-132. https://doi.org/10.1080/15389588.2011.638016

Stutts, J.C. (1998). Do older drivers with visual and cognitive impairments drive less? *Journal of American Geriatrics Society*, 46, 854-861. https://doi.org/10.1111/j.1532-5415.1998.tb02719.x

Szlyk, J.P., Pizzimenti, C.E., & Fishman, G.A. (1995). A comparison of driving in older subjects with and without age-related macular degeneration. *Archives of Ophthalmology,* **113**, 1033-1040. https://doi.org/10.1001/archopht.1995.01100080085033

van Landingham, S.W., Hochberg, C., Massof, R.W., Chan, E., Friedman, D.S., & Ramulu, P.Y. (2013). Driving patterns in older adults with glaucoma. *BMC Ophthalmology*, **13**, 4. https://doi.org/10.1186/1471-2415-13-4

Vance, D.E., Roenker, D.L., Cissell, G.M., Edwards, J.D., Wadley, V.G., & Ball, K.K. (2006). Predictors of driving exposure and avoidance in a field study of older drivers from the state of Maryland. *Accident Analysis & Prevention*, **38**, 823-831. https://doi.org/10.1016/j.aap.2006.02.008

West. C.G., Gildengorin, G., Haegerstrom-Portnoy, G., Lott, L.A., Schneck, M.E., & Brabyn, J.A. (2003). Vision and driving self-restriction in older adults. *Journal of the American Geriatrics Society*, **15**, 1348-1355. https://doi.org/10.1046/j.1532-5415.2003.51482.x

West, S.K., Muniz, B., Rubin, G.S., Schein, O.D., Bandeen-Roche, K., Zeger, S., German, P.S., Fried, L.P. & the SEE Project Team. (1997). Function and visual impairment in a population-based study of older adults. *Investigative Ophthalmology and Visual Science*, **38(1)**, 72-82.

World Health Organization (2012). *Global Data on Visual Impairments 2010*. Geneva, Switzerland, World Health Organization.