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Low Vision Rehabilitation

Driving Difficulties and Preferences of Advanced Driver Assistance Systems by Older Drivers With Central Vision Loss

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Purpose: The purpose of this study was to investigate driving difficulties and Advanced Driver Assistance Systems (ADAS) use and preferences of drivers with and without central vision loss (CVL).

Methods: Fifty-eight drivers with CVL (71 ± 13 years) and 68 without (72 ± 8 years) completed a telephone questionnaire. They rated their perceived driving difficulty and usefulness of technology support in 15 driving situations under good (daytime) and reduced visibility conditions, and reported their use experience and preferences for 12 available ADAS technologies.

Results: Drivers with CVL reported more difficulty ($P = 0.002$) and greater usefulness of technology support ($P = 0.003$) than non-CVL drivers, especially in reduced visibility conditions. Increased driving difficulty was associated with higher perceived technology usefulness ($r = 0.34$, $P < 0.001$). Dealing with blind spot road users, glare, unexpected pedestrians, and unfamiliar areas were perceived as the most difficult tasks that would benefit from technology support. Drivers with CVL used more advanced ADAS features than non-CVL drivers ($P = 0.02$), preferred to own the blind spot warning, pedestrian warning, and forward collision avoidance systems, and favored ADAS support that provided both information and active intervention. The perceived benefits of and willingness to own ADAS technologies were high for both groups.

Conclusions: Drivers with CVL used more advanced ADAS and perceived greater usefulness of driver assistance technology in supporting difficult driving situations, with a strong preference for collision prevention support.

Translational Relevance: This study highlights the specific technology needs and preferences of older drivers with CVL, which can inform future ADAS development, evaluation, and training tailored to this group.

Introduction

People with reduced visual acuity are permitted to drive on restricted licenses in the majority of jurisdictions in the United States. Therefore, older adults with vision impairments, such as central vision loss (CVL) from age-related macular degeneration (AMD), may be able to continue driving even when visual acuity no longer meets the criteria for an unrestricted license. These drivers may experience reduced visual acuity, reduced contrast sensitivity, sensitivity to glare, impaired color vision, impaired dark adaptation, or reduced night vision[1–3]; some of them may also have a blind area (scotoma) in their central visual field.

In prior questionnaire studies, drivers with AMD reported more difficulty with driving than drivers without AMD, and they tended to drive less often and with more restrictions (e.g. avoided driving at night, long distances, in unfamiliar areas, and busy traffic).[4–6] In driving simulator studies, drivers with macular disease were slower to detect pedestrian hazards than normal vision controls, both when the pedestrian was occluded by their scotoma and when it was not occluded.[7–9] In an on-road study, drivers with AMD

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were observed to make more critical errors requiring instructor intervention than drivers without AMD, especially in more complex situations (e.g. signalized intersections).[10] Drivers with AMD also exhibited more errors in observation, lane-keeping, and gap selection. Taken together, the results of these simulated and on-road driving studies suggest that drivers with CVL may experience more difficulty than drivers without CVL when perceiving information about the environment (e.g. reading road signs, seeing the markings on the road, and seeing brake lights on surrounding vehicles) and planning actions (e.g. lane changing, yielding, and pulling in and out of traffic). Other than vision impairment, older adults may also experience driving difficulties due to overall physical and cognitive declines from aging, which may put them at increased risk for unsafe driving, such as age-related reductions in neck flexibility or upper body range of motion, declines in memory performance, slower reaction times and reflexes, hearing loss, etc.[11–15]

A variety of Advanced Driver Assistance Systems (ADAS) have been developed and implemented in vehicles to increase mobility convenience, driving comfort, and maintain driving safety; these systems are widely available in new cars today. ADAS has been used as a term that includes a range of in-vehicle technology features. In this study, we define the scope of ADAS to refer to existing features at the Society of Automotive Engineers (SAE) level 0 (no driving automation or momentary driving assistance) and level 1 (driver assistance) of driving automation.[16] This includes some widely used features, such as global positioning system (GPS) and cruise control, as well as more advanced features such as blind-spot warning, lane departure warning, pedestrian warning, etc. Many studies have shown that these systems could increase driving safety by reducing crashes and injuries.[17–21] Recent data revealed that, collectively, blind-spot detection, lane keep assist, forward collision prevention, automatic braking, and pedestrian automatic braking technologies could prevent 62% of total traffic deaths per year.[22] For older drivers in general, ADAS could have substantial benefits to enhance driving safety and mitigate their age-related functional declines. For example, seniors with neck or upper body rotation difficulties may find blind spot warnings and rear-view cameras helpful, seniors with slower reaction times and reflexes in hazardous situations may benefit from forward collision avoidance and automatic braking systems.

Many studies have identified the potential of existing ADAS in alleviating age-related driving safety decrements for older drivers and explored their knowledge, perceptions, and opinions of using or purchasing ADAS technologies.[23–30] Although older adults normally consider the safety of a vehicle as a primary criterion in their purchasing decisions, they have been found to have less knowledge of ADAS technologies compared with other age groups.[31] In 2015, Hartford and the MIT AgeLab conducted a multi-method research project with 302 drivers aged 50 to 69 years to assess their knowledge, preferences, and likelihood to adopt current vehicle technologies.[32,33] This study revealed that 43% of surveyed drivers had some form of ADAS technology and the majority of them (75%) thought having safety technologies in their vehicle would help extend their safe driving years. The Hartford study also found that 76% of drivers who planned to buy a new car in the next 2 years would actively seek out high-tech safety features and would most like to own blind-spot warning systems (87%), crash mitigation systems (85%), lane departure warning systems (79%), and smart headlights (78%).

Central vision loss can add another layer of difficulty to daily driving for older drivers. The understanding of how drivers with impaired vision utilize ADAS technologies and the potential impact of these technologies on their driving is still in its early stages of exploration. One study found that 37% of surveyed drivers with impaired vision used GPS and reported increased levels of comfort or safety.[34] Deffler et al. recently surveyed drivers with AMD about their experiences and opinions of eight common ADAS. They found that the ADAS improved perceived driving safety in this population and might help to reduce self-imposed restrictions for difficult driving situations and mileage.[35] In a recent case study,[36,37] a driver with Stargardt disease (20/180 binocular visual acuity) reported improved driving confidence, reduced driving stress, and fewer self-imposed driving restrictions (e.g. long-distance travels, night driving, and city driving) since starting to drive a Tesla car. These positive outcomes were attributed to the use of various driver assistance and semi-automated systems in the Tesla car, including Traffic-aware Cruise Control, Autopilot, and Full Self-driving (Beta) systems, etc. Furthermore, a recent pilot driving simulator study directly investigated the effects of ADAS (a prototype pedestrian warning system) for drivers with CVL.[38] The warning system reduced collision risk by decreasing the time taken by drivers with CVL to perceive the risk level and initiate a braking response to pedestrian hazards.

Due to impaired central vision, older drivers with CVL may have different perceptions and preferences for using ADAS technologies than older drivers

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without CVL. Additionally, as ADAS technologies continue to advance rapidly, little is known about visually impaired drivers' opinions on relatively rare but more advanced driver assistance technologies which have potential to provide more support for this specific driving group, such as pedestrian warning systems, night vision systems, intersection assistance systems, etc. Therefore, we conducted a telephone questionnaire study with current drivers who have CVL and an age-matched control group without a diagnosis of CVL. We asked participants about their perceived difficulties in common driving situations and their perceived needs and preferences for existing driver assistance technologies, and we assessed ADAS technology use and their experiences. The goal of this study was to identify the unique challenging situations that drivers with CVL may encounter in daily driving, corresponding existing advanced vehicle technologies that may support these driving situations, and their special needs for technology support and preferences for ADAS features.

Methods

Questionnaire

The questionnaire was designed to address three main areas: (1) perceived driving difficulty in 15 specific driving situations under both good (daytime) and reduced visibility conditions (at night or in adverse weather conditions such as rain or fog); (2) perceived usefulness of technology support in these driving situations; and (3) use, perceived benefits, and preferences for 12 existing ADAS technologies. To investigate factors that might affect the opinions of surveyed participants, the questionnaire also included background information questions about demographics, CVL diagnosis, driving history and patterns, and owned vehicle information. Questions were primarily in 5-point Likert scale format, yes/no single choice format, and open-ended question format for short answers. Four experts with a background in low vision rehabilitation, driving research, psychology, and vision science reviewed the preliminary survey, and the survey was then pilot tested on a small group of older drivers with and without CVL ($n = 6$). Revisions were made based on feedback from expert reviews and pilot tests.

The 15 driving situations were generated from previous studies focused on difficult scenarios for older drivers,[23,24,39] as well as the knowledge of difficulties that drivers may experience due to CVL.[1,2,6,10] Several rounds of pilot testing were conducted to ensure that the listed situations and scenario descriptions were suitable (concise and easy to understand) for an older population. The specific 15 driving scenarios are listed in Table 1. For this set of questions, participants were asked to rate how difficult it was to drive in each of the 15 scenarios in the daytime and under reduced visibility conditions, on a 1 to 5 scale (1 = not difficult at all, 2 = slightly difficult, 3 = moderately difficult, 4 = very difficult, 5 = extremely difficult, and 0 = not applicable). For the perceived technology usefulness questions, participants were asked to rate how useful they thought it would be to have in-vehicle technology for support in the 15 scenarios to reduce the difficulty of handling these situations, in the daytime and reduced visibility conditions, on a 1 to 5 scale (1 = not useful at all, 2 = slightly useful, 3 = moderately useful, 4 = very useful, 5 = extremely useful, and 0 = not applicable). Participants were also asked to rank the top three situations for which they thought having technology support would be the most helpful.

After identifying challenging driving situations for older drivers with and without CVL, we selected 12 existing driver assistance technologies that could mitigate these driving difficulties and enhance older drivers' driving safety,[33,40] with a focus on currently available, lower-to-median level in-vehicle driver assistance technologies (see Table 1). The 12 systems included (1) the 3 most widely available and widely used systems (GPS Navigation, Rear-view Camera, and Cruise Control), (2) 5 technologies becoming more widely used (Blind Spot Warning, Lane Departure Warning, Forward Collision Warning, Forward Collision Avoidance, and Adaptive Cruise Control), and (3) 4 relatively rare but more advanced technologies (Pedestrian Warning System, Night Vision System, Adaptive Headlights, and Intersection Assistance System). Participants were asked questions to investigate their usage and experiences of these 12 ADAS. They were asked to rate how beneficial they thought each of the 12 systems might be to support driving, on a 1 to 5 scale (1 = not beneficial at all, 2 = slightly beneficial, 3 = moderately beneficial, 4 = very beneficial, 5 = extremely beneficial, and 0 = not applicable). All participants were asked to rank the top three ADAS they would most want/use in their own car and CVL participants were also asked to rate the top three ADAS they thought would help compensate for their vision problems.

The survey was managed by a web-based survey software, Qualtrics (Qualtrics, Inc., Provo, UT, USA), hosted at Wichita State University, and the examiner recorded each participant's responses during survey administration.

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Table 1. Summary of Items in Each of the Three Sets of Questions Analyzed With Rasch Analysis

Question	Items
Perceived driving difficulty and perceived technology usefulness	Dealing with other road users in the blind spot of your car while merging or changing lanes
	Dealing with other road users in the blind spot of your car at non-signalized intersections (no traffic light)
	Seeing pedestrians and other unexpected objects
	Seeing road markings
	Stopping at the appropriate place for the stop line at an intersection
	Reading road and traffic signs
	Identifying traffic signals
	Experiencing a temporary loss of visual information because of glare
	Maintaining an appropriate distance from the car in front of you, and responding to a sudden stop or slow down
	Estimating the movement, speed, and distance of other road users relative to your car
	Driving in rush hour or heavy traffic areas
	Driving through unfamiliar places
	Negotiating non-signalized intersections (no traffic light) on busy city roads, for example, making left turns across oncoming traffic
	Negotiating signalized intersections on busy city roads, for example, making left turns across oncoming traffic
	Locating the direction of sounds and noises from outside the car, for example, ambulance
	Entering and exiting a tunnel[a]
Perceived benefits of ADAS technologies	Forward collision warning
	Forward collision avoidance
	Blind spot warning
	Lane departure warning
	Rearview camera
	Cruise control
	Adaptive cruise control
	GPS navigation
	Pedestrian warning
	Night vision system
	Intersection assistant system
	Adaptive headlights

[a]Item excluded from analyses because this is not a situation which the majority of our surveyed participants typically encountered.

Participants

Current drivers with CVL were recruited from the Envision Vision Rehabilitation Center, low vision support groups in the Kansas area, and MD Support, a macular degeneration support organization (www.mdsupport.org). Non-CVL participants were recruited from the Wichita State University Visual Perception and Cognition Lab participant database and local senior living facilities. Eligible participants had to be 18 years or older, have a valid driver's license, and have driven in the last 2 months. CVL participants self-identified as having been diagnosed with some form of CVL (such as macular degeneration, Stargardt disease, macular dystrophy, or macular holes). Non-CVL participants self-reported as having no known eye disease. Non-English speakers and those with a hearing impairment that prohibited verbal completion of the survey were excluded. The study conformed to the tenets of the Declaration of Helsinki and was approved by the Wichita State University Institutional Review Board (IRB).

Procedures

The questionnaire was administered by telephone interview (authors A.H. and J.X.), lasting 40 minutes to 1 hour. Three participants completed the survey at Envision through an in-person interview. Before the interview, participants were sent a training document that included the name, functional descriptions, and icon images of the 12 existing ADAS technologies included in the telephone questionnaire. They were instructed to review the document prior to, and have it available during, the interview.

At the beginning of the interview, participants were read the consent form and any questions they had were addressed before they provided verbal consent. Four questions from the Short Portable Mental Status Questionnaire (SPMSQ) were used as screening questions to ensure participants were oriented to time and place. All participants answered these questions correctly. Participants were then asked 4 blocks of questions: (1) background information, (2) perceived driving difficulties, (3) perceived usefulness and preferences for technology support, and (4) ADAS use and experience. Before the ADAS use and experience section, they were provided opportunities to ask for explanations about information in the training document or clarifications on the function of the 12 ADAS. No participants were excluded based on SPMSQ screening questions. However, six participants (4 CVL and 2 non-CVL) were excluded for failure to understand the questions during the interview ($n = 2$) or not being able to finish the survey ($n = 4$). After the interview, participants were sent a copy of the consent form along with a gift card.

Data Analyses

Rasch analyses were used to estimate item and person measures for each of the three sets of questions (see Table 1). The first set (perceived driving difficulty) included 30 items about the driving scenarios with which older drivers with CVL may experience difficulties during daily driving. The 30 items came from the 15 driving situations in both good (daytime) and reduced visibility conditions. The second set (perceived usefulness for technology support) also included 30 items about the driving scenarios for which older drivers with CVL may think having in-vehicle technology for support would be useful to reduce the difficulty of handling these situations. The 30 items are the same items as those in the first question set. The third set (perceived benefits of ADAS) included 12 items about the perceived benefits of the 12 specific ADAS technologies that drivers may or may not use in their own cars.

All Rasch analyses were performed using Winsteps software version 5.1.2 according to the Andrich rating scale model for polytomous data using joint likelihood estimation.[41] Rasch analysis of responses to the driving difficulty question set was used to calculate a summary difficulty score (in logits) for each participant; responses to the perceived usefulness of technology support question set were used to calculate a summary usefulness score, and responses to the perceived benefit of ADAS question set were used to calculate a summary benefit score. The infit mean square fit statistic was used to assess the fit of each set of items to the Rasch model, with values between 0.7 and 1.5 considered acceptable.[42] We assessed the unidimensionality of the scale using a principal component analysis of model residuals, with an eigenvalue of the first contrast of less than 2.5 considered evidence of unidimensionality.

Statistical analyses were performed using R version 1.3.959. $P = 0.05$ was used to define statistical significance. Descriptive statistics were used to summarize participant demographics, vision, driving habits, and self-reported difficulties. The *t*-test or Wilcoxon tests for continuous variables and Chi-square tests for categorical variables were used to analyze differences between groups. Spearman correlation and Kruskal-Wallis tests were used to assess relationships among participant characteristics, driving exposure, driving difficulty scores, technology usefulness scores, ADAS benefit score, and the number of ADAS used. The Kruskal-Wallis test was used to compare the CVL and non-CVL groups, as well as good and reduced visibility conditions, for the question sets regarding perceived driving difficulty and perceived usefulness of technology. Open-ended responses were reviewed by two study team members and broad response themes were identified. The frequency of each response theme was summarized for each subject group.

Results

Characteristics of CVL and Non-CVL Participants

A total of 126 participants completed the telephone survey (58 CVL vs. 68 non-CVL; Table 2). Participants were from 8 states in the United States, 83% from Kansas; all were licensed drivers who reported having driven within the past 2 months. The two groups did not differ in gender (about 40% male), age (mean 71.6 years), and education level (67% associate degree

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Table 2. Self-Reported Demographic, CVL Diagnoses, Driving Exposure, and Owned Car Characteristics

	CVL (n = 58)	Non-CVL (n = 68)	*P* Value
Age (y), mean (SD)	71.4 (12.6)	71.8 (7.7)	0.23
Male, n (%)	24 (41.4)	25 (36.8)	0.73
Education (associate degree or above), n (%)	36 (62)	50 (74)	0.24
Self-reported CVL causes, n (%)			
AMD	49 (84.5)	n/a	n/a
JMD	9 (15.5)	n/a	
Years since diagnosis (y), median (IQR)[a]	8 (4, 12.3)	n/a	n/a
Driving mileage per week, median (IQR)	50 (12.5, 97.5)	60 (37.5, 100)	**0.02**[c]
Number of days driven per week, median (IQR)	4 (2.3, 5.8)	6 (5, 7)	**<0.001**[c]
Common driving environment, n (%)			
Urban	60	75	0.17
Rural	10	4	
Urban and rural	29	21	
Number of driving situation avoided, Median (IQR)[b]	4 (2, 6)	1 (0,3)	**<0.001**[c]
Age of vehicle (y), Median (IQR)	7 (3, 11.8)	8 (5, 11)	0.43
Total number of ADAS used, median (IQR)	3 (2, 5.75)	3 (2, 3)	0.46

[a]IQR: interquartile range, reported as 25^{th} – 75^{th} percentile.
[b]The total number of driving situations in this survey is 11.
[c]Bold text indicates significant *P* values.

or above). In terms of physical, visual, or hearing conditions that made driving difficult, 78% of non-CVL participants reported no problem, compared to only 9% of participants with CVL. The most common issues reported by participants with CVL were related to vision (85%), followed by hearing (17%), head and/or neck (3%), and other difficulties (3%). Eighty-six percent of participants reported having AMD as the cause of CVL. Self-rated vision was significantly worse among participants with CVL, with 45% describing their vision as poor or fair (vs. 1% for non-CVL group). Participants with CVL reported a range of vision problems, including glare or light sensitivity (69%), night vision loss (67%), blind area (48%), blurry vision (41%), near vision loss (40%), and depth perception issues (38%), intermediate vision loss (28%), and distortion (24%).

Thirty-one percent of participants with CVL owned their vehicle for 5 or fewer years, compared to 21% of non-CVL participants. The median vehicle age reported by CVL participants was 7 years (interquartile range = 3 to 11.8), which was comparable to the non-CVL group at 8 years (interquartile range = 5 to 11, $P = 0.43$; see Table 2). The majority of both CVL (64%) and non-CVL (74%) participants reported feeling comfortable trusting new vehicle technologies. However, 66% of participants with CVL reported that their vision made driving more stressful, compared to only 10% of non-CVL participants ($P = 0.009$).

Driving Exposure and Perceived Driving Difficulties

Participants with CVL reported driving significantly less miles ($P = 0.02$; see Table 2), driving less often ($P < 0.001$), and avoiding significantly more driving situations than those without CVL ($P < 0.001$). The most common situations that participants with CVL avoided were night driving (78%), peak-hour traffic (55%), long distance driving (53%), and bad weather (53%). The driving environment (urban or rural) did not differ between the two groups ($P = 0.17$).

Overall, participants with CVL reported significantly more difficulty in common driving situations than non-CVL participants (median [IQR]: 0.89 [IQR = 0.05–1.85] vs. 1.59 [IQR = 0.68–2.60] logits, $P = 0.002$; Fig. 1 left). Both groups reported significantly more difficulty in reduced than in good visibility conditions (median [IQR]: 0.57 [IQR = –0.45 to –1.43] vs. 1.82 [IQR = 1.10–2.81] logits, $p < 0.001$). However, the difference in reported difficulty between reduced and good visibility conditions was significantly greater for CVL than non-CVL participants (median differences: 2.21 vs. 1.18 logits, $P < 0.001$; see Fig. 1 left).

Participants (both CVL and non-CVL) reported the greatest difficulty for driving through unfamiliar areas, seeing and reacting to unexpected pedestrians, experiencing vision loss from glare, and dealing with other road users in the blind spot of their cars, for both

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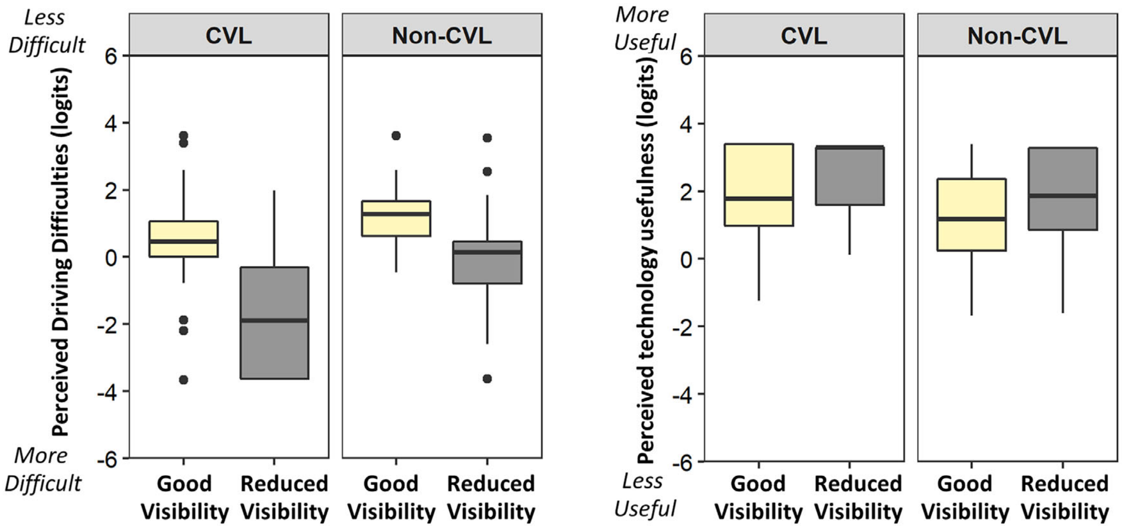

Figure 1. Perceived difficulties when driving (*left*) and perceived technology usefulness (*right*) for CVL and non-CVL groups in good and reduced visibility conditions.

reduced and good visibility conditions. Stopping at the appropriate location before the stop line for intersections was reported as the least difficult in both visibility conditions.

Drivers with CVL who reported higher weekly mileage also reported driving more days per week ($r = 0.67$, $P < 0.001$) and avoiding fewer situations ($r = -0.40$, $P = 0.001$). For both groups, older participants drove fewer days per week ($r = -0.35$, $P < 0.001$), while women drove fewer miles than men (median 50 vs. 75 miles/week, $P = 0.04$) and avoided more driving situations (median 3 vs. 2 situations, $P = 0.02$). Participants with CVL who reported poorer vision drove less ($P = 0.01$), avoided more situations ($P < 0.001$), and perceived greater driving difficulty ($P < 0.001$); these patterns were not found for non-CVL participants ($P = 0.82$, $P = 0.75$, and $P = 0.20$, respectively). In addition, higher levels of perceived driving difficulty were correlated with greater driving avoidance ($r = 0.60$, $P < 0.001$) for both groups, and with lower weekly mileage ($r = –0.43$, $P < 0.001$) and fewer days driven ($r = –0.33$, $P = 0.01$) for participants with CVL, but not for non-CVL participants.

Perceived Usefulness for Technology Support

In general, the participants of the CVL group reported significantly higher perceived usefulness for technology support in common driving situations compared to those in the non-CVL group (median [IQR]: 2.02 [IQR = 1.21–3.65] vs. 1.35 [IQR = 0.58–2.27] logits, $P = 0.003$; see Fig. 1 right). Both groups perceived significantly higher technology usefulness in reduced visibility conditions than in good visibility conditions (median [IQR]: 2.28 [IQR = 1.24–3.29] vs. 1.44 [IQR = 0.52–3.36] logits, $P = 0.02$) with no between group differences (median differences between reduced and good visibility: CVL 0.10 vs. non-CVL 0.35 logits, $P = 0.56$). When asked to identify situations in which technology support would be most beneficial, both groups selected the same 4 situations: (1) dealing with other road users in their car's blind spot, (2) detecting and reacting to unexpected pedestrians, (3) experiencing visual information loss due to glare, and (4) driving through unfamiliar areas. The situation requiring the least amount of support was stopping at the appropriate location before entering intersections.

Participants who drove greater mileage ($r = –0.21$, $P = 0.02$), more frequently ($r = –0.29$, $P < 0.001$), and with less avoidance ($r = 0.22$, $P = 0.01$) also reported higher perceived technology usefulness. Furthermore, there was a positive correlation between the perceived driving difficulties and the perceived usefulness of technology support ($r = 0.34$, $P < 0.001$). Participants who reported higher levels of driving difficulty also reported higher levels of perceived usefulness of technology support. Interestingly, for the CVL group, perceived technology usefulness correlated with participants' age. Older participants with CVL perceived less technology usefulness ($r = –0.30$, $P = 0.02$), a correlation not observed for non-CVL participants.

ADAS Use, Preferences, and Willingness to Own

The median number of ADAS owned and used did not differ between the two groups, with both CVL

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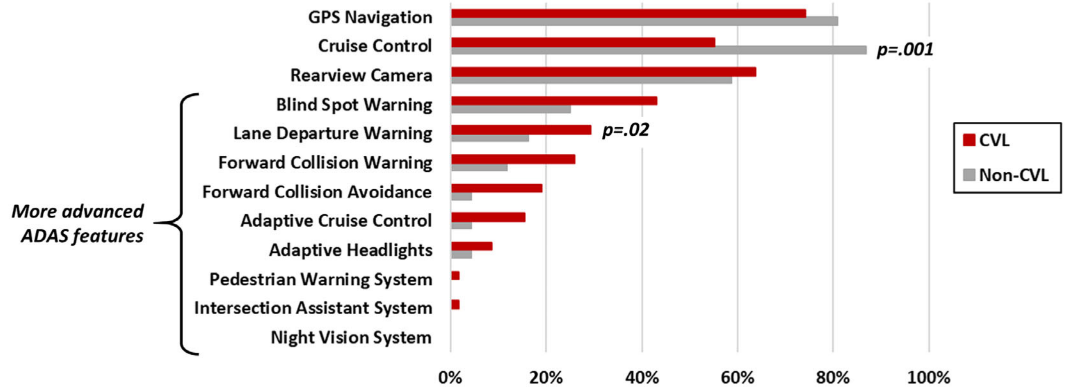

Figure 2. Percentage of participants who used each type of ADAS in the CVL and non-CVL groups.

and non-CVL groups reporting a median of three ADAS technologies (IQR = 2 to 6 and 2 to 3, respectively, $P = 0.46$). GPS, Cruise Control, and Rearview Camera were the most used ADAS by both groups. However, significantly fewer participants with CVL reported using Cruise Control compared to non-CVL participants (55% CVL vs. 87% non-CVL, $P = 0.001$; Fig. 2). In terms of more advanced ADAS technologies (8 ADAS systems, excluding GPS, Cruise Control, and Rearview Camera), drivers with CVL used significantly more of these systems than non-CVL drivers (1.6 vs. 0.7, $P = 0.02$). Additionally, significantly more drivers with CVL reported using Forward Collision Avoidance than non-CVL drivers (19% vs. 4%, $P = 0.02$).

Both CVL and non-CVL drivers agreed that having ADAS in their car could be highly beneficial (no differences between the 2 groups, $P = 0.08$). When asked to select the top three ADAS technologies they would want or use in their car, the CVL group selected Blind Spot Warning, Pedestrian Warning System, and Forward Collision Avoidance System. In contrast, the non-CVL group listed Blind Spot Warning as their first choice, followed by Rearview Camera and Cruise Control.

Furthermore, there were significant differences between CVL and non-CVL drivers in terms of the level of assistance they desired from their vehicle technologies ($P = 0.001$). The majority of drivers with CVL (90%) preferred ADAS technologies that provided both information (e.g. warnings) and active intervention (e.g. automatic brake or stop) in imminent crash situations, whereas only 7% opted for systems that only provide information. In contrast, non-CVL drivers had a more mixed opinion, with 34% preferring information-only and 62% favoring systems that include both information and active intervention. Interestingly, 46% of drivers with CVL indicated a desire for as many ADAS systems as possible, whereas only 26% of non-CVL drivers agreed with this, with 57% preferring to own 4 to 8 systems. Moreover, a large percentage of both groups (CVL 83% vs. non-CVL 73%) thought that ADAS would play a role in their next car purchasing decision.

For both groups of participants, as expected, the number of ADAS owned was negatively associated with the vehicle age ($r = -0.68$, $P < 0.001$). Newer vehicles were equipped with more ADAS technologies. Participants with CVL who owned newer vehicles ($P < 0.001$) with more ADAS technologies ($P < 0.001$) reported a higher comfort level in trusting new technologies than those who owned older vehicles with fewer technologies. These differences were not found for non-CVL participants ($P = 0.53$ and $P = 0.96$).

Discussion

Consistent with previous research, participants with CVL had significantly worse self-rated vision, drove less frequently, and avoided more driving situations (e.g. night driving, peak-hour traffic, long distance driving, and bad weather) than non-CVL participants.[35,43–45] They also reported significantly more difficulty in common driving situations in both good and reduced visibility conditions, and their higher perceived driving difficulty was correlated with more driving avoidance and less driving frequency. These self-restrictions could be an adaptive strategy employed by drivers with CVL to cope with their visual limitations. In this study, however, participants with CVL still drove 50 miles/4 days per week in similar driving areas as non-CVL participants, suggesting that despite visual challenges and self-imposed restrictions, drivers with CVL are still active on the roads, especially in areas with few public transit options. This may be because the majority of our participants were from the more spread-out Midwest regions, where few public transportation options are available.

Our study identified specific driving situations that were particularly challenging for older drivers with CVL, including driving through unfamiliar areas, seeing and reacting to unexpected pedestrians, experiencing vision loss from glare, and dealing with other road users in the blind spot of their cars. Both groups perceived ADAS as highly useful for supporting driving in challenging situations, especially in dealing with other road users in the blind spot of their cars, seeing and reacting to unexpected pedestrians, experiencing visual information loss because of glare, and driving through unfamiliar areas. Notably, the top four most difficult driving situations identified by participants were also the top four situations for which they perceived ADAS as most useful, although the orders differed. Prior research by Davidse (2005) suggested that, from a safety perspective, the most important situations in which older drivers need technology support are: seeing other road users when merging/changing lanes, judging the approach speed of other road users at intersections, noticing traffic signs, and responding in complex traffic situations.[23] Our participants agreed with Davidse about the need for support in seeing other road users in the vehicle's blind spot, but the other top three situations in which they thought ADAS would be most useful differed from Davidse's suggestions. One possible explanation is the different methodologies used. Our results were based on participants' subjective opinions obtained from questionnaire interviews, whereas Davidse's results were based on theoretical frameworks of summarizing older drivers' weakness in general, accompanied by the extent to which these problems contribute to the total number of crashes. Additionally, our study focused specifically on older drivers (mean age 72 years) with and without CVL, who may be more sensitive to glare and have more difficulty detecting unexpected pedestrians due to impaired vision. We also found that participants with CVL perceived ADAS technologies to be more useful than did non-CVL participants. This is in line with the strong positive correlation found between perceived driving difficulties and perceived usefulness of technology support, suggesting that these technologies could be particularly beneficial for older drivers with CVL.

Based on our findings and those of previous studies,[23,46] we summarized the driving situations rated most difficult, desired functionalities, and potential ADAS that may offer support for drivers with CVL in Table 3. These findings suggest the need for targeted interventions to support older drivers with CVL in these challenging situations and prioritize the consideration of these ADAS technologies for this driving group.

Moreover, we found that participants with CVL used significantly more advanced ADAS technologies than non-CVL drivers in their cars, with a higher percentage of drivers with CVL using forward collision avoidance systems. Consistent with a prior study,[35] we also found that significantly fewer CVL participants reported using Cruise Control. This could be due to their self-restricted driving, with less driving on highways and long-distance travel where Cruise Control is designed to support driving comfort in these situations. However, we did not find less usage of GPS than non-CVL drivers in our study. This may be because CVL and non-CVL participants in this study mainly came from Midwest regions where they might need less use of GPS to travel to unfamiliar places.

Among the 12 existing ADAS included in the survey, the 3 technologies most desired by drivers with CVL all supported some form of collision avoidance, namely Blind Spot Warning, Pedestrian Warning System, and Forward Collision Avoidance System, which also align with the most difficult driving situations and desired technology support systems identified by these drivers (see Table 3). In contrast, non-CVL drivers selected ADAS technologies they were more familiar with or had prior use experience with (Blind Spot Warning, Rearview Camera, and Cruise Control). Nevertheless, the Blind Spot Warning system was consistently rated as the top desired technology which was commonly believed to improve safety for older drivers across different age ranges and different vision conditions.[29,33,35] Interestingly, 90% of drivers with CVL reported that they prefer ADAS technologies that provide both information (e.g. warnings) and active intervention (e.g. automatic emergency braking) in imminent hazardous situations, whereas non-CVL drivers were more divided between receiving information-only and both information and active intervention systems. The utilization of more advanced driver assistance technologies may instill confidence in individuals with vision impairments, offering reassurance and alleviating the anxiety that is often associated with driving when vision is impaired.[36,37] Increased technology support and a stronger emphasis on collision prevention may mitigate concerns associated with reduced biomechanical tolerances to injury during the aging process.[47,48] Furthermore, drivers with CVL may be more motivated to adopt new technologies that could support daily driving, recognizing the potential safety benefits these technologies

Table 3. Driving Situations Rated Most Difficult, Desired Functionalities, and Potential In-Vehicle Technologies That May Offer Support

Situations Rated Most Difficult	Desired Functionality	Potential ADAS and in-Vehicle Technologies
Dealing with other road users in the blind spot of their cars	Detect and alert driver of nearby road users located in the blind spot of driver's car, assisting them in safely changing lanes	- Blind Spot Warning System - Automatic Lane Changing and Merging Assist Systems
Seeing and reacting to unexpected pedestrians	Prevent accidents by notifying drivers of pedestrians and unexpected hazards ahead, offer alerts and automatic emergency braking to prevent collisions	- Pedestrian Warning System - Collision Warning/Avoidance System
Experiencing vision loss from glare	Minimize glare from on-coming vehicles, bright ambient light at night or adverse weather, and intense sunlight during sunny days, and/or provide alerts or automatic emergency braking features to prevent collisions	- Adaptive Headlight (automatic dimming) - Lane Departure Warnings/Assist - Collision Warning/Avoidance Systems, Blind Spot Warning Systems, Pedestrian Warning Systems - Glare-reducing Rearview Mirrors - Tinted sunglasses or visors for sunlight glare (*consult with healthcare provider for guidance*)
Driving through unfamiliar areas	Provide advance knowledge of upcoming traffic situations and offer clear and precise voice-guided turn-by-turn directions	- GPS Navigation System - Head-up Displays (provide directions and road information at eye level) - Intersection Assist System (navigate through complex intersections that the driver is about to cross)
Night driving	Improve the front road visibility and enhance hazards awareness on the road during nighttime, offer alerts and automatic emergency braking to prevent collisions	- Night Vision System - Adaptive Headlights - Lane departure warnings - Collision Warning/Avoidance Systems

could offer in compensating for their visual impairments.

Both CVL and non-CVL drivers who drove more frequently and with less avoidance perceived ADAS technology support as more useful. The negative correlation between age and driving exposure suggests that older drivers, both with and without CVL, tend to drive less frequently. However, there was a disparity between these two groups in how age affects the perception of technology usefulness. Although drivers with CVL of older age perceived ADAS technologies to be less useful, this was not the case for non-CVL drivers. These findings suggest that drivers with more driving exposure may have higher driving confidence, leading them to perceive driver assistance technologies as more useful. However, at some point in the aging process, drivers with CVL may begin to perceive these technologies as less useful. This may be due to the progression of their CVL, making it more challenging for them to use and access technologies. Some participants with CVL even expressed their reluctance to purchase another car or their intention to cease driving soon, as they perceive technologies as less helpful or irrelevant to their daily lives. Therefore, the vision condition may be an important factor in influencing the perception and adoption of advanced in-vehicle technologies among the older population. However, despite this, 83% of participants with CVL believed that ADAS would play an important role in their next car purchasing decision. This suggests that older drivers with

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and without CVL recognize the potential benefits of these ADAS technologies for supporting their daily driving.

Our study also found that participants with CVL who owned newer vehicles with more ADAS features reported more comfort in trusting new technologies, which is similar to the older driver population in general.[29] More knowledge about, or direct exposures to, ADAS can increase confidence with use of, trust in, and adoption of these technologies. Whereas half of the drivers with CVL (vs. 26% non-CVL) desired as many ADAS systems as possible in their cars, it is important to consider the potential risks associated with increased cognitive and physical workload due to more in-vehicle technology use, which could compromise driving safety for older drivers.[24] Furthermore, visually impaired drivers may have difficulties in navigating the complexity of new vehicle interfaces and utilizing new technologies, as reported in the previous case study of the driver with CVL who drove a Tesla car.[36,37] Therefore, selecting specific ADAS technologies that consider the specific driving needs and challenges of these drivers, ensuring that the user interface of ADAS systems is designed intuitively and customized to be senior-friendly and visually impaired-friendly, and providing comprehensive and targeted training on the proper utilization of these technologies is necessary for drivers with vision impairments.

In interpreting the results of this study, a few limitations need to be considered. First, there may be some selection and response bias; participants who were willing to participate may have possessed a higher level of interest in technology or safety compared to the general population. Second, the majority of our participants were from the Midwest region. In future studies, it would be interesting to recruit participants from a wider range of geographic locations to investigate whether there are regional differences in owning and usage of ADAS technologies. Third, the training document, which included functional descriptions of each ADAS and the interview topic, could have influenced participants' perceptions in a positive manner. Fourth, estimates of vision status and driving difficulties were based on self-report and many participants were rating the usefulness of ADAS systems they had never used. Naturalistic driving[49,50] could be used in future studies to provide objective data on the everyday driving difficulties experienced by drivers with CVL and their ADAS use experiences, which would provide more insights on the effectiveness of these technologies in real-world driving situations for older drivers with CVL. This approach could also provide insights into the extent to which vision status impacts the use of ADAS and the associated use challenges.

Conclusions

Overall, our study provides insights into the specific technology needs and preferences of older drivers with CVL. Our findings suggest that participants perceived the potential benefits of ADAS technologies to support their driving, particularly in challenging situations such as dealing with blind spot road users, experiencing vision loss from glare, detecting and reacting to unexpected pedestrians, and driving through unfamiliar areas. The greater usage of advanced ADAS features, along with higher perceived usefulness and strong willingness to own ADAS technologies, by drivers with CVL underscores the importance of developing and evaluating technologies that are specifically tailored to this driving group. For older drivers with CVL, ADAS technologies should prioritize collision prevention support by incorporating features such as blind spot warning, pedestrian warning, and forward collision avoidance. Educational programs that provide focused training and comprehensive support for understanding and properly utilizing ADAS technologies could further augment their adoption and effectiveness in enhancing driving safety for older drivers with CVL.

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