Review Article

A Review of Driving and Binocularity

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ABSTRACT

Although most jurisdictions allow stereoscopically deficient and monocular individuals to drive, studies regarding these visual components' effects on driving have to date yielded contradicting results. Interviews, record reviews, and experiments have been used to unmask these effects. In interviews, participants with amblyopia reported several difficulties operating automobiles. Record reviews yielded mixed results, with studies revealing an increased crash rate and/or severity in a group of stereoscopically deficient commercial drivers, whereas studies of non-commercial drivers failed to make that association. Furthermore, experimental studies showed that individuals with reduced stereopsis braked earlier and were less likely to crash. With regard to monocularity, real-life experiments failed to demonstrate a poorer driving performance and simulation studies showed that drivers with sudden monocularity were more likely to crash and drive off the road. **[*J Pediatr Ophthalmol Strabismus*. 2022;59(1):6-12.]**

INTRODUCTION

Driving requirements may differ from country to country and research is continually investigating various components of vision and their impact on driving performance. Although there are certain components, including visual acuity, that almost all licensing authorities require, other visual parameters such as stereopsis are still a controversial topic.[1] Likewise, drivers with conditions such as monocularity are generally permitted to drive, although studies lack a consensus on the safety of their driving.[1,2]

In many parts of the world, such as the United States and the European Union, it suffices to have a certain visual acuity and to pass a visual field test to obtain a driver's license.[3-5] In Canada, there is no legislation that prevents monocular individuals from driving.[2] Although there are some concerns about the importance of depth perception to drivers, the Canadian Medical Association Driving Fitness Document recognizes the availability of monocular clues (parallax, relative size, interposition, and texture) that may aid drivers with limited stereopsis.[2] Restrictions are mostly placed on drivers who have recently become monocular because they may require some adaptation time.[2]

One of the conditions that may contribute to the loss of stereoscopic vision is amblyopia, a frequently encountered ophthalmological condition characterized by a reduced best corrected visual acuity in the absence of a structural cause.[6] The condition may lead to the suppression of the amblyopic eye and subsequently to the loss of stereoscopic vision.[7,8] The causes of amblyopia vary and include strabismus, neglected refractive errors, and diseases that obstruct the visual axis, such as congenital cataracts.[6] The effects of amblyopia (and subsequent loss of stereoscopic vision) on visuomotor skills such as grabbing objects, driving, reading, and walking have been investigated in the literature.[9,10] Individuals with amblyopia performed worse on tasks requiring eye–hand coordination such as placing pegs in a board, pouring water, and threading beads.[11,12] The impact of the condition on driving has been inadequately assessed to date.[1,13]

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Although regulations generally allow stereoscopically deficient individuals to drive, previous studies have revealed discordant findings with regard to their on-road performance and safety.[1,13] Surveys, registry reviews, prospective analyses, and controlled experiments have been conducted to investigate both the subjective and objective effects of reduced stereoscopic vision and monocularity on driving performance. To our knowledge, no review has previously addressed this topic. This article reviews the available literature on the effect of reduced stereopsis and loss of binocularity on driving performance.

RECORD REVIEWS AND QUESTIONNAIRES

The impact of conditions such as amblyopia on patients' driving abilities has been subjectively addressed with the aid of questionnaires, interviews, and focus group discussions. **Table 1** summarizes the pertinent studies.

Kumaran et al[14] interviewed adults with various types of amblyopia (strabismic, anisometropic, and deprivational) about their difficulties with driving. Participants reported numerous challenges, including inability to judge distances accurately when reversing or parking their cars. Moreover, they needed to turn their heads more often to see things on the side of their amblyopic eye, especially when changing lanes.[14] Estimating the speed of other vehicles was another challenge; some participants had to give up driving at night, in unfamiliar areas, or altogether.[14]

West et al[15] explored driving self-restriction behavior among 629 adults in relation to their performance on various visual tests. Results revealed that poor stereopsis was associated with restricting behavior. In another study, although visual acuity and contrast sensitivity were linked to various forms of self-reported disabilities, no direct link was found between stereoacuity and any of these activities (including driving).[16] In a cohort of patients who underwent enucleation for choroidal melanoma,[17] only 13% reported a decrease in functionality from the time of enucleation (ranging from 2 to 25 years). Moreover, 15 years after enucleation, 90% and 96% retained the ability to drive and read, respectively.[17] Other research created study models to correlate the number of accidents per year with the medical conditions of truck drivers. Results showed that diabetic truck drivers had more accidents than healthy controls, but no significant correlation was found between ophthalmologic disorders and truck accident rates.[18]

Although certain studies relied on interviews as their primary methodology, others used data registries and record reviews. Maag et al[19] studied the effect of binocular vision problems (non-stereoscopic vision/monocular vision) on the frequency and severity of taxi car crashes. Binocular vision problems were associated with a significantly higher number of car crashes (0.369 vs 0.218 crashes/year for drivers with binocular vision problems and those without, respectively); severity (in terms of people injured/dead) was comparable between study groups.[19] This was confirmed by others showing increased severity in car crashes of truck drivers with reduced stereopsis.[20]

Furthermore, Davison[21] studied the relationship between the age and vision of 1,000 British drivers with regard to their road accident history. The drivers were stopped on the street and asked about their interest in participating. Thereafter, they were subjected to a comprehensive ophthalmological examination and an interview on their accident history. Positive associations were found with several ophthalmological conditions, including visual acuity and hyperphoria; however, poor stereopsis was not associated with accidents. The observed increasing road accidents with increasing age was associated with age-related visual disabilities. Rubin et al[22] analyzed the role of vision in automobile crashes and found that binocular field loss and glare sensitivity were predictors of automobile accidents, but decreased stereoacuity, contrast sensitivity, and visual acuity were not.

An earlier study from South Africa assessed color vision, stereopsis, and visual acuity in accident-free and accident-involved drivers and correlated findings to crash rates.[23] Results demonstrated that depth perception was poorer in the accident group (4 of 196) than in the accident-free group (5 of 170).[23] Gresset and Meyer[24] recruited 1,400 drivers in their 70s with a history of motor vehicle accidents. Data concerning ophthalmologic conditions were collected from the Quebec Automobile Insurance Board for the 1,400 participants and for 2,636 accident-free drivers (controls). A questionnaire gathering information anonymously about mileage and prevailing driving conditions was sent to the participants. Results demonstrated no difference in accident risk between drivers with minimal visual acuity (defined as 6/12 in this study) as compared to other drivers (odds ratio = 0.97, 95% CI = 0.68 to 1.38).[24] However, motorists with both minimal visual acuity and lack of binocu-

TABLE 1

Summary of Record Reviews and Questionnaires

Study	Sample Size	Aims/Methods	Results
Kumaran et al,[14] 2019	37 adults with amblyopia	Subjective driving difficulties	Numerous challenges during both parking and driving were reported
West et al,[15] 2003	629 adults older than 55 years	Visual function examination followed by questions on current driving behavior	Poor stereopsis associated with restriction of driving
Rubin et al,[16] 1994	222 adults older than 65 years	Eye examination followed by a questionnaire on current functionality	No link between stereoacuity and driving behavior
Edwards & Schachat,[17] 1991	71 patients with one eye enucleated	Questionnaire about postoperative functionality (2 to 15 years later)	90% retained ability to drive; 96% retained ability to read
Dionne et al,[18] 1995	1,307 truck drivers	Questions about medical conditions and accident history	No correlation between ophthalmologic disorders and accident rates
Maag et al,[19] 1997	116 taxi drivers	Nested case–control study from a large database with data on medical conditions and accident rates	Drivers with binocular vision problems (nonstereoscopic vision/monocular vision) had a significantly higher number of car crashes
Laberge-Nadeau et al,[20] 1996	542 truck drivers involved in crashes (1985 to 1990)	Nested case–control study from a large database with data on medical conditions and accident rates	Truck drivers with reduced stereopsis had more severe car crashes (in terms of number of victims/crash)
Davison,[21] 1985	1,000 British drivers	Comprehensive eye examination followed by interview on accident history	Poor stereopsis not associated with an increased frequency of accidents
Rubin et al,[22] 2007	1,801 drivers aged 65 to 84 years	Baseline interview and ophthalmological examination; drivers observed for a median of 1,807 days for crash involvement	Reduced stereoacuity not associated with an increased rate of automobile accidents
Humphries,[23] 1987	196 accident involved drivers and 170 accident-free drivers	An Ortho-Rater device (Bausch & Lomb) assessed color vision, stereopsis, and visual acuity; data correlated to existing car crash history	The accident-involved group had poorer depth perception than the accident-free group
Gresset & Meyer,[24] 1994	1,400 drivers with a positive accident history and 2,636 controls	Data on ophthalmologic conditions from records; questionnaires about mileage and driving conditions	Drivers with both minimal visual acuity (6/12) and lack of binocularity had a non-significant increased risk of accidents
Baker et al,[25] 2019	66,253 young adults including 352 with amblyopia and 62 with unilateral visual impairment	Health records of New Jersey residents who were patients of the Children's Hospital in Philadelphia linked to respective crash rates and driver licensing	Individuals with amblyopia/unilateral visual impairment had similar car crash risk to controls but were less likely to obtain a driver's license

larity tended to have an increased risk of accidents, albeit with no statistical significance (odds ratio = 1.23, 95% CI = 0.88 to 1.72).[24] In 2019, Baker et al[25] studied a sample of New Jersey citizens who were patients of Children's Hospital of Philadelphia. Patients with unilateral vision impairment or amblyopia diagnosed between the ages of 12 and 15 years were found using electronic health records and International Classification of Disease, 9th edition codes. State licensing and crash data were used to compare accident rates of drivers with and without amblyopia or unilateral vision impairment. Although individuals with amblyopia or unilateral visual impairment had a similar crash risk to controls, they were less likely to obtain a driving license.[25]

Research involving record reviews and questionnaires or interviews reported mixed results. From the above 12 studies reviewed, 6 supported a negative relationship between poor stereopsis/deficient binocular vision and driving performance and the other 6 showed no correlation.

EXPERIMENTS

In addition to registry and record reviews, the driving performance of stereoscopically deficient and monocular individuals has been studied with the aid of controlled experiments. **Table 2** summarizes their pertinent findings. In 1991, McKnight et al[26] compared 40 monocular and 40 binocular tractor trailer drivers with regard to the various components of driving. After undergoing a series of ophthalmological examinations, participants were asked to drive along certain paths. Various aspects of their driving (mirror checks, gap judgment, information recognition, and staying in the lane) were studied with the use of three cameras mounted on or in the truck. No significant differences between groups were found with respect to staying in the lane, gap judgment, clearance judgment, and hazard detection.[26] In monocular drivers, depth perception (stereopsis) was only significantly associated with the distance needed to recognize signs (eg, honk and swerve). The distance measured was 41.8 and 47.8 m for monocular and binocular drivers, respectively. The authors concluded that monocular drivers were not substantially worse than binocular drivers when it came to most day-to-day driving skills.[26] Others studied the role of stereovision in avoiding rear-end crashes.[27] Thirteen "stereonormal" (40 seconds of arc or better) and 13 "stereoweak" (400 seconds of arc or worse) participants were made to drive a go-cart toward a target and were given a choice to commence braking from 4, 7, or 10 m. Position of the go-cart and deceleration behavior were assessed with the aid of a laser. Stereoweak drivers commenced braking earlier and had a greater stopping distance. This careful braking behavior may be due to an underestimation of distance or an unconscious adaptation of their perceptomotor system.[27] Either way, poor stereopsis was not associated with increased rear-end collisions.

Bauer et al[28] also investigated relevance of stereoscopic vision for motorists. Participants and controls were asked to stop in front of an obstacle, drive through a slalom (zigzag) course, reverse into a parking space, and estimate the relative position of two cars. Participants with defective stereopsis performed worse only in the slalom test, suggesting that stereoscopic vision may be useful in performing dynamic tasks at intermediate distances. Recently, the impact of strabismus correction surgery on driving was studied both subjectively and objectively.[29] Patients presented 1 month before and 3 months after their strabismus correction surgery. They were subjected to various ophthalmological tests, drove on a simulator equipped with an eye tracker, and completed a driving self-confidence questionnaire. Improvement in postoperative binocular visual field was observed; however, stereopsis and binocular visual acuity did not significantly change.[29] Driving simulation revealed a postoperative improvement in the distance at which road signs were recognized (81.0 ± 7.2 vs 94.7 ± 5.2 m, before and after surgery, respectively). There was also a decrease in the total number of brake pedal pressures along with an improvement in driving self-confidence questionnaire results.[29]

Others simulated monocular conditions in drivers with normal vision. Wood and Troutbeck[30] had participants wear goggles and used frosted lenses to simulate cataracts, pinholes to simulate binocular visual field loss, and an eye patch for monocular vision. Driving was tested in a circuit at an advanced driving training center. The vehicle was designed to record location and reaction times. Additionally, a video camera was installed in the vehicle to record performance. Analyses showed that driving performance was most affected by cataracts, followed by binocular visual field restriction. Monocularity did not have a substantial impact on driving performance.[30]

Adrian et al[31] assessed the impact of monocularly reduced and monocular vision on car racing.

TABLE 2

Summary of Studies Involving Experiments

Study	Sample Size	Aim/Methods	Results
McKnight et al,[26] 1991	40 monocular and 40 binocular tractor trailer drivers	Driving performance comparison between monocular and binocular drivers; driving tasks video-taped	No significant difference in most studied parameters; monocular drivers non-inferior
Tijtgat et al,[27] 2008	13 stereoweak and 13 stereonormal participants	Role of stereovision in rear-end collisions	Braking time assessed with laser detector; stereoweak participants braked earlier and had greater stopping distance
Bauer et al,[28] 2001	10 participants with poor stereopsis; 10 controls	Role of stereopsis in driving; observer assessed studied parameters	Stereoweak participants only did worse in slalom (zigzag) course, performed similarly in other tests (reverse parking, stopping)
Derhy et al,[29] 2020	20 participants in study group and controls	Effect of correcting strabismus on driving performance; used simulator equipped with an eye tracker	Improvement in driving (road sign identification, number of brakes) despite no difference in preoperative and postoperative stereopsis
Wood & Troutbeck,[30] 1994	14 adults with 6/6 visual acuity (conditions simulated)	Effect of cataract, monocularity, and binocular visual loss on driving; used a driving circuit and video cameras	Monocularity did not have substantial impact on driving performance
Adrian et al,[31] 2019	75 visually healthy participants (monocular conditions simulated)	Impact of monocularly reduced and monocular vision on race car driving; used a driving simulator with video cameras	Monocular drivers twice as likely to crash; monocularly reduced vision similar to participants' baseline
Molina et al,[32] 2021	24 visually normal participants (monocular conditions simulated)	Assessment of sudden monocularity on driving; used a driving simulator	Abrupt loss of binocular vision led to unsafe driving (out-of-road driving and increased braking intensity)

Ophthalmological conditions were simulated using a Ryser filter (monocularly reduced vision) and an occlusive patch (monocular vision). Participants underwent a series of experiments on a driving simulator in which they had to perceive (and react to) the abrupt intrusion of a racing car into their trajectory. Monocular drivers had slower reaction times and were twice as likely to crash.[31] More recently, Molina et al[32] assessed the impact of sudden monocularity on visually healthy participants. Participants drove through three different traffic situations (city, highway, and rural) under normal, monocularly blurred, and monocular vision. Sudden monocular vision (by occlusion of one eye using a 0.0 Bangerter filter) led to participants driving outside the road, especially in the city scenario. Participants also subjectively reported having more difficulties in the monocular states; vagal tone showed similar results.[32]

In general, experimental studies demonstrated difficulties in driving skills, road performance, and crash rates among participants with deficient stereopsis/binocular vision. Of the 7 studies considered, 2 showed no significant correlation between monocularity/reduced stereopsis and poor driving behavior, 1 showed a protective effect (braking earlier), and 4 linked monocularity/poor stereoacuity to an increased risk of car crashes.

CONCLUSIONS

The effects of impaired binocular vision and reduced stereopsis on driving performance and safety have been evaluated using several methods. Interviews and questionnaires mostly reported mixed results, but a major drawback of using interviews is their

subjective nature. Regarding monocularity, most participants after enucleation who were questioned on their functionality stated that they retained the ability to read and drive.[17] However, whether these drivers were later more prone to car crashes is unknown. Although they were still actively driving, little was mentioned about their accident involvement rate and other new subjective difficulties. Two studies looked specifically at commercial motor vehicle drivers and their car crash rates/severity in relationship to decreased stereopsis/monocular vision.[19,20] Although both correlated poor stereopsis to an increased accident rate or severity, the study populations were commercial drivers who represent a special group of on-road drivers; findings may not be applicable to non-commercial drivers, who most likely do not spend as much time on the road.[1] Other reviews on a large number of individuals (1,000 and 1,801 drivers, from each study, respectively) from the general population found no correlation between reduced stereopsis and car crash rates.[21,22]

Experimental studies showed that stereoweak participants were generally non-inferior to their stereonormal counterparts when performing most components of real-life tasks.[27,28] Individuals with surgically corrected strabismus showed an improvement in driving, despite no improvement in stereopsis.[29] The improvement in driving could be attributed to an expanded visual field and an increase in self-confidence after strabismus correction and not to an improvement in stereoacuity per se. Of the experimental studies investigating monocularity and driving, only one involved both monocular and binocular participants. This study did not detect differences in most day-to-day driving scenarios.[26] Similarly, studies with simulated monocularity showed mixed results with respect to driving performance.[30] On the other hand, studies using driving simulators showed an increased car accident rate in contrast with the former studies that had participants do real-life tasks.[26-32] Molina et al[32] investigated sudden monocularity in several scenarios (city and rural) and revealed that participants drove unsafely, especially in the city scenario. This difference may be attributed to reckless driving on simulators, not being a real-life situation. An alternative explanation could be that the earlier experiments were less complicated and did not uncover differences in a busy regular day-to-day scenario.[29] Moreover, it is also plausible that the simulation experiment has a learning curve, causing participants to perform better when repeated, such as after strabismus corrective surgery. Finally, Adrian et al[31] targeted race car drivers and the impact of sudden monocularity on their driving skills; results of this study have to be interpreted with caution and may not be generalizable to other driver groups in different scenarios.

Although most jurisdictions allow stereoscopically deficient and monocular individuals to drive, studies have to date yielded contradicting results. Most studies indicate that reduced stereopsis is not a hazard in regular day-to-day driving among non-commercial drivers. With regard to monocularity, real-life experiments have failed to demonstrate poorer driving performance in monocular drivers, whereas some simulation studies showed that drivers with sudden monocular vision were more likely to crash and drive off the road. Based on this review, reduced stereoacuity and long-standing monocularity, whether simulated or not, may impact driving performance. However, further prospective longitudinal studies using controlled experiments are needed to truly uncover the effects of these visual impairments on the operation of automobiles in different driving situations.

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