**REVIEW ARTICLE**

# A Scoping Review on the Intrinsic & Extrinsic Vision-Related Factors in Driving

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**Abstract:**

Driving performance can be influenced by multiple factors. The intrinsic factors encompass age, gender, visibility, visual field and movement patterns of the driver. The extrinsic factors cover road signage, lane, streetlight, weather and time of the day. Driving is undisputedly a highly visual task. The visibility of drivers can be affected by visual acuity, contrast sensitivity, illumination and glare issues. Contrast sensitivity is a better predictor of driving performance than visual acuity. Driving performance downgrades with increasing blur. Uncorrected refractive error reduces the distance to recognize road signs and increases driving time. Central visual field defect displays more difficulty in driving performance compared to peripheral visual field defects. Binocular visual field defects have more severe impacts on driving performance. Homonymous hemianopia is considered not safe for driving. The impacts of altitudinal visual field defects and scotoma remain inconclusive. Driver's movement patterns have been employed in various driving research to indicate distraction and engagement. Eye, head, and body movements are closely linked to driving behaviours. The legibility of the road sign is essential to provide a safer road environment for road users. The road signs should be legible sufficiently far away to give advanced notice to road users. Appropriate spacing and positioning of lanes and streetlights are crucial for safe daytime and night-time driving.

**Keywords:** driving, eye movement, refractive error, visibility, visual field defects

## 1. INTRODUCTION

Many people die or suffer non-fatal injuries in road traffic accidents annually (Atreya, Shrestha, Budhathoki, & Nepal, 2021; Larsson, Dekker, & Tingvall, 2010; Mohd Saman, Jothee, Nor, & Shafie, 2021; Poudel, Dhungana, & Dahal, 2021; Yan, Chen, Wang, Zhang, & Zhao, 2021). Major contributions include the human factor, vehicle factor, road conditions and surroundings. Numerous studies have reported that driver-related behaviour is responsible for 95% of traffic accidents (Petridou & Moustaki, 2000; Poudel et al., 2021; Yan et al., 2021). The behavioural factor can be notable as those that have poor capability on a long-term basis (inexperience, ageing, disease, disability, alcoholism, and drug abuse), those that have inadequate capacity on a short-term basis (drowsiness, acute alcohol intoxication, fatigue), those that encourage risk-taking behaviour with long-term influence (habitual speeding, disregard traffic regulation, indecent driving behaviour) and, those that encourage risk-taking behaviour with the short-term consequence (suicidal behaviour, moderate ethanol intake, motor vehicle crime (Petridou & Moustaki, 2000; Poudel et al., 2021; Yan et al., 2021).

There is a growing body of literature that recognizes the importance of age factor in driving performance (Borowsky, Shinar, & Oron-Gilad, 2010; Hills & Burg, 1977; Kosnik, Winslow, Kline, Rasinski, & Sekuler, 1988; Mortimer & Fell, 1989; Quaglino et al., 2008). Some believe that age is an advantage. Older and experienced drivers have been reported to be more proficient in detecting potentially hazardous events than the young-inexperienced drivers (Borowsky et al., 2010). An elderly group (65+ years old) has been reported to have less error in road test skills than the younger group (age 18-19 and age 25-35 years old) (Quaglino et al., 2008). The distraction of visual-manual impacts the drivers of all ages, whereas cognitive distractions have a more considerable impact on young drivers (Guo, Pleiss, Sun, & Weinberger, 2017). In contrast, others consider advancing age probably relates to a general decline of perceptual, behavioural, and cognitive abilities (Kosnik et al., 1988). Older drivers are more prone to fatal injury than other ages (Mizenko, Tefft, Arnold, & Grabowski, 2015).

Similarly, gender is one of the contributing factor in driving performance (Borowsky et al., 2010; Hills & Burg, 1977; Kosnik et al., 1988; Mortimer & Fell, 1989; Quaglino et al., 2008). Male has been consistently reported as a worse driver than female. Male drivers are more likely to have accidents than female drivers (Bener & Crundall, 2008; Subramanian & Najeeb, 2013). Males tend to express more aggressive and angry behaviour while driving than females (Bener & Crundall, 2008). Female drivers have a higher number of violations and lapses than male drivers (Bener & Crundall, 2008). However, in terms of understanding the risk of driving, both men and women have the same understanding to detect the risk, but women are much concerned about the risk (de Haan et al., 2014).

Driving is irrefutably a highly visual task. However, visual requirements for driving varies between countries (Bron et al., 2010; Decina & Staplin, 1993; Drasdo & Haggerty, 1981; Haliza, Syah, & Norliza, 2010; Huisingh, McGwin Gerald, Wood, & Owsley, 2015). There is slight variation in driver's license requirements in developed countries in terms of visual acuity, visual field, monocular vision, night vision, and chromatic vision (Bron et al., 2010). The legal age for driving in Malaysia is 18 years old and above. Vision screening is mandatory before a drivers' license can be issued. According to the Malaysian Society of Ophthalmology, the visual requirements for a driver's license in Malaysia for a private vehicle or personal license are the driver should have visual acuity better than 6/12 at least in one eye and a pass in the Ishihara test (Haliza et al., 2010). There is no visual field recommendation for Malaysian drivers. Largely, developed countries advocate for a normal binocular visual field that extends at least 120° along the horizontal meridian and 20-30° above and below the horizontal midline (Bron et al., 2010).

The purpose of this scoping review is to provide an overview of the breadth of literature; and identify gaps in vision and driving research. We aim to capture the types, and extents of the internal and external vision-related factors that linked to driving performance.

## 2. REVIEW METHODS

A methodical literature search was conducted on vision and driving. Boolean operator, truncation, and phrase searching were the search techniques employed to trace articles in the database of MEDLINE, Science Direct, Web of Science, PubMed, EBSCO Host Journals, Google Scholar, Research Gate and Sage Journal. Inclusion criteria: full paper in English languages, used either driving simulator or naturalistic driving, year of publication between 1990 and 2020. Exclusion criteria: non-English articles, case reports, letters to editors, executive summary, government report, policy brief, abstract only. The flow of the review process is summarised in Figure 1.

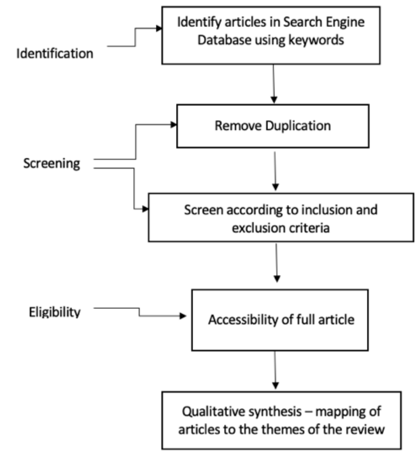


Figure 1. Flow chart of the review process

## 3. VISION-RELATED INTRINSIC FACTORS IN DRIVING

### 3.1. Visibility and Driving

Visibility is vital during driving to allow the driver to perceive and assess risk to avoid collision with other traffics (McGwin, Chapman, & Owsley, 2000; McGwin et al., 2004; Owsley & McGwin, 2010). Visual acuity, contrast sensitivity, and glare issues have been shown in the literature to be related to adverse effects in driving.

Poor visibility becomes a hindrance as driving requires timely detection of critical events and relevant changes in traffic circumstances. Visual acuity and contrast sensitivity are two common parameters used in assessing the visibility of drivers. Visual acuity is the ability of the eye to discriminate the details of the objects at a given distance (Marsden, Stevens, & Ebri, 2014). Road signage and information are designed to read with 6/12 or better visual acuity (Johnson & Wilkinson, 2010). Contrast sensitivity is defined as the ability of the eye to distinguish an object from its background. It measures how much a pattern must vary in contrast to being seen, and it has different functions than visual acuity. Visual acuity only reveals the size of high contrast black and white letters that can be seen by an individual, while contrast sensitivity is the capacity to discriminate between similar shades (Lohmann & Neubauer, 2018). Contrast sensitivity is a better predictor of response time and deceleration than visual acuity (Swan, Shahin, Albert, Herrmann, & Bowers, 2019). Contrast sensitivity can be reduced by eye diseases such as cataracts, glaucoma, and macular degeneration. Driving safety can be compromised in drivers with reduced contrast sensitivity (Freeman, Muñoz, Turano, & West, 2005). Driver with reduced contrast sensitivity in both eyes has been reported to be six times more likely to have a history of a car crash

 

(Owsley, Stalvey, Wells, Sloane, & McGwin, 2001).

Optical blur due to uncorrected or under-corrected refractive error is the leading cause of reversible impairment (Bourne, Dineen, Huq, Ali, & Johnson, 2004; Lamoureux et al., 2009). Many individuals drive with uncorrected refractive error. Driving measures such as sign recognition and distance, hazards recognition and avoidance, hazards recognition distance, and driving time has significant effects when induced blur lens was introduced (Chu, Wood, & Collins, 2009, 2010; Higgins, Wood, & Tait, 1998; Owens & Tyrrell, 1999; J. M. Wood et al., 2014). Uncorrected myopia affects overall driving measures as low as +0.50DS. Driving performance downgrades with increasing blur severity. Uncorrected refractive error reduces the distance to recognize road signs and increases driving time. However, the lane-keeping and gap judgment have minor effects when the lens is introduced before the eyes while performing the driving task.

Astigmatism is when light cannot focus on the retina due to the scattered light and cannot be fully corrected by a spherical lens. It has been linked to glare issues among drivers, especially during night driving (Wolffsohn, Bhogal, & Shah, 2011). Vision clarity lessens as the uncorrected astigmatism power increases (Wolffsohn et al., 2011). A low amount of uncorrected astigmatism can reduce visual acuity and further reduce the ability to perform low-contrast tasks. Correction with toric lenses has improved night driving performance such as sign recognition, hazards avoidance and pedestrian detection (Black, Wood, Colorado, & Collins, 2019). Detection and recognition of objects during driving can be affected by over or under correct the refractive error (Chen AH, Shah SSM, & Rosli SA, 2013).

Glare is visual perception caused by extreme and uncontrolled brightness and is often considered as disabling or simply uncomfortable (Davoudian, Raynham, & Barrett, 2014; Theeuwes, Alferdinck, & Perel, 2002). Glare increases when the source luminance increases, the background luminance decreases, and the angle between the line of sight and the direction of the light source decreases. When the glare increases, the ability of the eye to perceive slight contrast is reduced. This reduction may affect the variety of visual tasks performed in traffic, such as critical objects detection, headways control, signs reading, and critical encounters evaluation. Discomfort glare is a subjective feeling of annoyance caused by the blinding light in the field of view. The increased reflection and light scattering can cause disability glare (Aslam, Haider, & Murray, 2007; Davoudian et al., 2014). The disability glare, along with high-order aberration and diffraction, leads to distorted retinal image and attribute to impaired visual function (Aslam et al., 2007; Davoudian et al., 2014). Disability glare can be caused by eye diseases too (Asbell et al., 2005). Drivers with cataracts usually have a lot of issues with glare because the incoming light is scattered. Simulated cataract has been linked to reduced ability to recognize road signs, avoid road hazards, and detect and anticipate traffic hazards compared to normal vision (Marrington, Horswill, & Wood, 2008; J. M. Wood et al., 2014). Simulated cataracts also took longer to complete the driving course than subjects with normal visual status (J. M. Wood, 2002). Sign detection and time taken to drive is longer with cataracts and optical blur (Higgins et al., 1998; Owens & Tyrrell, 1999; Owens, Wood, & Owens, 2007; J. Wood, Chaparro, Carberry, & Chu, 2010; J. Wood, Chaparro, & Hickson, 2009; J. M. Wood et al., 2012). Not only elderly drivers with visual impairment reported difficulties performing night driving and glare, and those with healthy eyes (McGregor & Chaparro, 2005). The visibility of an object can be altered in many ways and often depends on the contrast luminance caused by reflection, shadows, the colour of the object, and the reflection inflicted by the colour. Fatal accidents often occurred on undivided rural roads in dark conditions without proper illumination (Abdel-Aty, Ekram, Huang, & Choi, 2011; Owens & Tyrrell, 1999; Owens et al., 2007).

The natural ageing process or any medical conditions can lead to vision-related problems that may affect driving (Kosnik et al., 1988; McGregor & Chaparro, 2005; Owsley & McGwin, 2010; Owsley et al., 2002, 2001). Older drivers are estimated to have an increment in crash rate per mile driven compared with other age groups (Owsley & McGwin, 2010; Owsley et al., 2002, 2001). It is difficult for older drivers to view a dimly lit dashboard, read street signs, and estimate vehicle speed and the unexpected appearance of vehicles that pass them. Slower reaction times or poor vision are common problems among elderly drivers (Kosnik et al., 1988). Most elderly drivers have trouble in static and dynamic acuity, illumination, contrast and peripheral vision (McGregor & Chaparro, 2005). Debate continues about the best strategies for the optical management of old drivers. There has been disagreement on spectacle versus contact lens correction for drivers with presbyopia. Contact lens wearers with presbyopia have reported to experience more difficulties in night-time than daytime driving (Black et al., 2019). Spectacle correction has been claimed to have better performance than contact lens correction (Chu et al., 2009, 2010). A multifocal contact lens was stated to negatively impact driving performance (Chu et al., 2009, 2010). Most drivers in Nigeria tended not to wear any optical correction as they believed that it created more problems to the eyes that affected driving (Odugbo, Wade, Velle, & Kyari, 2012).

Negative impact of visibility on driving performance is undeniable. Visual attention and alertness can be affected by low visibility too (Gabel et al. 2020). Visual attention and alertness towards driving environment are essential elements for safe driving (Gabel et al. 2020; Atreya, Shrestha, Budhathoki, & Nepal, 2021; Poudel, Dhungana, & Dahal, 2021; Yan, Chen, Wang, Zhang, & Zhao, 2021).

Nevertheless, regular eye check-up is essential to enhance safe driving among drivers. Appropriate optical correction is imperative (Black et al., 2019; Chu et al., 2009, 2010; Odugbo et al., 2012). Both scientific and driver licensing communities agree upon establishing a vision requirement for safe driving (Charman, 1997; Owsley & McGwin, 2010). The safety margins adopted reflect the amount of time drivers interact with other road users and the environment (Hulst, Zwart, Hop, & Joosten, 2010).

### 3.2. Visual Field and Driving

The visual field enables the drivers to see the road at the corner of their eyes and see the wider area without moving the eyes or even the head. Visual field plays crucial role in a complex and challenging task where the drivers need to use their peripheral vision to keep their lane position, avoid obstacles, and pass through intersections (Huisingh, Jr, Wood, & Owsley, 2015). A good visual field can maneuverer hazardous reactions to avoid any road accidents that could lead to death (Huisingh, Jr, et al., 2015).

Road accident has been reported to happen in unilateral amblyopic adults (Baker, Drews-Botsch, Pfeiffer, & Curry, 2019). Drivers with binocular vision read road signs with an average of 13% (5.6 meters) and 12% (3 meters) farther than the drivers with monocular vision during day and night, respectively (Hilburn, 1991). However, clearance judgement and lane-keeping remain intact (Hilburn, 1991; McKnight, Shinar, & Hilburn, 1991). The effect of monocular vision on driving performance is more apparent under racing conditions because racing requires very high speeds and fast reaction time (Adrian et al., 2019). A racing driver with simulated monocular vision managed to complete an entire season but failed to see and react to a penalty flag waved on his normally sighted left side during the seven laps (Adrian et al., 2019). The monocular visual fields of an ordinary human observer can extend to approximately 50 degrees superiorly, 70 degrees inferiorly, 60 degrees nasally, and 100 degrees temporally (Spector, 1990).

Visual field defects affect the driving performance (Bowers, Bronstad, Spano, Goldstein, & Peli, 2019; Bowers, Mandel, Goldstein, & Peli, 2009; Bronstad, Albu, Bowers, Goldstein, & Peli, 2015; Coechelbergh, Brouwer, Cornelissen, Van Wolffelaar, & Kooijman, 2002; Coeckelbergh, Brouwer, Cornelissen, & Kooijman, 2004; de Haan et al., 2014; Dow, 2011; Glen, Smith, & Crabb, 2015; Glen, Smith, Jones, & Crabb, 2016; Racette & Casson, 2005; Sengupta et al., 2014; Swan, Savage, Zhang, & Bowers, 2021; J. M. Wood et al., 2011; J. M. Wood & Troutbeck, 1992). Driving is more difficult for those with binocular visual field defects than monocular visual field defects (Patterson, 2021). Drivers with binocular visual field defects took a longer time to complete the driving task. The ability to search for the road signs and steer clear from obstacles weakens (J. M. Wood & Troutbeck, 1994). However, the monocular effects on the average distance to react, the velocity estimation and period for the steering tasks are trivial.

There are four common visual field defects types: central scotoma, homonymous hemianopia, bitemporal hemianopia, and altitudinal hemianopia (Kedar, Ghate, & Corbett, 2011). Drivers with central visual field defects face more difficulty than drivers with peripheral visual field defects in driving (Patterson, 2021). Drivers with central visual field defects drive slower than drivers with peripheral visual field defects (Coeckelbergh et al., 2004). The slow reaction can be due to the foveal perception in detecting the velocity change of the car. Drivers with central visual field defects have a low passing rate than drivers with peripheral visual field defects (Coeckelbergh et al., 2004). Braking reaction, manoeuvring performance and hazards perception are affected (Coeckelbergh et al., 2004). Full or partial scotoma located laterally slow down reaction to approaching hazards (Bronstad et al., 2015). Drivers with superior visual field defects have worse performance in detecting hazards than inferior visual field defects (Glen et al., 2015, 2016). Most of the hazardous events are more likely to occur at the superior region of the visual field coincide with the vehicle's windscreen. The inferior visual field coincides with the vehicle's controlling system. Localized vision field defects on the left hemifield and diffused vision field defects on the right hemifield have been reported to affect driving performance (Racette & Casson, 2005). The ability to locate pedestrians on the street worsens in the defective range compared to the normal region for drivers with homonymous hemianopia defects (Alberti, Peli, & Bowers, 2014; Bowers et al., 2019, 2009; de Haan et al., 2014).

The impact of visual field defects locations on driving performance remains debatable. Not every visual field defect can be hazardous to driving because some drivers can adapt and learn to compensate (Bowers et al., 2019, 2009; Dow, 2011). Wood and associates believed that drivers with homonymous hemianopia defects are fit to drive as numerous head movements compensated it (J. M. Wood et al., 2011). The impact of scotoma that disturbs the central vision between right and left fixation on hazard detection showed no significant difference (Glen et al., 2015, 2016). The scanning skills of those with peripheral visual field defects improve as they tend to move their head to scan the surroundings while driving (Bowers et al., 2019, 2009).

### 3.3. Eye-Head-Body Movement and Driving

Previous research has established eye-head coordination in driving conditions (Guidetti et al., 2019; Talamonti, Kochhar, & Tijerina, 2014). Good coordination between the eye, head and body movements is highly associated with a driver's steering action negotiating a winding road (Gadotti, Hernandez, Manguson, Sanchez, & Cevallos, 2020). The head movement component of gaze is variable (Guidetti et al., 2019). The direction of gaze can be a mixture of fast saccadic eye movements and slow head movements but predictable (Guidetti et al., 2019). Although there are individual differences in head-eye correspondence while driving, head-rotation data may be a valuable analyst of glance position

(Talamonti et al., 2014). Drivers are more likely to keep their heads oriented towards the road while glancing (Victor, 2005). The role of eye movement in driving can be evident from the impact study of nystagmus on driving performance (Singh, James, & Yadav, 2016).

Stable gaze should be constantly maintained with brief interruptions to look at other objects of interest during driving (Singh et al., 2016; Stapel, Hassnaoui, & Happee, n.d.; Swan, Goldstein, et al., 2021; Swan, Savage, et al., 2021; J. M. Wood & Troutbeck, 1994). The number of fixations, the duration of fixations and the number of saccades increase progressively at the transition zone during driving (Wang, Liu, Xu, & Xia, 2019). Drivers tend to be more cautious at the transition zone, driving conservatively at a lower speed while decreasing their steering wheel angle and minimizing the vehicle's lateral deviation (Stapel, Hassnaoui, & Happee, n.d.; Swan, Goldstein, et al., 2021; J. M. Wood & Troutbeck, 1994).

Driving requires a continuous perception, decision, and action (Hollnagel, 2000). The frequency of body movements has been reported to reduce when a driver performs a mental arithmetic task due to cognitive distraction (Ferdinand & Menachemi, 2014; Shimozuma et al., 2006; Stéfan & Mathé, 2016; Zhang & Kumada, 2017). Personality and mental health affect driving style (Alavi et al., 2017; Bokare & Maurya, 2017). The riskiest character is the aggression-hostility trait (Gugerty, 1997). Human errors are responsible for 93% of traffic accidents. About 34% are due to operational deficiencies, and 12% are due to vehicle malfunctions. Eye movements, head movements and body movements can be associated with visual disorders, internal and external environment, personalities and behavioural fitness while driving vehicles.

## 4. VISION-RELATED EXTRINSIC FACTORS IN DRIVING

### 4.1. Road Signage

Signboards are either based on words or logical visual images to convey the message to users (Bazire & Tijus, 2009). The main objective of signs is to give directions and information (Garvey & Kuhn, 1999). They are placed at critical locations to help space navigation. Road signs are mainly aimed to provide a safer road environment to road users. Road signs are used to regulate traffic, warn road users, and provide helpful information (Garvey & Kuhn, 1999; Owsley & McGwin, 2010). To assist mobility, signs must be visible. Signs should be legible at an appropriate distance so that they can give advanced notice (Costa, Bonetti, Vignali, Lantieri, & Simone, 2018; Liu & Lu, 2013). Effective signage can lessen the superficial complication of an enclosure, thus improving wayfinding under wide-ranging and emergency circumstances (Lyu, Xie, Wu, Fu, & Deng, 2017).

In designing a sign, the main objective is to ensure users can view and understand the message (Arditi, Llc, & York, 2017; Rae, Latham, & Katsou, 2016). Information retrieval involves complex cognitive processes of decoding texts or symbols (Jufri, Buari, & Chen, 2015; Khalid, Buari, & Chen, 2016). Before engaging in any form of information processing, the eye must first identify and read the text. Appropriate lighting enables the text to be visible. At the same time, contrast is what makes it legible. Legibility is about the quality of being clear enough to read. Legibility of information and traffic signs and their respective maximum readable distances for an individual to see is correlated with visual acuity or the level of sharpness of an individual's vision. There are three main types of acuity: detection acuity, resolution acuity, and recognition acuity (Anderson, 2017). The ability to detect and discriminate the presence of the words or visual images against a background on the sign can be easily estimated using detection acuity and resolution acuity. Recognition acuity required additional cognitive input to recognize and identify the target on the sign. Acuity is needed to discriminate the signs to change their behaviour accordingly (Owsley & McGwin, 2010).

Electronic-message signs are supplementary to the existing conventional road signs on roadways to give road users information, such as traffic conditions, accidents, roadwork zones, speed limits, guide vehicles to take alternative routes on specific road segments. Legibility of the electronic-message signs is essential to convey the message effectively to road users. Detection and recognition ability is the main factor in making the information visible, which involved a complex series of sequentially occurring events, both mental and physical (O'Hara, Higgins, & Kramer, 2000). To recognize the objects, parafoveal and peripheral vision are also used instead of the macula (Henderson, Pollatsek, & Rayner, 1987). Better legibility has been associated with increased contrast (Tinker & Paterson, 1931). Reading rate was faster for black-on-white text than any other colour combination (Tinker & Paterson, 1931). Reading speed is reduced by a factor of two when text contrast reduces from 100% to 10% (Legge, Parish, Luebker, & Wurm, 1990). High contrast between the text and its associated background is vital for efficient reading. Positive text-background polarity has been associated with efficient information retrieval due to high display luminance (Buchner, Mayr, & Brandt, 2009). Insufficient lighting is likely to cause visual discomfort and compromised legibility (Boyce & Wilkins, 2018). Visual or ocular discomfort has been linked to spatial structure and perceived naturalness (Jaiswal et al., 2019; Yoshimoto, Jiang, Takeuchi, Wilkins, & Webster, 2020). Inappropriate background luminance triggers discomfort or disability glare (Duchnicky & Kolers, 1983). Adaptive luminance contrast has been indicated after prolonged exposure (Na & Suk, 2014).

### 4.2. Road Conditions

Road conditions have a considerable impact on driving performances that lead to the predispose of car crash fatalities.

Crashes are more prominent on two-lane rural roads, high-speed roads, undivided roads, and roads with no sidewalks (Abdel-Aty et al., 2011; Abdel-Aty & Wang, 2017). Consistency reduces variation and increases familiarity among road users, facilitating smooth traffic movement to ensure a safe road environment. Uniformity in road design can be achieved by adhering to road standards, providing consistency of standards and improving road safety.

The width allocated to lanes for cars, motorcycles, buses, and lorries is crucial for road design (Asgarzadeh, Verma, Mekary, Courtney, & Christiani, 2016). Lane width provides space to serve all traffic and pedestrian needs, including travel lanes, safety stops, bike lanes, and sidewalks (Dixon, Hummer, & Lorscheider, 1996). Wider lanes are preferred to generate a buffer for drivers, especially in high-speed environments where narrow lanes may increase the chances for side-swipe collisions (Dumbaugh & Gattis, 2005). The relationship between lane widths and road safety is complicated as it involves many factors, including times of day, the volume of traffic, and even the driver's age. These factors contribute to local and global economies and societies, especially in the modern sustainability of urban road transport (Rahman, Armson, & Ennos, 2014).

Streetlights play a crucial role in road safety, especially in transition areas. The primary purpose of installing a streetlight is to increase the visual range afforded by vehicle headlamps while driving at night (Bullough, Renko, & Myatt, 2014). Safety is enhanced through visibility improvements among road users (Bullough et al., 2014). The streetlight positioning should be strategized to not visually mislead drivers regarding the route ahead. However, inappropriate streetlight installation might introduce unnecessary glare and aggravate the glare from oncoming vehicles (Chen, Rosli, & Muhamad, 2020).

Weather can compromise the road condition and security (Wanvik, 2009). Rainy weather resulted in more crash rates than sunny conditions (Andrey & Yagar, 1993). The risk of road crash surges by 12% in hazardous conditions (heavy rain, thick fog, dust storm, and foggy snow conditions on low illumination roads).

### 4.3. Time of the Day

Light sensitivity is one of the setbacks during daytime driving. Tinted lenses are usually used to protect the eyes from sunlight. Tinted lenses can absorb, transmit or reflect excessive light and enhance vision comfort by reducing glare. However, the unequal luminous transmission of a pair of lenses might create a Pulfrich effect, possibly making driving hazardous (Dain, 2003). Wearing tinted lenses give rise to a reduced ambient light effect; consequently, pupil size enlarges. Larger pupil size increases the degree of aberration and reduces contrast sensitivity (Karatepe, Köse, & Eğrilmez, 2017). Various tints and densities affect spatial frequencies differently (Shaik et al., 2013). At low spatial frequencies, the darker tinted lens reduces glare and improves contrast. Lighter tints allow for better contrast sensitivity function at high spatial frequencies. The more the lens absorbs light, the lesser the light is transmitted through it. Visual perception is crucial in understanding the environment using light in the visible spectrum (Wagemans et al., 2012). Adaptive luminance contrast in enhancing usage performance and visual comfort on smartphone displays has been reported (Na & Suk, 2014). Tinted windshields can be hazardous due to similar contrast reduction (Allen, 1966). Lower light condition can affect alertness of the drivers (Gabel, Miglis, & Zeitzer, 2020).

Night-time driving poses a lot of risks compared to daytime driving. Crash risk is more significant for night-time than other times of day. Poor visibility is the leading cause of fatalities occur at night due to driver's misjudgement of the limitation of their vision. Sleepiness during night driving is one of the contributing factors to a night-time traffic accident. The level of drowsiness is higher during the night drive based on the response achieved using the Karolinska Sleepiness Scale for every 5 min while the participants were driving (Lowden, Anund, Kecklund, Peters, & Åkerstedt, 2009).

In night conditions, glare produced by vehicles impairs the visual performance, affecting drivers in seeing and detecting the road sign (Bullough et al., 2014). Glare is a discomfort sensation and central vision depressed in the eyes due to a bright light entering the visual pathway (Saunders, 2012). It can be direct glare, which means it falls right onto the fovea or indirect, which the light falls onto outside the fovea in the retina. Most of the glare encounter at night during driving comes from the opposite vehicle headlamps. High-intensity discharge lamps (HID lamps) are a type of electrical gas-discharge lamp. HID headlamps give more advantages than traditional headlamps (Sivak, Flannagan, Schoettle, & Adachi, 2003). It is widely known that the HID headlamps produce more light and have a longer life than conventional halogen headlamps (Sivak et al., 2003). The lights projected by the HID headlamps are much farther down the roads than traditional halogen headlamps. Thus, it provides a wider peripheral illumination for the drivers. This speciality improves driver's safety as it increases their time to react to potential harms (Mainster & Timberlake, 2003). This is the fact that the luminous power produced by HID headlamps are two to three times greater than halogen bulbs (Mainster & Timberlake, 2003). A bluer appearance of light reflects higher colour temperature sources of that particular light. The colour temperature of halogen bulbs, Xenon HID and ordinary sunlight are 3200°K, 4200°K and 5600°K, respectively (Mainster & Timberlake, 2003). Thus, it shows that although HID bulbs are not as blue as the ordinary sunlight, it is bluer and brighter than halogen bulbs. Mesopic condition is the condition between photopic and scotopic (Eloholma, Ketomäki, Orreveteläinen, & Halonen, 2006). In night driving, several light sources are present in the road traffic, and these lights (road lighting, emergency lighting and vehicle lights, etc.) contribute to the mesopic condition. Visibility has a detrimental effect during night-time driving performances due to low luminance condition that makes it difficult for the driver to see the direction of the road (Bella Francesco, Ben-bassat, & Shinar, 2013; Belle Francesco & Calvi, 2013).

## 5. CONCLUSION

Driving is a highly visual task. Understanding the vision-related intrinsic and extrinsic factors in driving is essential. The intrinsic factors mostly encompass age, gender, visibility, visual field and movement patterns of drivers. The extrinsic factors predominantly cover road signage, road conditions and time of the day.

The visibility of drivers can be affected by visual acuity, contrast sensitivity, illumination and glare issues. Reduced acuity and contrast can affect the behaviour and performance of a driver in recognizing road signs, detecting road hazards, maintaining lane keeping and braking time needed when hazards appear. Contrast sensitivity is believed to be a better predictor of driving performance compared to visual acuity. Uncorrected refractive error reduces the distance to recognize road signs and increases driving time. Driving performance downgrades with increasing blur severity. Optical correction can improve certain aspects of visual performance, but it also might negatively affect visual function for driving ability, mobility, and safety. Glare is a significant problem for older drivers, but it may also be experienced by young drivers, especially in detecting roadside pedestrians. Weather conditions have noticeable impacts on roadway traffic operations, especially traffic safety. Eye, head, and body movements are closely linked to driving behaviours, personality and cognition. Visual distraction impacted drivers of all ages, whereas cognitive distraction has a more noticeable impact on young drivers.

Binocular visual field defects have more severe impacts on driving performance. Homonymous hemianopia is considered not safe for driving due to insufficient detection of the blind zone. There is a relative lack of evidence-based literature describing the impact of altitudinal visual field defects and scotoma. Central visual field defect displays more difficulty in driving performance compared to peripheral visual field defects. However, experienced drivers who suffered from visual field defects somehow adapt and compensate for their visual field loss in driving. Drivers with central visual field defects adapt with slower velocity in driving. Drivers with peripheral visual field defects develop skills in scanning behaviour while driving.

The legibility of the road sign is essential to provide a safer road environment for road users. The road signs should be legible sufficiently far away to give advanced notice to the road user. Appropriate spacing and positioning of lanes and streetlights are crucial for safe daytime and night-time driving. Night-time driving performance decrease in older drivers compared to young drivers.

Future research direction concerning vision and driving can benefit from multidisciplinary approach and move towards translational exploration. Comprehensive eye examination can be included as a pre-requisite for driving test registration. A self-administered questionnaire on driving-related ocular signs and symptoms can be added as a screening filter in renewing driving licenses. All eye care practitioners can take a proactive approach to advise their clients against driving if detect any ocular condition that is an immediate risk to other road users.

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