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**Impact of Central Vision Loss on Eye Movements and Time-to-Contact
Judgments**

by

Melissa Cloutier

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UNDER REVIEW, THESIS COMMITTEE

Patricia R. DeLucia, Chair
Professor of Psychological Sciences,
Associate Dean for Research, School of
Social Sciences

Philip Kortum
Professor of Psychological Sciences

Michael D. Byrne
Professor of Psychological Sciences

HOUSTON, TEXAS
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ABSTRACT

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Background: Time-to-contact (TTC) judgments can be influenced by eye movements as well as by multisensory stimuli (i.e., presenting a stimulus that has both an auditory and visual component). To date, no study has investigated the interaction between eye movements and unimodal (visual-only) versus multimodal (audiovisual) presentation on TTC estimates. Further, eye movements differ between individuals with normal vision and individuals with central vision loss during navigation tasks. However, no study has investigated eye movement differences between individuals with normal vision and individuals with central vision loss in a TTC task. The current study investigated (1) if eye movements differed between unimodal and multimodal presentations and if that difference influenced TTC estimates, and (2) whether eye movements differed between individuals with central vision loss and individuals with normal vision.

Method: Individuals with normal vision and individuals with central vision loss completed a TTC estimation task in an immersive virtual reality environment. Participants were asked to indicate when they believed the approaching object would reach them, after the object had disappeared in both unimodal and multimodal conditions. Saccade amplitude, saccade duration, and fixation duration were recorded in all trials.

Results: Results showed that saccadic eye movements predict TTC estimates in the unimodal condition but not in the multimodal condition. Further, for both vision groups (central vision loss and normal vision) in the unimodal condition, TTC estimates increased as saccadic eye movement (i.e., saccade amplitude and saccade fixation) increased. However, there was a greater increase in the central vision loss group compared to the control group. Neither group exhibited an effect of saccadic eye movements on TTC estimates in the multimodal condition.

Conclusion: Results suggest that eye movements do not predict TTC estimates in a multimodal condition for both the central vision loss and normal vision groups. Future research should investigate why the addition of an auditory stimulus removed the effect of saccadic eye movements on TTC estimates.

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Introduction

Judgments of collisions play a critical role in daily life as people routinely move through their environment while avoiding obstacles. This is especially true in traffic environments, where drivers, pedestrians, and cyclists must judge whether and when a collision would occur with a moving vehicle so that they can take evasive action and avoid injuries (DeLucia, 2015). Therefore, it is important to identify factors that influence such judgments.

Overview of Research Goals

The manner in which information (auditory vs. visual) about a moving vehicle is presented to a driver may influence collision judgments. For example, prior studies showed that presenting information about a moving object in both the visual and auditory modalities led to better judgments of when a collision would occur compared to presenting information in only the visual modality (Keshavarz et al., 2017). Prior research also demonstrated that eye movements can affect the accuracy of collision judgments. For example, individuals who tracked a moving object with their eyes provided more accurate judgments of collision than individuals who only fixated on the arrival location of the object (Bennett et al., 2010). However, those studies presented information in only the visual modality. Moreover, prior studies have not investigated whether eye movements are altered when an auditory stimulus is added or whether such altered eye movements impact judgments of collisions. The first aim of this thesis was to determine whether eye movements differ between unimodal (visual) and multimodal (audiovisual) presentations, and whether such differences affect collision judgments.

Another factor that can affect both eye movements and judgments of collisions is a visual impairment which is the basis for the second aim of this study. Visual impairments can alter the accuracy of judgments of collision, which has implications for safe mobility in traffic environments. Furthermore, eye movements in street crossing tasks differ between individuals with central vision loss and individuals with normal vision; individuals with central vision loss looked less at the moving vehicle compared to individuals with normal vision (Geruschat et al., 2006). Indeed, individuals with central vision loss displayed more dangerous behavior when crossing a street than individuals with normal vision (Geruschat et al., 2011). It is not known whether this is due to different eye movement patterns. Specifically, there is a lack of research investigating eye movement patterns when participants with central vision loss view an approaching object. The second aim of this thesis was two-fold. The first goal was to investigate differences in eye movement patterns between individuals with central vision loss and individuals with normal vision in a judgment of collision task. The second goal was to determine if eye movements influenced judgments of collisions differently for individuals with central vision loss and individuals with normal vision.

Time-to-Contact Judgments

One critical component of collision judgments is time-to-contact (TTC). TTC involves estimating the arrival time of a moving object at a certain location within the environment (Baurès et al., 2021). TTC can also be used to determine when an object would collide with one's self. TTC estimations can have important applications in traffic environments in which it is essential to accurately judge the arrival time of an

approaching vehicle so that a safe action can be completed such as crossing the street or making a left turn.

TTC estimations have been studied in the lab using both desktop computer simulations and virtual reality headsets (e.g., DeLucia et al., 2016). A common task used to study TTC estimations is the prediction-motion task (e.g., DeLucia et al., 2016). In this task, individuals must judge when a moving object would collide with a target or with themselves after the moving object has been removed from view. When an object approached the observer head-on, TTC was underestimated (Schiff & Oldak, 1990). Further, longer actual TTC resulted in greater underestimation of TTC than shorter actual TTC. TTC estimates can also be influenced by other factors, such as multimodal stimulus presentation.

Effect of Multisensory Integration on Time-to-Contact Judgments

Multisensory integration is the process by which an observer combines stimulus information from at least two different modalities, such as auditory and visual information. This type of stimulus is known as a multimodal stimulus. Previous research showed that a multimodal stimulus that presented both visual and auditory information about the stimulus improved detection of a visual target during a visual search task, compared to a unimodal visual stimulus (Berti, 2013; Giard & Peronnet, 1999; Mastroberardino et al., 2008; Schröger & Widmann, 1998; Stevenson & Wallace, 2013; Targher et al., 2012, 2017; Török et al., 2014). Participants were presented with a visual array consisting of eight LED lights and were asked to report whenever one of the lights was turned on. Detection was faster when the visual stimulus occurred concurrently with an auditory stimulus coming from the same location as the visual stimulus than when it

was presented alone (Targher et al., 2012). The implication for time-to-contact judgments is that adding an auditory stimulus that matches (e.g., a car engine sound added to the visual of a moving car) the visual stimulus may improve the detection of obstacles and, thus, the ability to avoid collisions while walking.

Indeed, presenting an auditory stimulus at the same time as a visual stimulus altered judgments of collisions (Chotsrisuparat et al., 2017). An auditory rhythm was generated from a sinusoidal sound wave presented at a frequency of 1500 Hz with a slow or fast tempo. When the auditory rhythm with a slow tempo was presented at the same time as the approaching visual stimulus, individuals underestimated the time-to-contact of the visual stimulus, meaning that the auditory stimulus influenced time-to-contact judgments of the visual stimulus (Chotsrisuparat et al., 2017). Even though auditory information can affect time-to-contact estimates, studies showing the effects of eye movements on time-to-contact estimates typically used a unimodal (visual) stimulus. It remains unclear what effect a multimodal stimulus (audiovisual) has on eye movements in a time-to-contact task.

Effect of Eye Movements on Time-to-Contact Judgments

The detection and pursuit of an object's motion is a necessary component of collision judgments and eye movements contribute to them. Eye movements are composed of two basic components: fixations and saccades (Purves et al., 2001). Fixational eye movements, or fixations, occur when the eyes of the observer are relatively unmoving while foveating (i.e., looking at) an object, both moving and stationary (Purves et al., 2001). One fixation typically lasts for 250 ms (Galley et al., 2015) and is always preceded and followed by saccades (Purves et al., 2001). Saccades

are ballistic eye movements with the typical goal of repositioning the eye to fixate a target, both moving and stationary (Barnes, 2011). When the observer's intentional tracking motions fail to accurately track a moving target, saccades bring the eyes back onto the moving target (Barnes, 2011). These are known as “catch-up” saccades. When observers conduct a task requiring pursuit eye movements, a relatively higher number of catch-up saccades would indicate more tracking failures and, greater difficulty with object tracking.

Specific eye movements have been shown to predict performance on visual-perception tasks. For example, longer saccade duration, measured as the length of time (in ms) between the start and end of a saccade, can represent greater difficulty with tracking a moving object as it takes longer for the eyes to refocus on it (Fooker et al., 2021). On the other hand, longer fixation durations, measured as the length of time (in ms) between the start and end of a fixation, are thought to represent better focus on an object because the eyes are foveating the stimulus (Krukowski et al., 2003). Saccade amplitude represents the distance traveled by the eyes during a saccadic eye movement (Fooker et al., 2021). Amplitude is measured by recording the location of the eyes at the start and end of a saccade and measuring the distance, in degrees, between the two points. Previous studies showed that the speed the eyes travel after a laterally moving object has been removed from view can predict accuracy of time-to-contact estimates (Bosco et al., 2015). However, no study has investigated the importance of saccade amplitude before an object is removed from view in a time-to-contact task (prediction-motion task).

Time-to-contact judgments were more accurate when eye movements were unconstrained than when eye movements were restricted, indicating that eye movements

can play an essential role in judgments of collisions (Bennett et al., 2010). In the same study, the accuracy of time-to-contact estimations depended on the ability to make effective pursuit eye movements. Participants completed a prediction motion task while they either fixated the arrival location of the moving object or in separate trials tracked the object with their eyes. Participants responded when they believed the moving object would reach the arrival location. Tracking the moving object so that it remained on the fovea resulted in more accurate time-to-contact estimations than when fixating the arrival location of the moving object which made the object fall in peripheral vision (Bennett et al., 2010). This suggests that eye movements, such as pursuit, can influence TTC estimations accuracy and thus have implications for individuals with atypical eye movement patterns, such as patients with visual impairment due to age-related macular degeneration (Verghese et al., 2021).

Effects of Age-Related Macular Degeneration on Time-to-Contact Judgments

Age-related macular degeneration is a condition affecting the macula within the retina of the eyes, leading to loss of central vision (Cleveland Clinic, 2022). This condition is the leading cause of permanent vision loss in older adults in the United States, affecting 11 million individuals (Center for Disease Control, 2020; Tielsch et al., 1990). To compensate for loss of central vision, individuals with age-related macular degeneration often rely on peripheral vision to partake in tasks of daily living. Peripheral vision is associated with reduced visual acuity, making it challenging to notice fine details (Vater et al., 2017). Further, peripheral vision has been associated with reduced perception of approach motion, meaning that observers had greater difficulty detecting an approaching object's optical expansion in peripheral vision compared to central vision

(Regan & Vincent, 1995; Wann et al., 2011). That is, the expansion detection threshold was larger in peripheral vision; more expansion was needed before it was noticed (Wann et al., 2011). In practical terms, this suggests that the expansion is noticed later when the object is closer, and TTC could be overestimated; the object is perceived as arriving later than it actually would. This is especially important for individuals with central vision loss, such as those with age-related macular degeneration, as they may rely on peripheral vision when making time-to-contact judgments of approaching objects. The implication is that reduced visual acuity, difficulty seeing fine details, and difficulty detecting expansion due to approach motion can result in less safe decisions in traffic environments for individuals with age-related macular degeneration compared to individuals with normal vision (Taylor et al., 2016).

Indeed, visual impairments, such as age-related macular degeneration, are associated with reduced mobility and independence, increased isolation and increased risk of mental health diagnoses. Individuals with age-related macular degeneration are at higher risk of falls compared to those with normal vision and are more likely to make riskier street-crossing judgments (Hassan & Snyder, 2012; Wood et al., 2011). Further, age-related macular degeneration can lead to unsafe driving behavior and greater likelihood of failing an on-road driving assessment (Wood et al., 2022). As a result, most individuals with central vision loss make fewer trips outside the home and have increased social isolation (Avila, 2018; van Landingham et al., 2014). This, in turn, leads to higher rates of depression and anxiety (Brody et al., 2001).

Eye movements also are altered in central vision loss compared to normal vision. In general, age-related macular degeneration leads to difficulty fixating objects, requiring

more eye movements to view a scene compared to normal vision (Verghese et al., 2021). Physiologically, individuals with age-related macular degeneration may have a scotoma in their central vision, requiring them to use an alternate area of their vision as a surrogate fovea, known as the preferred retinal locus (Bernard & Chung, 2018; Crossland et al., 2011). It has been suggested that this area is the “locus for eye movements,” meaning that eye movements are centered around the preferred retinal locus instead of the fovea (Bernard & Chung, 2018). Although individuals with central vision loss use their preferred retinal locus as a surrogate fovea, this location may not be the one with the best visual acuity; other locations may have higher visual acuity but are unused (Bernard & Chung, 2018). It remains unclear why the location with the best acuity is not selected as the preferred retinal locus. As a result of visual impairments, individuals with central vision loss and those with normal vision displayed different eye movement patterns while performing detailed tasks such as reading, and mobility tasks such as navigation and street-crossing (Hassan & Snyder, 2012; Verghese et al., 2021).

Differences in eye movements between individuals with age-related macular degeneration and individuals with normal vision have been observed in mobility tasks. While navigating towards a specified target in a corridor, individuals with central vision loss looked frequently toward the intersections of the environment, such as where the wall meets the floor (Freedman et al., 2019). On the other hand, individuals with normal vision barely looked at the intersections; instead, they kept their gaze toward the anticipated location of the target (Freedman et al., 2019). In traffic environments, while trying to cross a street, individuals with central vision loss had different eye fixation patterns and reduced head movements compared to individuals with normal vision

(Geruschat et al., 2006; Hassan et al., 2005). Eye and head movements were recorded using portable eye and head trackers while individuals with macular degeneration and normal vision made street-crossing decisions in various traffic environments. These environments included 2-way intersections and 3-leg roundabouts. Measures included length of fixation, number of fixations, and number of head turns. Individuals with age-related macular degeneration spent longer fixating static elements essential to crossing the street, such as a pedestrian traffic signal, compared to individuals with normal vision, whose gaze tended to be on moving vehicles (Geruschat et al., 2006). Visually impaired individuals also failed to meet the number of safe head turns needed to cross a street established by the National Highway Traffic Safety Administration (Hassan et al., 2005). These results suggest that eye movement patterns of individuals with central vision loss influence their ability to safely navigate a traffic environment.

There is a dearth of research on eye movement patterns and time-to-contact estimates in individuals with central vision loss, including individuals with age-related macular degeneration. Studies typically focused on eye movement patterns during detailed visual tasks such as reading (Rubin & Feely, 2009; Seiple et al., 2005). Other studies showed that individuals with age-related macular degeneration may struggle to maintain a stable fixation on a static object (Bellmann et al., 2004; González et al., 2019; Kumar & Chung, 2014; Van Der Stigchel et al., 2013). Compared to individuals with normal vision, individuals with age-related macular degeneration had shorter fixation times and more short saccades (Bellmann et al., 2004; Kumar & Chung, 2014; Little et al., 2008; Tarita-Nistor et al., 2009; Verghese et al., 2021; Vullings et al., 2022). Further, when completing a visual search task, individuals with macular degeneration tended to

make a saccade back to the previously explored area, suggesting that they needed more viewing time to scan the entire scene (Verghese et al., 2021). Therefore, individuals with age-related macular degeneration had fixation and saccadic behavior that differed from individuals with normal vision.

Individuals with macular degeneration also differ in pursuit eye movements while tracking moving objects. They exhibited more saccades compared to individuals with normal vision, which suggests greater difficulty with keeping the target foveated (Little et al., 2008; Shanidze et al., 2022; Van Der Stigchel et al., 2013; Verghese et al., 2021; Vullings et al., 2022). These so-called catch-up saccades are used to keep a target on the fovea, compensating for deficiencies in maintaining fixation on the target (Shanidze et al., 2022). Indeed, during pursuit eye movements, not all saccades performed by individuals with macular degeneration were in the direction of the target; some were orthogonal to it (Shanidze et al., 2022). Pursuit eye movements are important when making judgments of collisions because individuals must visually track a moving object to accurately judge its time to contact (Bennett et al., 2010). However, previous studies of eye movements in individuals with age-related macular degeneration in traffic environments focused solely on where participants fixated and did not investigate factors that characterize eye movements, such as saccades and pursuit. Further, research investigating pursuit eye movements in individuals with age-related macular degeneration focused on laterally moving stimuli presented on a two-dimensional computer screen (Little et al., 2008; Shanidze et al., 2022) rather than approaching objects which are more relevant to collision avoidance. These two gaps were addressed in the current study.

Specific Aims of this Thesis

Previous research showed that tracking a moving object with the eyes led to more accurate TTC estimates than fixating the arrival location of the object; however, specific characteristics of the eye movements, such as saccades and fixations, were not investigated. Further, previous studies were conducted with unimodal, visual displays; it remains unclear how eye movements influence TTC estimates in an audiovisual condition. The first goal of this thesis was to determine whether adding an auditory stimulus would alter eye movements and lead to more accurate time-to-contact judgments.

Previous research also showed that individuals with age-related macular degeneration have different eye movement patterns than those with normal vision (González et al., 2019; Tarita-Nistor et al., 2009; Van Der Stigchel et al., 2013), have unstable fixation patterns in which they cannot maintain fixation on an object leading to both forward and retroactive saccades (i.e., eye moves back to the previously fixated position) (González et al., 2019); and rely on peripheral vision which is associated with higher detection thresholds for optical expansion which is essential for effective time-to-contact judgments (Bennett et al., 2010; Wann et al., 2011). The implication is that eye movement patterns in individuals with age-related macular degeneration contribute to less effective collision judgments. The second aim of the present thesis was to identify differences in eye movement patterns between individuals with age-related macular degeneration and individuals with normal vision while they performed time-to-contact judgments in a traffic environment. Results potentially will provide new avenues for visual rehabilitation, help increase mobility and independence in individuals with age-

related macular degeneration, and advance our understanding of eye movements and theories of collision perception.

Aim One

The first aim was to determine how multimodal stimuli influence eye movements in judgments of collisions. Are eye movements, such as duration of saccades and duration of fixations, more stable (i.e., increased duration of saccades or lower fixation duration) when an auditory stimulus is presented concurrently with a visual stimulus compared to a visual stimulus being presented alone? Based on prior research I assume that auditory stimuli could stabilize eye movements by focusing the eyes on the perceived location of the auditory stimulus (Bellman et al., 2004). Therefore, as a result of the multisensory integration process, I predicted that multimodal presentation would lead to more stable eye movements, characterized by longer fixations and fewer saccades and more accurate perception of time-to-contact, compared to unimodal presentation.

Aim Two

The second aim was to determine how eye movements differ between people with age-related macular degeneration and normal vision and whether this was associated with differences in the accuracy of time-to-contact judgments. Related questions include Which specific factors within a traffic scene, such as vehicle speed, size or time-to-contact, influence eye movements? Do these factors differ between normal vision and central vision loss and are such differences associated with differences in judgment accuracy? Individuals with age-related macular degeneration have shorter fixations and more frequent short saccades than controls, and typically use regressive eye movements to fixate an area of a scene more than once, leading to an unstable eye movement pattern

when interacting with moving objects. Therefore, I expected to see similar unstable patterns of saccades and fixation when individuals with age-related macular degeneration used pursuit eye movements to track an approaching object, leading to less accurate judgments of collisions (i.e., time-to-contact judgments). I predicted that, due to unstable fixation patterns individuals with age-related macular degeneration would have shorter fixations and an increased number of saccades compared to individuals with normal vision and that this would influence their visual perception of moving objects, in particular, time-to-contact judgments.

Method

The apparatus and methods were established in a prior study. Specifically, the auditory and visual virtual reality simulations, tasks, and equipment described below have been developed and are currently being used in a separate project sponsored by the National Eye Institute (1R01RY30961-01). I used the same equipment and methods so that previously collected data on individuals with AMD could be used as a comparison group in this study.

Participants

Existing data from individuals with age-related macular degeneration, the central vision loss group ($N=15$, $M_{age}=79.1$, $SD_{age}=8.6$), were collected through a separate project as part of an NEI-sponsored grant. The control group (normal vision group) was recruited through the Rice University Undergraduate Research Pool ($N=21$, $M_{age}=19.7$, $SD_{age}=1.6$) and compensated with course credit. Due to time-intensive and expensive audiological and ophthalmological testing requirements for older adults, age-matched controls were not recruited. Consequently, one limitation of the current study is that any

observed differences may be due to differences in age between the groups. Both groups completed the same tasks using an audiovisual virtual reality system.

Inclusion and Exclusion Criteria

Participants in the normal vision group needed to meet the following criteria to be included:

- 18 years old or older
- Visual acuity of 20/25 or better in both eyes
- Normal color vision
- Normal hearing
- No history of cognitive or motor disorders
- No history of seizures

Participants in the central vision loss group needed to meet the following criteria to be included:

- Diagnosis of age-related macular degeneration in both eyes, as established by a board-certified ophthalmologist
- No other eye disorder that may affect their vision, as determined by an ophthalmologist
- No cognitive impairments, as measured by a score of 18 or more on the Montreal Cognitive Assessment for the Blind
- Normal color vision

Participants who had participated previously in the pilot study of this study were not permitted to participate. Individuals in the control group were included in the study

only if they had a visual acuity of 20/25 or better in both eyes as measured using a Snellen (far) and Landolt-C charts (near). All participants in this group had a visual acuity of 20/15-20/25 in the right eye and a visual acuity of 20/15-20/20 in the left eye. Participants who reported being color blind were excluded. Participants in the control group self-reported having normal hearing.

Participants in the central vision loss group had a visual acuity ranging from 20/20 to 20/640 (N= 3, 20% had a visual acuity of 20/60 or better) in the right eye and 20/20 to 20/250 (N = 4, 26.7% had a visual acuity of 20/60 or better) in the left eye. Participants also had normal to mild corrected hearing loss (i.e., hearing aids in both ears were permitted) as determined by an audiologist. Participants had hearing thresholds of less than or equal to 25dB HL at 1000Hz, considered as normal hearing, and 26-40db HL at 1000Hz, considered as mild hearing loss. Participants in the central vision loss group whose score on the Blind Montreal Cognitive Assessment test (t-MoCA) would indicate cognitive decline ($< 17/22$) were excluded. Both groups self-reported no neurological and no motor behavior disorders.

Materials

The experiment was conducted using a Dell Optiplex 7080 Tower XCTO desktop computer with 10-Core i9-10900K processor, 32GB of RAM; NVIDIA GeForce RTX 2070 Super graphics card, and Windows 10 Pro operating system. The scenes were displayed on a wired HTC VIVE Pro Eye Virtual Reality Headset. The VIVE Pro Eye headset uses a Dual OLED 3.5" diagonal screen with a resolution of 1440 x 1600 pixels per eye with a combined 2880 x 1600 pixel resolution, a refresh rate of 90 Hz, and a 110° field of view across both eyes. A Tobii eye tracker with 0.5-1.1 degrees of accuracy and

120Hz was integrated within the VIVE Pro Eye. Visual stimuli were created with Unity 2019.4.9f1 and projected to the HTC VIVE Pro Eye using Steam software.

Auditory stimuli were presented on 16 Genelec 4" 8000 Series speakers, mounted 104 cm above the ground, separated by equal distances in a circle with a 5-meter diameter. Auditory stimuli were rendered with the Toolbox for Acoustic Scene Creation and Rendering (TASCAR) on a Dell Optiplex 7080 Tower running Ubuntu Linux operating system. Speakers were connected to the computer using a Ferrofish Pulse 16 ADAT converter.

Eye movement recording and analysis were performed using iMotions 9.0 software. Before the start of the task, the eye tracker was calibrated through a 5-point calibration, and the interpupillary distance was adjusted via a setting on the HTC Vive Pro Eye headset. Eye movements were rendered in real time on the experimenter's monitor.

Simulations

Virtual scenes depicted a single, one-way road that was 3.65 meters wide, viewed from the perspective of a participant located 1 meter from the edge of the road. A vehicle approached the participant's location from the left side for 3 seconds before disappearing. The auditory simulation of this scene was created from recordings of tire and engine sounds from a real moving vehicle. TASCAR was used to adjust these sounds to reflect the parameters of the scenes (vehicle speed and distance from observer) to create a plausible auditory simulation of a vehicle moving through 3D space. The auditory

background environment included sounds of birds and other traffic. The visual background environment included buildings, sky, and grass.

Experimental manipulations included visual and auditory manipulations as well as their combinations. For the visual manipulations, the size of the vehicle was manipulated to be either a small car or a larger pick-up truck. The vehicle velocity was either 30 km/h or 50 km/h, and time-to-contact at the time of vehicle disappearance was either 1.5 seconds, 3.25 seconds, or 5 seconds. The auditory manipulations included the same vehicle velocity levels and time-to-contact levels as the visual manipulations. The sound intensity of the vehicle was manipulated to be either 2.5 dB or 17.5 dB. Audiovisual trials presented matching auditory and visual velocity and time-to-contact; however, sound intensity was fully crossed with vehicle size, meaning that a small car had both a soft and loud sound. Pairing a small vehicle with a loud sound (or a large vehicle with a soft sound) made it possible to determine if participants used the vehicle size or the sound intensity as a cue in their TTC estimates.

In order to decouple visual and auditory simulations in the audiovisual condition, “jitter” was added to the vehicle’s time-to-contact and velocity variables. In addition to the three specified time-to-contact levels, each level had two additional jitter levels corresponding to slightly faster and slightly slower time-to-contact and velocity (see Table 1 and Table 2) presented in separate scenes. This approach allowed for a psychophysical reverse correlation analysis in order to determine how changes in auditory stimuli influence behavior (Okazawa et al., 2018). This analysis falls outside the scope of this thesis; however, this methodology was employed to replicate the methods used with the central vision loss group in the NEI project. For example, the time-to-

contact level of 1.5 seconds had jitter levels of 1.125 seconds and 1.875 seconds, and the vehicle speed of 30 km/h had jitters of 20 km/h and 40 km/h. These experimental manipulations (time-to-contact and velocity) and its jitters led to 90 unique trials in the visual-only condition. In the audiovisual condition, the combination of the time-to-contact and jitters for the visual and auditory modality led to 9 different combinations (Refer to Table 3). The combination of velocity and its jitter in the audiovisual condition also led to 10 different combinations (Refer to Table 4). By crossing all the TTC combinations in Table 3 with the velocity combinations in Table 4, and the vehicle size and sound intensity, 360 audiovisual trials were obtained. By crossing the TTC combinations in Table 1 and the velocity combinations in Table 2, with vehicle size, 90 visual-only trials were obtained. Though the auditory-only condition was presented to all participants, it was not analyzed in this study as there was no visible vehicle within the HTC Vive Pro Eye headset for the user to track with their eyes.

Trials were presented in blocks of 90 trials; each block took participants approximately 10 minutes to complete. One block was Visual-Only, and four blocks were Vision Plus Auditory (“AudioVisual”).

Table 1

Time-to-Contact values and corresponding jitter levels (in seconds)

Time-to-Contact	Jitter Levels
1.5 Seconds	1.125 Seconds, 1.875 Seconds
3.25 Seconds	2.75 Seconds, 3.5 Seconds
5 Seconds	4.3 Seconds, 5.7 Seconds

Table 2*Velocity values and corresponding jitter levels (in km/h)*

Velocity	Jitter Levels
30 km/h	20 km/h, 40 km/h
50 km/h	60 km/h

Table 3*Time-to-Contact Visual and Auditory Pairings in Audiovisual trials (in seconds)*

Time-to-Contact: Visual	Time-to-Contact: Auditory
1.125 seconds	1.875 seconds
1.5 seconds	1.5 seconds
1.875 seconds	1.125 seconds
2.75 seconds	3.75 seconds
3.25 seconds	3.25 seconds
3.75 seconds	2.75 seconds
4.3 seconds	5.7 seconds
5 seconds	5 seconds
5.7 seconds	4.7 seconds

Table 4*Velocity Visual and Auditory Pairing in Audiovisual trials (in km/h)*

Velocity: Visual	Velocity: Auditory
20 km/h	30 km/h
30 km/h	20 km/h
30 km/h	30 km/h
30 km/h	40 km/h
40 km/h	30 km/h
40 km/h	50 km/h
50 km/h	40 km/h
50 km/h	50 km/h
50 km/h	60 km/h
60 km/h	50 km/h

Procedure

Signed informed consent was obtained from all participants at the start of the experiment. To ensure that control participants had normal vision, near and far visual acuity were measured using a Snellen chart and Landolt-C chart, respectively. To measure far visual acuity, participants stood 20 feet away from a Snellen Chart. Participants covered one eye and read aloud the smallest line they could see. This procedure was repeated for the second eye. To measure near visual acuity, participants completed the Landolt-C, one eye at a time, standing 60 cm away from the chart.

Individuals needed to successfully read line 20/25 or lower (20/20, 20/15) in both charts to be included in this study.

Following the visual assessment, participants completed a time-to-contact estimation (i.e., prediction motion) task while wearing the HTC VIVE Pro Eye headset. Participants were instructed to press the round controller button at the exact moment they believed the vehicle would reach them had the simulated movement continued after it disappeared. Once participants responded, they pressed the trigger button to start the subsequent trial. Eye movements were recorded during the task at a sampling rate of 120 Hz.

Three eye movement characteristics were measured: (1) saccade amplitude, which is the distance traveled by the eye during a saccade; (2) saccade duration, which is the length of time a saccade lasted; and (3) fixation duration, which is the length of time a fixation lasted, defined as a minimum of 200 ms. These variables were calculated for the duration the vehicle was visible for each trial completed by a participant. Four scene parameters were used as independent variables in the analyses: modality, time-to-contact of the vehicle, vehicle velocity, and vehicle size. Percentage estimates of time-to-contact were obtained by converting estimated time-to-contact to a percentage of actual time-to-contact, with 100 percent estimate representing perfect accuracy and above and below 100 percent representing overestimation and underestimation, respectively (Schiff & Oldak, 1990). This was necessary because errors in time-to-contact estimates are larger with larger actual values of time-to-contact; this measure scales the estimated time-to-contact to the actual time-to-contact.

Results

Results: Aim One

The first aim was to determine how eye movements and TTC estimates differed between the visual-only and audiovisual conditions. Only the control group was used for this aim (N= 21). Effects of modality on eye movements were analyzed in two ways. First, a linear mixed effect model was run to determine if eye movements predicted time-to-contact estimates. This model also determined interaction effects between eye movements and scene elements, such as modality, to predict time-to-contact estimates. Second, nine ANOVA models with eye movements as the outcome variables were run to determine if specific scene elements (e.g., velocity) predicted eye movement patterns. Together, the linear mixed effect and ANOVA models explain the role of eye movements in judgments of collisions.

Linear Mixed Effect Model

A linear mixed effect model was run to determine the influence of eye movement patterns (i.e., saccade amplitude, saccade duration, fixation duration) on percentage estimates of time-to-contact. Linear mixed-effect models allow for between-subject regression analysis when there is more than one observation per participant (Quené & Van den Bergh, 2004). As such, data that is both within and between subjects (i.e., mixed) can be analyzed using this model. This model was selected to examine the predictive power of eye movements on percentage estimates of time-to-contact, similar to the outcome of a linear regression model, while taking into account that the observations were not independent from one another. The linear mixed effect model reports the estimated slope (i.e., *B-value*) for each term (i.e., predictor) of the model as well as the

test of significance for each slope (t -test). The t -test determines if the estimated slope is significantly different from zero. Main effects of the three eye movement pattern variables (Saccade Amplitude, Saccade Duration, Fixation Duration) and all scene element variables (Actual Time-to-Contact, Velocity, Vehicle Size, Modality) were included, as well as all two-way interactions between eye movement pattern variables and scene elements variables. As this study aimed to investigate the impact of modality on eye movement and time-to-contact estimates, only the interactions between modality and eye movements were examined. For all other two-way interactions, refer to Appendix A. Table 5 shows all main effects and two-way interactions from the linear mixed effect model relevant to the aim of this study.

Table 5*Main effects and two-way interactions from the linear mixed effect model*

Main Effects and Interactions	Degrees of Freedom	Estimates (<i>B</i> value)
Saccade Amplitude	16,390	-0.25*
Fixation Duration	16,390	-6.27E-3
Saccade Duration	16,390	0.04*
Modality	16,390	8.37*
Vehicle Size	16,390	-2.24
Velocity	16,390	15.20*
Actual TTC	16,390	-23.49*
Saccade Amplitude by Modality	16,390	.22*
Fixation Duration by Modality	16,390	1.32E-03
Saccade Duration by Modality	16,390	-0.06*

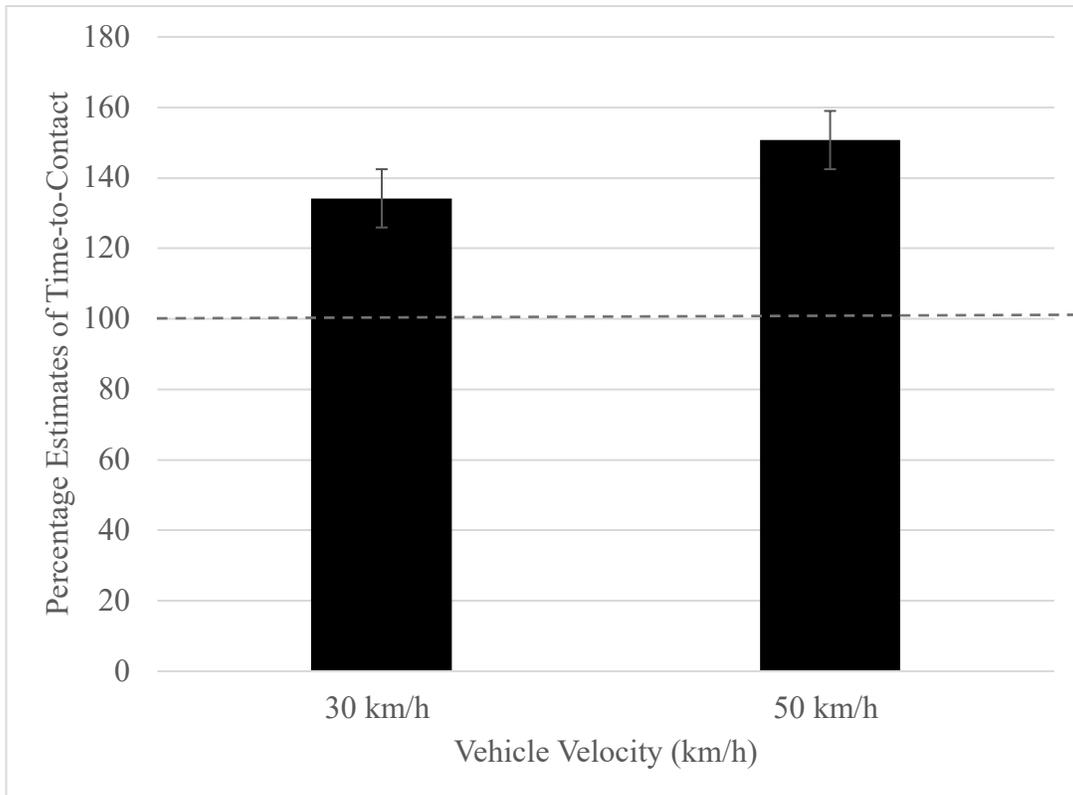
Note. * denotes a significant value of $p < .05$. *B*-value estimates represent the slopes

Previous research has shown that actual TTC, vehicle velocity and vehicle size can influence time-to-contact estimates (DeLucia, 2015). As such, the main effects of the aforementioned variables were investigated to determine if results match what is expected based on the literature. There was a significant main effect of **velocity**, $B = 15.20$, $t(16,390) = 7.49$, $p < .001$, 95% *CI* [11.10, 19.00]. Mean estimates of time-to-contact were more accurate when the vehicle traveled slower (i.e., 30 km/h) than when it traveled faster (i.e., 50 km/h) (see Figure 1). Participants had greater overestimation of time-to-contact when the vehicle traveled faster than when the vehicle traveled slower.

This finding is consistent with previous literature showing an effect of velocity on time-to-contact estimates (Schiff & Oldak, 1990).

Figure 1

Main Effect of Vehicle Velocity on Estimated Time-to-Contact



Note. The dashed line represents perfect time-to-contact estimation. Estimates above the line represent overestimations and estimates below the line represent underestimations. Error bars represent +/- 1 standard error of the mean.

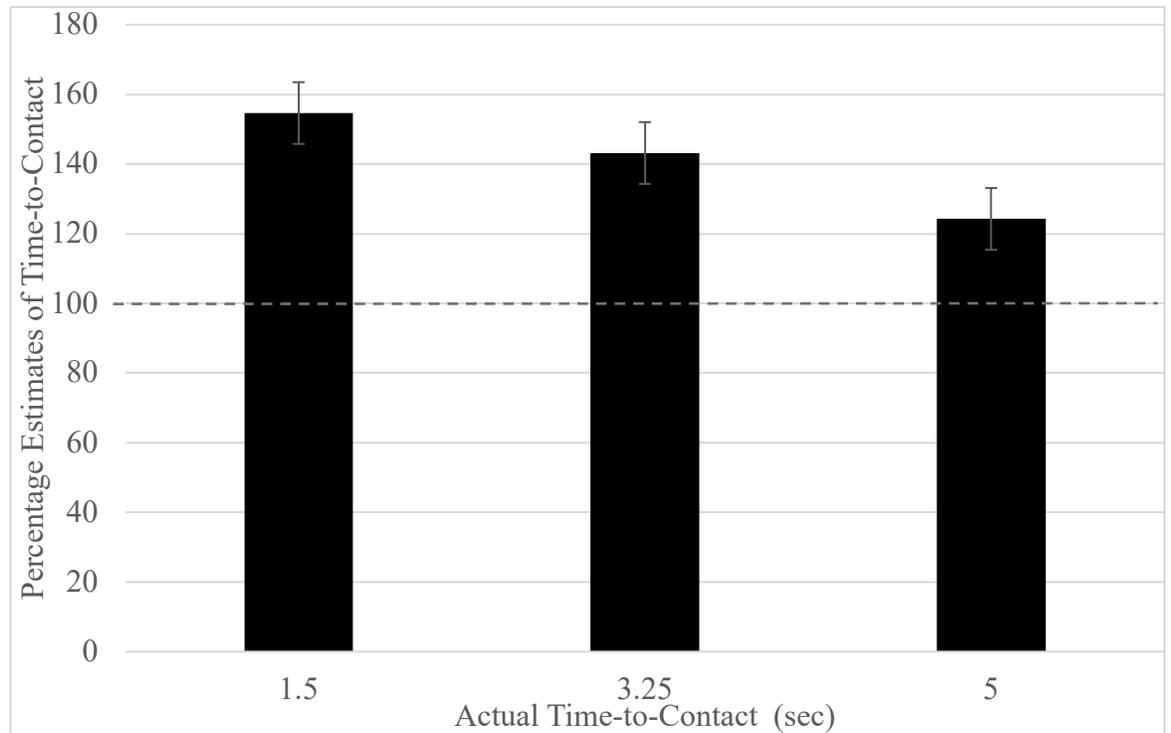
There was a significant main effect of **actual time-to-contact**, $B = -23.49$, $t(16,390) = 3.11$, $p = .002$, $95\% CI [-28.3, -18.7]$ on time-to-contact estimates.

Participants had lower percentage estimates of time-to-contact (i.e., smaller overestimation) when they viewed longer actual time-to-contacts than shorter actual time-

to-contacts. Participants had the greatest overestimation of time-to-contact at a time-to-contact of 1.5 seconds and the smallest overestimation of time-to-contact at a time-to-contact of 5 seconds (see Figure 2). This pattern of results matches observed patterns in the time-to-contact literature where longer actual time-to-contacts results in smaller percentage estimates than shorter actual time-to-contacts (Schiff & Oldak, 1990). There was no significant main effect of vehicle size on percentage estimates of time-to-contact, $B = -2.24$, $t(16,390) = -1.13$, $p = .261$, $95\% CI [-6.13, 1.66]$. The observed pattern of results for vehicle velocity and actual TTC match what is expected from the literature. However, although object size has been shown to influence time-to-contact estimates in previous studies (e.g., DeLucia, 1991), this effect was not observed here. This likely occurred because the size difference between the small car and the pick-up truck was not large enough.

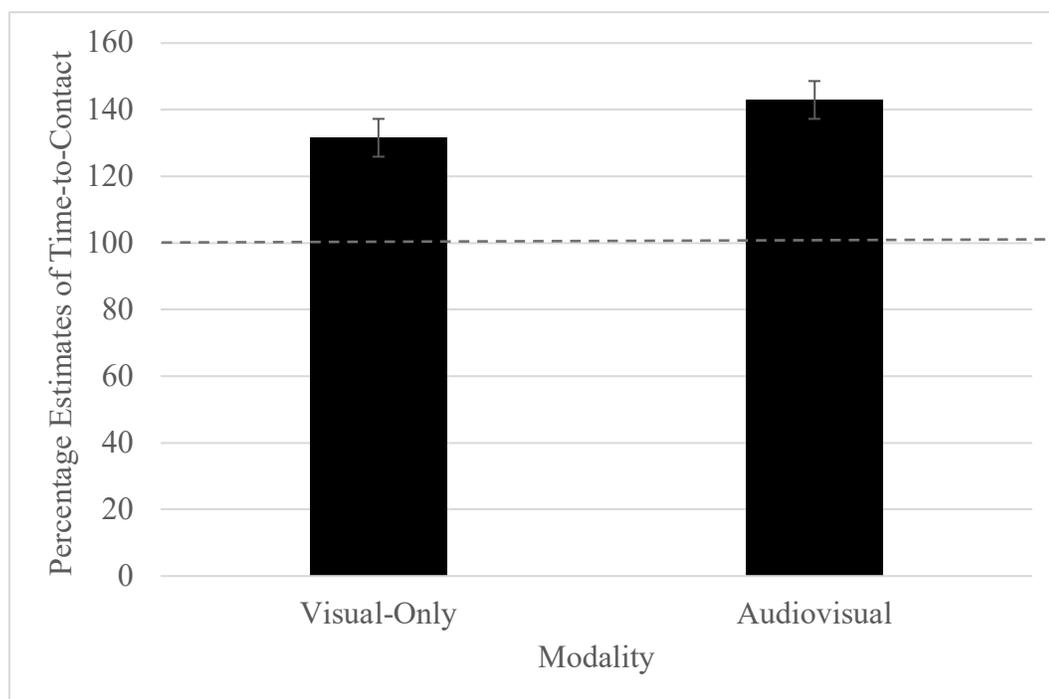
Figure 2

Main Effect of Actual Time-to-Contact on Percentage Estimated Time-to-Contact



Note. The dashed line represents perfect time-to-contact estimation. Estimates above the line represent overestimations and estimates below the line represent underestimations. Error bars represent +/- 1 standard error of the mean.

There was a significant main effect of **modality**, $B = 8.37$, $t(16,390) = 3.46$, $p < .001$, $95\% CI [3.63, 13.10]$. Participants overestimated time-to-contact in both the visual-only and audiovisual conditions; however, there was greater overestimation in the audiovisual condition and more accurate time-to-contact estimates (closer to 100% percentage estimates of TTC) in the visual-only condition (see Figure 3).

Figure 3*Main Effect of Modality on Estimated Time-to-Contact*

Note. The dashed line represents perfect time-to-contact estimation. Estimates above the line represent overestimations and estimates below the line represent underestimations. Error bars represent +/- 1 standard error of the mean.

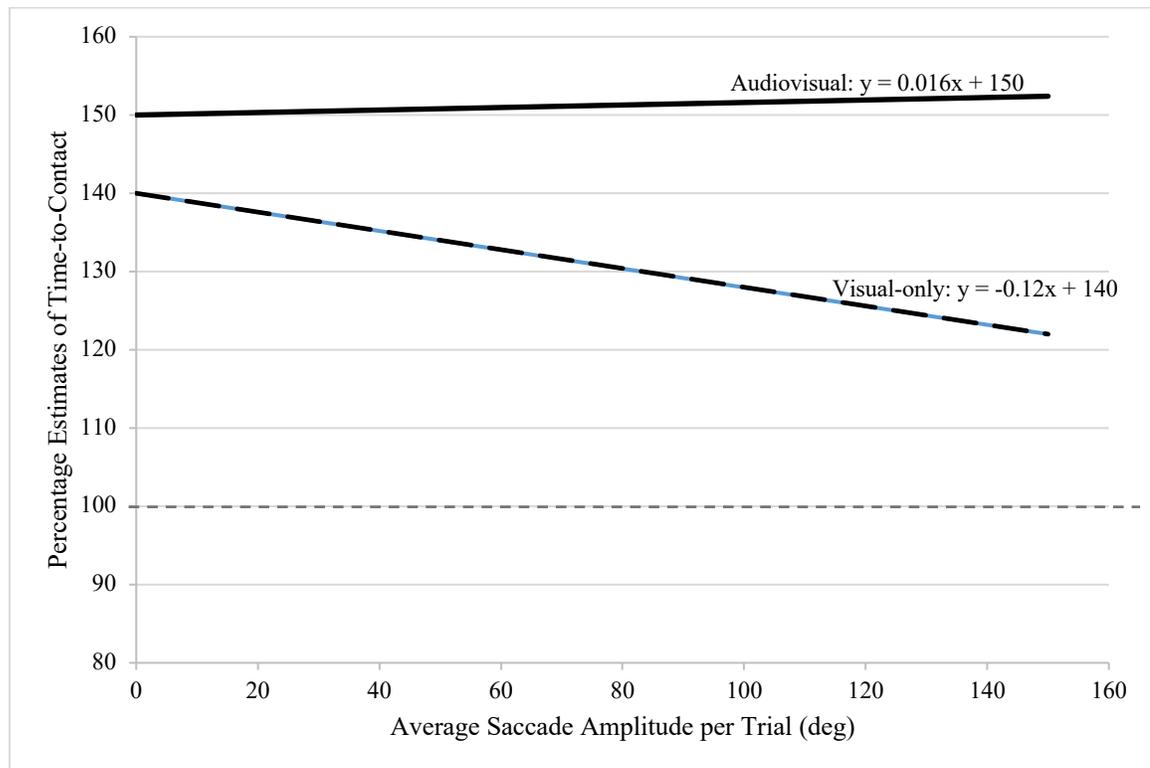
Saccadic eye movements significantly predicted percentage estimates of time-to-contact. There was a significant main effect of **saccade amplitude** on percentage estimates of time-to-contact, $B = -0.25$, $t(16,390) = -4.13$, $p < .001$, $95\% CI [-.37, -.13]$. A decrease in saccade amplitude led to a greater overestimation of time-to-contact, while an increase in saccade amplitude led to smaller overestimations of time-to-contact. The further the eyes traveled during a saccade, the more accurate people were at estimating time-to-contact.

There was a significant main effect of **saccade duration** on percentage estimates of time-to-contact, $B = 0.04$, $t(16,390) = -3.67$, $p < .001$, $95\% CI [.04, .14]$. An increase in saccade duration led to greater overestimation of time-to-contact; trials with longer saccade duration led to greater overestimations of time-to-contact than trials with shorter saccade duration. The longer it took to complete a saccade, the greater time-to-contact was overestimated. There was no significant main effect of **fixation duration** on percentage estimates of time-to-contact, $B = -6.27E-3$, $t(16,390) = -.83$, $p = .404$, $95\% CI [-.02, 8.45e-3]$. Based on the observed main effects of eye movement variables on percentage estimates of time-to-contact, we can conclude that saccadic eye movements (i.e., saccade amplitude and saccade duration), but not fixational eye movements (i.e., fixation duration) can predict time-to-contact estimates.

To determine how eye movements and modality impact percentage estimates of time-to-contact, interactions between eye movement behavior and modality were investigated. There was a significant interaction between **saccade amplitude and modality** on percentage estimates of time-to-contact, $B = .22$, $t(16,390) = 4.37$, $p < .001$, $95\% CI [.12, .32]$. Examination of simple slopes revealed that higher saccade amplitude led to smaller overestimations of time-to-contact estimates in the visual-only condition, $p < .001$. Saccade amplitude did not significantly influence time-to-contact estimates in the audiovisual condition, $p > .05$ (see Figure 4).

Figure 4

Interaction between Saccade Amplitudes and Modality on Estimated Time-to-Contact



Note. The dashed line represents perfect time-to-contact estimation. Estimates above the line represent overestimations and estimates below the line represent underestimations.

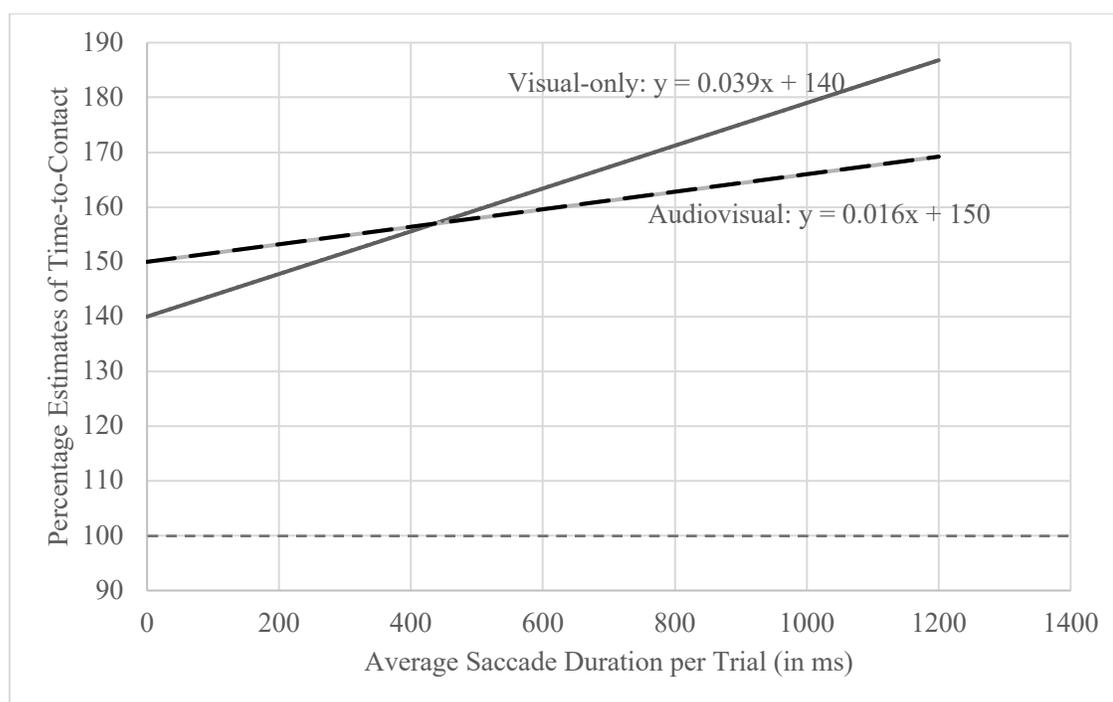
There was a significant interaction between **saccade duration and modality on percentage estimates of time-to-contact** $B = -0.06$, $t(16,390) = -3.15$, $p = .002$, $95\% CI [-.11, -.02]$. Examination of simple slopes revealed that higher saccade duration led to greater overestimations of time-to-contact in the visual-only condition (see Figure 5). There was no significant effect of saccade duration on percentage estimates of time-to-contact in the audiovisual condition.

The significant interactions between modality and saccadic eye movements (i.e., saccade amplitude and saccade duration), suggest that the observed main effect of

saccadic eye movements on percentage estimates of time-to-contact differed between the visual-only and audiovisual conditions. Saccadic eye movements (i.e., saccade amplitude and saccade duration) predicted time-to-contact estimates in the visual-only condition but not in the audiovisual condition.

Figure 5

Interaction between Saccade Duration and Modality on Estimated Time-to-Contact



Note. The dashed line represents perfect time-to-contact estimation. Estimates above the line represent overestimations and estimates below the line represent underestimations.

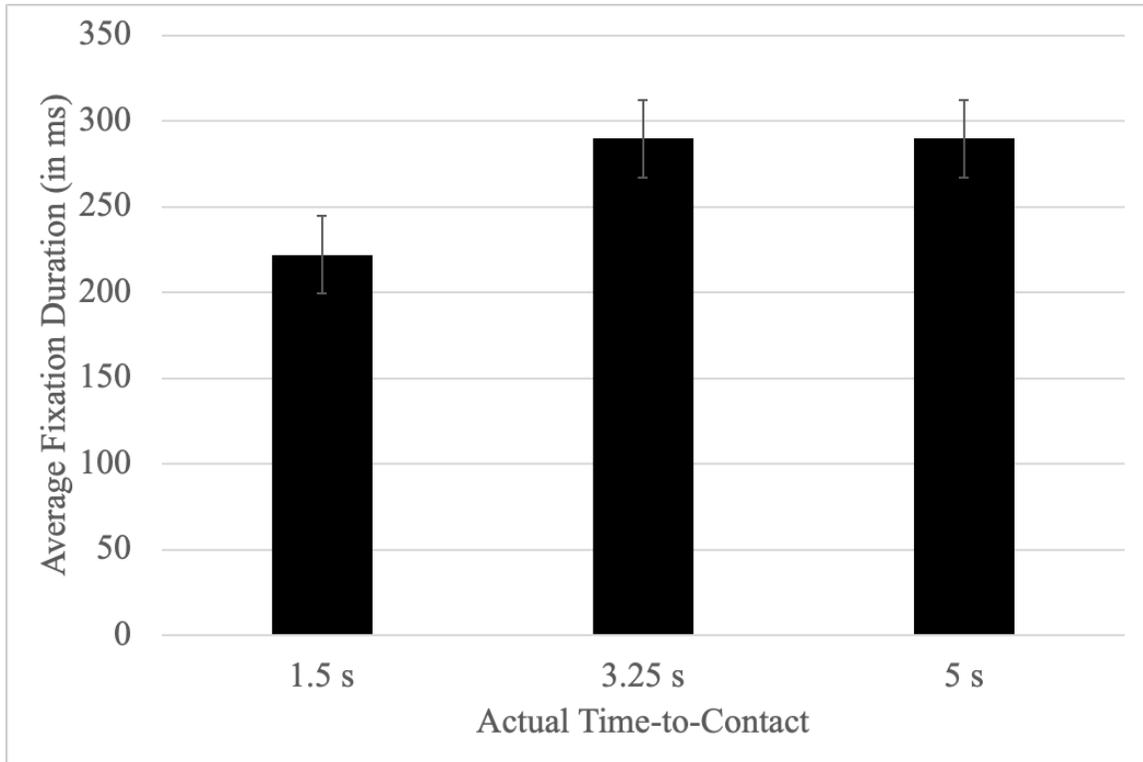
ANOVA Models

To assess the impact of vehicle velocity, actual time-to-contact and vehicle size on eye movement measures, nine ANOVAs were run with the different eye movement variables (fixation duration, saccade amplitude, saccade duration) as the dependent variables. The eye tracker did not record eye movements on certain trials for 2

participants. As a result, 2 participants had missing data and were excluded from the ANOVA analyses; 19 control participants were included in the analyses. See Appendix B for ANOVA source tables. First, ANOVA models were run on the visual-only trials. A 2 (velocity: 30 km/h or 50 km/h) by 3 (actual time-to-contact: 1.5 s, 3.25 s or 5 s) by 2 (vehicle size: car or truck) within-subjects ANOVA was run using the **visual-only trials**, with **fixation duration** as the dependent measure. There was a significant main effect of actual time-to-contact, $F(2, 36) = 8.23, p = .001, \eta^2p = .31$. Post-hoc Tukey's HSD revealed that fixation duration was significantly lower when actual time-to-contact was 1.5 s ($M = 222.0, SE = 28.6$) compared to actual time-to-contact of 3.25 s ($M = 289.9, SE = 48.2$), $p = .017$, and actual time-to-contact of 5 s ($M = 289.8, SE = 40.6$), $p = .002$. Vehicles that arrived sooner had shorter fixations than vehicles that arrived later. There was no significant difference in fixation duration between actual time-to-contact of 3.25 s versus 5 s, $p = .990$ (See Figure 8).

Figure 8

Main Effect of Actual Time-to-Contact on Average Fixation Duration in the Visual Modality

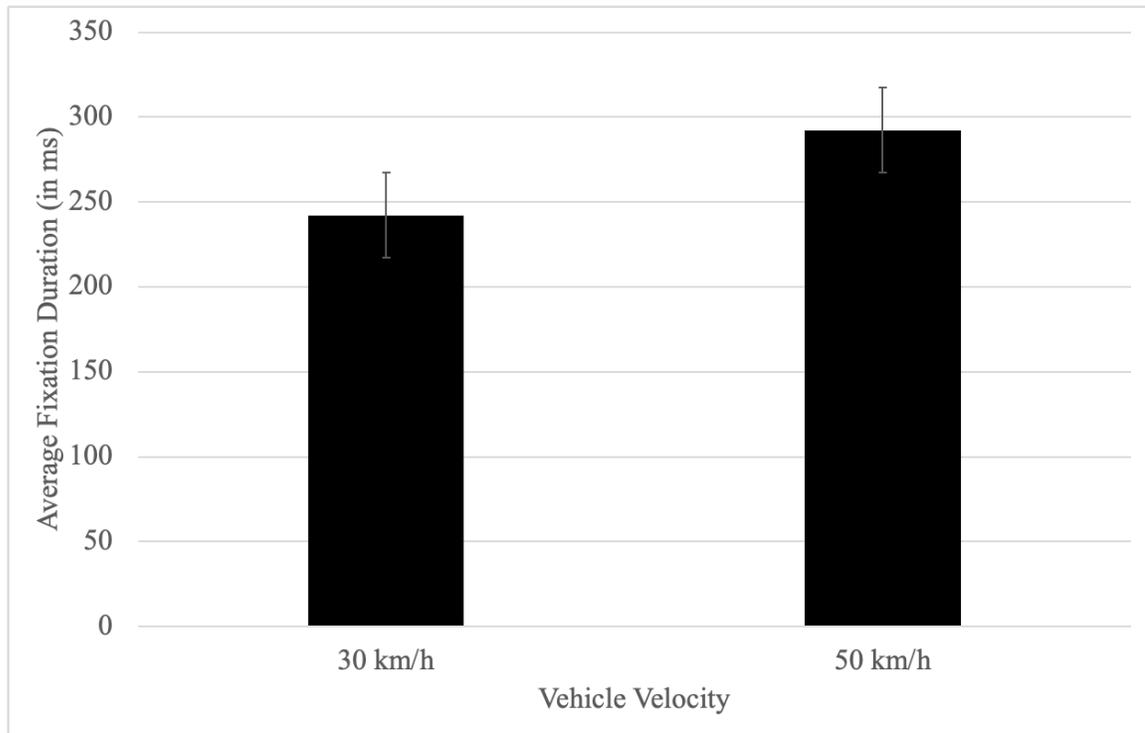


Note. Error bars represent +/- 1 standard error of the mean.

There was a significant main effect of velocity, $F(1, 18) = 15.04, p = .001, \eta^2 p = .46$. Fixation duration was significantly higher in the 50 km/h condition ($M = 292.3, SE = 44.1$) than the 30 km/h condition ($M = 242.2, SE = 32.9$). See Figure 9.

Figure 9

Main Effect of Velocity on Average Fixation Duration in the Visual Modality



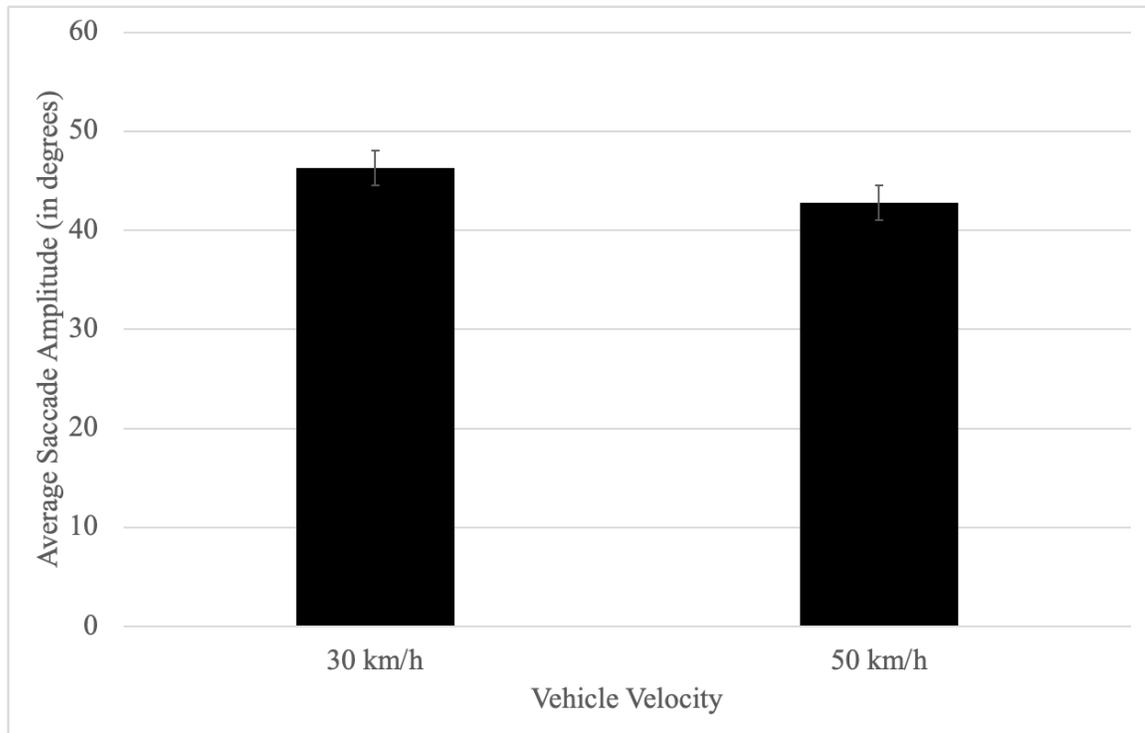
Note. Error bars represent +/- 1 standard error of the mean.

There was no significant main effect of vehicle type and no significant interactions between actual time-to-contact, velocity, and vehicle size, $p > .05$.

A 2 (velocity: 30 km/h or 50 km/h) by 3 (actual time-to-contact: 1.5 s, 3.25 s or 5 s) by 2 (Vehicle size: Car or Truck) within-subjects ANOVA was run using the **visual-only trials**, with **saccade amplitude** as the dependent measure. There was a significant main effect of velocity, $F(1, 18) = 11.93, p = .003, \eta^2 p = .40$. Saccade amplitudes were significantly lower at a velocity of 50 km/h ($M = 42.8, SE = 3.4$) versus 30 km/h ($M = 46.3, SE = 3.7$). (see Figure 10).

Figure 10

Main Effect of Velocity on Average Saccade Amplitude in the Visual Modality



Note. Error bars represent +/- 1 standard error of the mean.

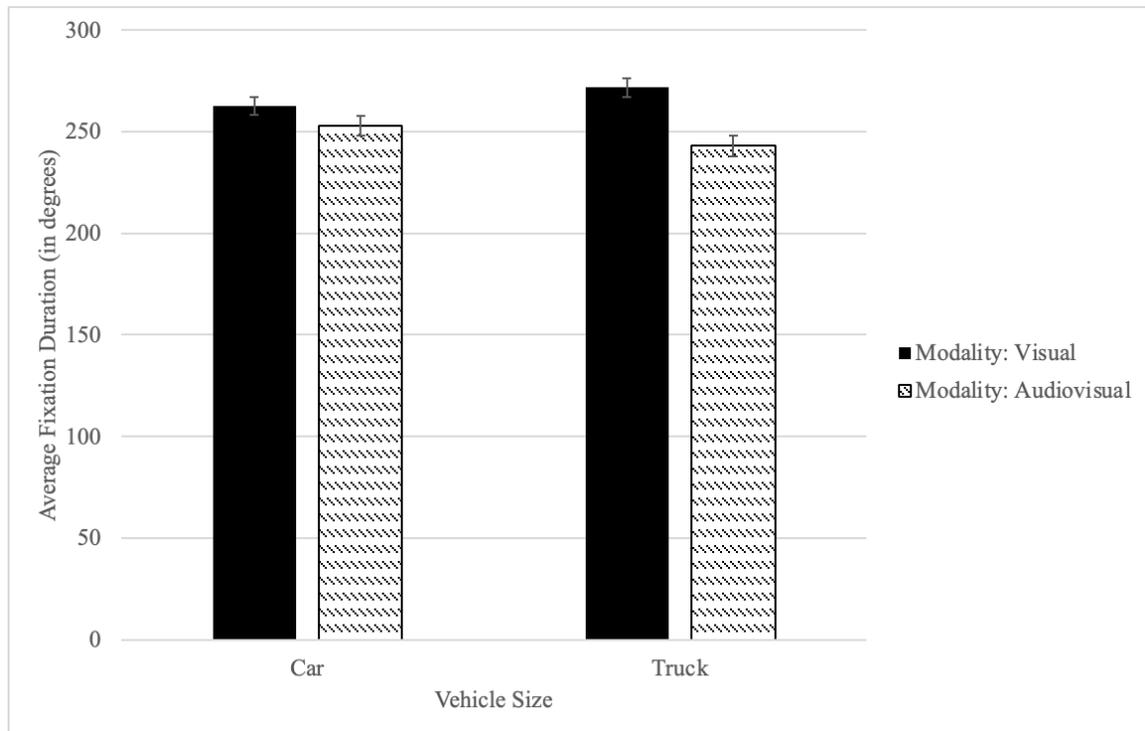
There was no significant main effects of actual time-to-contact and vehicle size and no significant interactions between actual time-to-contact, velocity, and vehicle, $p > .05$.

A 2 (velocity: 30 km/h or 50 km/h) by 3 (actual time-to-contact: 1.5 s, 3.25 s or 5 s) by 2 (vehicle size: car or truck) within-subjects ANOVA was run using the **visual-only trials**, with **saccade duration** as the dependent measure. There were no significant main effects of actual time-to-contact, vehicle size, and velocity on saccade duration and no significant interactions between actual time-to-contact, velocity, and vehicle size, $p > .05$.

Multimodal ANOVA Models. The primary objective of aim one was to determine the impact of modality (i.e., visual-only and audiovisual) on eye movement patterns (fixation duration, saccade duration, saccade amplitudes). Thus, ANOVA models were run to compare the visual-only condition to the audiovisual condition. Only the main effect and interactions with modality are reported. A 2 (velocity: 30 km/h or 50 km/h) by 3 (actual time-to-contact: 1.5 s, 3.25 s or 5 s) by 2 (vehicle size: car or truck) by 2 (modality: visual-only or audiovisual) within-subjects ANOVA was run with **fixation duration** as the dependent measure. There was a significant interaction between vehicle size and modality, $F(1, 18) = 7.81, p = .012, \eta^2 p = .30$. For the visual-only modality, fixation durations were higher for the truck ($M = 271.8, SE = 40.8$) than for the car ($M = 262.7, SE = 36.1$). When participants only saw the vehicle but did not hear it, they fixated longer on the truck than on the car. For the audiovisual modality, the opposite was true; fixation durations were lower for the truck ($M = 243.3, SE = 25.7$) than for the car ($M = 253.0, SE = 25.6$). When participants both saw and heard the vehicle, they fixated longer on the car than on the truck. See Figure 11.

Figure 11

Interaction between Vehicle Size and Modality on Average Fixation Duration



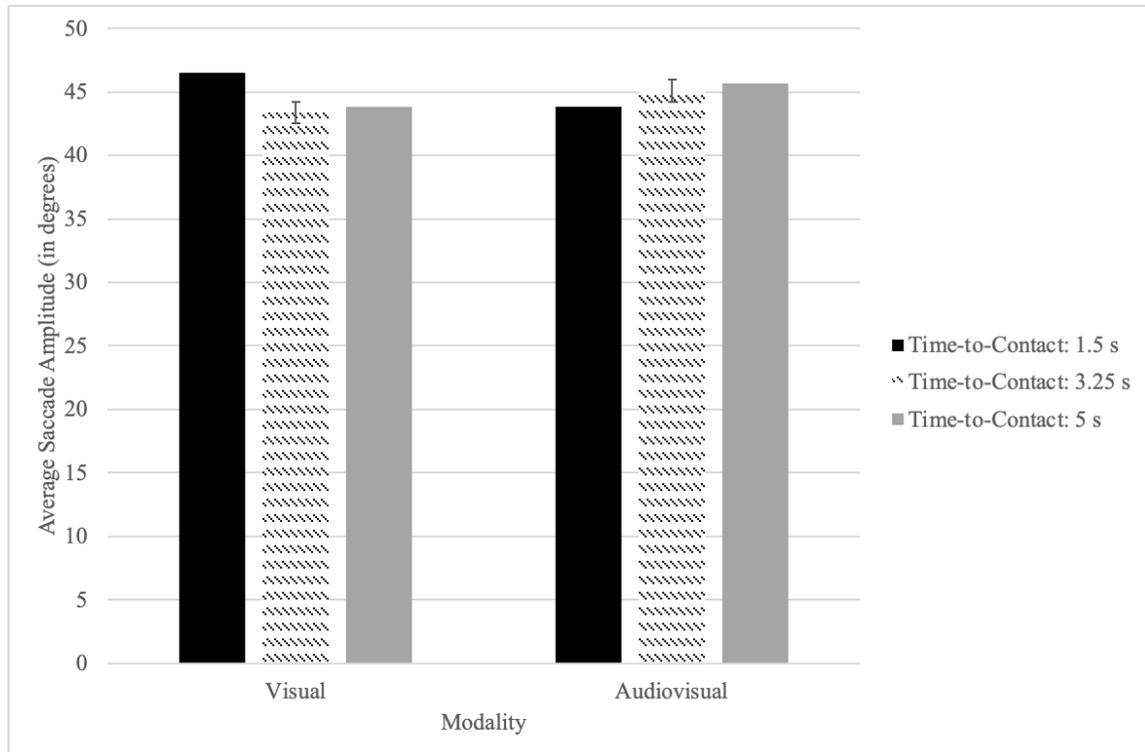
Note. Error bars represent +/- 1 standard error of the mean.

A 2 (velocity: 30 km/h or 50 km/h) by 3 (actual time-to-contact: 1.5 s, 3.25 s or 5 s) by 2 (vehicle size: car or truck) by 2 (modality: visual-only or audiovisual) within-subjects ANOVA was run with **saccade amplitude** as the dependent measure. There was a significant interaction between actual time-to-contact and modality on saccade amplitude, $F(2, 36) = 4.67, p = .016, \eta^2 p = .21$. For the visual-only modality, saccade amplitudes were significantly higher for an actual time-to-contact of 1.5 ($M = 46.5, SE = 3.5$) compared to actual time-to-contact of 3.25 ($M = 43.4, SE = 3.6$) and 5 ($M = 43.8, SE = 3.6$). When participants saw the vehicle but did not hear it, the distance traveled by the eyes during a saccade was greater when the vehicle arrived sooner than when the vehicle arrived later. There was no significant difference in saccade amplitude for the audiovisual

modality for actual time-to-contact of 1.5 ($M = 43.8$, $SE = 2.8$), 3.25 ($M = 45.1$, $SE = 3.1$), and 5 ($M = 45.7$, $SE = 3.2$). See Figure 12.

Figure 12

Interaction between Actual Time-to-Contact and Modality on Average Saccade Amplitude



Note. Error bars represent +/- 1 standard error of the mean.

There was a significant interaction between actual time-to-contact, vehicle velocity and modality on saccade amplitude, $F(2, 36) = 4.49$, $p = .018$, $\eta^2 p = .12$. Follow-up two-way ANOVAs revealed that in the audiovisual condition, for time-to-contact of 1.5s, saccade amplitude was significantly higher for vehicles traveling at 30 km/h ($M = 46.1$, $SE = 2.8$), compared to 50 km/h ($M = 41.5$, $SE = 2.9$). Saccade amplitude was significantly higher in the audiovisual condition for time-to-contact of 1.5s and vehicle

velocity of 50 km/h compared to a time-to-contact of 3.25 and vehicle velocity of 30 km/h ($M = 44.6$, $SE = 3.0$), and 50 km/h ($M = 45.6$, $SE = 3.4$). A 2 (velocity: 30 km/h or 50 km/h) by 3 (actual time-to-contact: 1.5 s, 3.25 s or 5 s) by 2 (vehicle size: car or truck) by 2 (modality: visual-only or audiovisual) within-subjects ANOVA was run with **saccade duration** as the dependent measure. There were no significant main effects of modality on saccade duration and no significant interactions between actual time-to-contact, vehicle size, velocity, and modality $p > .05$.

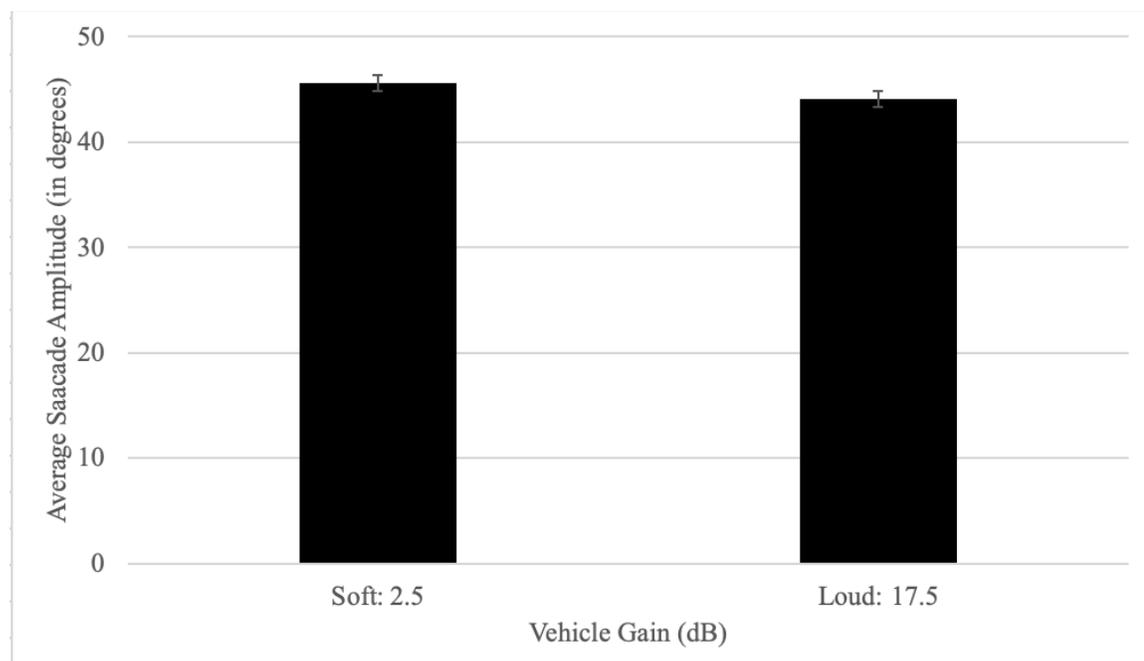
ANOVA Models for the Audiovisual Trials. To determine if inconsistent information between vehicle size and sound intensity (i.e., car with loud sound intensity or truck with soft sound intensity) influenced eye movement patterns (fixation duration, saccade duration, saccade amplitude), within-subject ANOVAs were run on the audiovisual trials. Only the main effect and interactions with gain are reported. A 2 (velocity: 30 km/h or 50 km/h) by 3 (actual time-to-contact: 1.5 s, 3.25 s or 5 s) by 2 (vehicle size: car or truck) by 2 (gain: soft or loud) within-subjects ANOVA was run using the **audiovisual trials only** with **fixation duration** as the dependent measure. There were no significant main effects of gain on fixation duration and no significant interactions between actual time-to-contact, vehicle size, velocity, and gain $p > .05$.

A 2 (velocity: 30 km/h or 50 km/h) by 3 (actual time-to-contact: 1.5 s, 3.25 s or 5 s) by 2 (vehicle size: car or truck) by 2 (gain: soft or loud) within-subjects ANOVA was run using the **audiovisual trials only** with **saccade amplitude** as the dependent measure. There was a significant main effect of gain on saccade amplitude, $F(1, 18) = 4.57$, $p = .047$, $\eta^2 p = .20$. Softer sounds ($M = 45.6$, $SE = 3.2$) led to higher saccade amplitudes than louder sounds ($M = 44.1$, $SE = 2.8$). The eyes traveled a greater distance during a

saccade when a softer vehicle sound was presented than when a louder sound was presented. See Figure 13.

Figure 13

Main Effect of Gain on Average Saccade Amplitude



Note. Error bars represent +/- 1 standard error of the mean.

There was a significant interaction between gain and velocity on saccade amplitude, $F(1, 18) = 5.88, p = .026, \eta^2 p = .25$. Saccade amplitudes were significantly larger for a soft sound traveling at 30 km/h ($M = 46.1, SE = 3.1$) compared to a loud sound traveling at 50 km/h ($M = 42.8, SE = 2.9$). There was no other significant differences between velocity and gain conditions.

There were no other significant interactions between actual time-to-contact, vehicle size, velocity, and modality $p > .05$.

A 2 (velocity: 30 km/h or 50 km/h) by 3 (actual time-to-contact: 1.5 s, 3.25 s or 5 s) by 2 (vehicle size: car or truck) by 2 (gain: soft or loud) within-subjects ANOVA was run using the **audiovisual trials only** with **saccade duration** as the dependent measure. There were no significant main effects of gain and no significant interactions between actual time-to-contact, vehicle size, velocity, and gain $p > .05$.

To summarize, actual time-to-contact and velocity predicted saccade amplitude for the visual-only trials; there was no influence of actual time-to-contact and velocity on the audiovisual trials. Vehicle size did not significantly predict saccade amplitude, regardless of modality. Vehicle velocity, actual time-to-contact and vehicle size did not significantly predict saccade duration, regardless of modality. Similarly, fixation duration was not predicted by vehicle velocity, actual time-to-contact, or vehicle size, regardless of modality.

Results: Aim Two

Aim two was to compare eye movement between individuals with normal vision and individuals with central vision loss. As in aim one, two main types of analyses were run in order to understand the difference in eye movement behavior in judgments of collisions between unimodal and multimodal trials for individuals with central vision loss. First, a linear mixed effect model was run to determine if eye movements predicted time-to-contact estimates differently for individuals with central vision loss compared to individuals with normal vision. Second, three ANOVA models with eye movements as the outcome variables were run to determine if vehicle velocity, actual TTC, vehicle size and modality predicted eye movement patterns differently for the central vision loss group compared to the normal vision group. Together, the linear mixed model and

ANOVA models explain how eye movements differ in individuals with central vision loss versus individuals with normal vision and how eye movements can influence judgments of collisions.

Linear Mixed Effect Model

A linear mixed effect model was run to determine the difference in influence of eye movement patterns (i.e., saccade amplitude, saccade duration, fixation duration) on percentage estimates of time-to-contact between individuals with central vision loss and individuals with normal visions. 21 control participants and 15 central vision loss participants were included in this analysis. Two-way interactions between group and eye movement variables as well as groups and vehicle velocity, actual TTC, vehicle size and modality were analyzed. For the purposes of this study, only the three-way interactions between groups, modality and eye movements are discussed. Other interactions from this model can be found in Appendix C. Table 6 shows the linear mixed effect model's two-way and three-way interactions.

Table 6*Two-way and three-way interactions from the linear mixed effect model*

Interactions	Degrees of Freedom	Estimates (B values)
Group	13,000	95.90*
Group by Modality	13,000	-17.29*
Group by Velocity	13,000	-23.10*
Group by Vehicle Size	13,000	.51
Group by Actual Time-to-Contact	13,000	-35.20*
Group by Saccade Amplitude	13,000	-.44*
Group by Fixation Duration	13,000	-.04*
Group by Saccade Duration	13,000	-.19*
Group by Modality by Saccade Amplitude	13,000	-.04
Group by Modality by Fixation Duration	13,000	.07*
Group by Modality by Saccade Duration	13,000	.20

Note. * denotes a significant value of $p < .05$. B-value estimates represent the slopes.

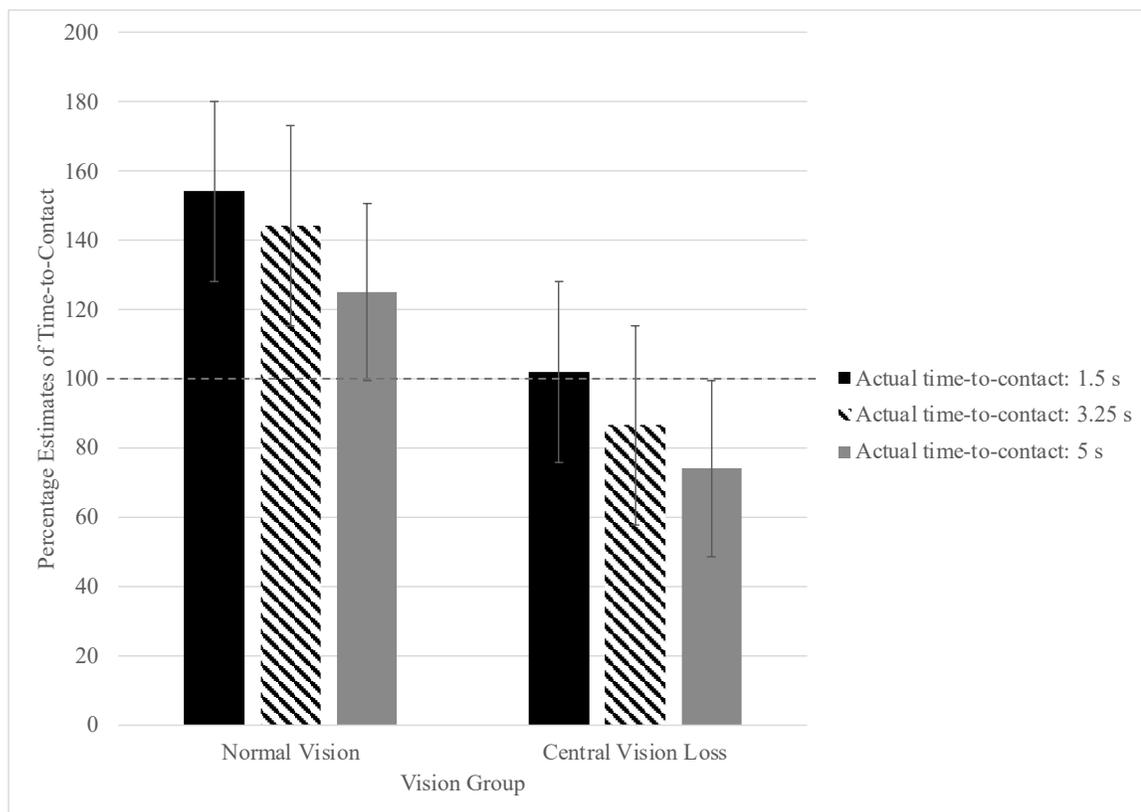
As in aim one, the effects of vehicle size, velocity, actual TTC and modality on percentage estimates of time-to-contact were investigated to determine if the relationship of the aforementioned variables vary by group. There was a significant main effect of **group** on time-to-contact estimates, $B = 95.90$, $t(13,000) = 4.71$, $p < .001$, 95% CI [56.50, 135.37]. On average, individuals in the central vision loss group underestimated time-to-contact, while individuals in the normal vision group overestimated time-to-contact. In practical terms, individuals in the central vision loss group exhibited safer behavior than those in the normal vision group as they viewed the vehicle as arriving

before it actually reached them, while the normal vision group viewed the vehicle as arriving after it would have reached them.

There was also a significant interaction between **group and actual time-to-contact** of the vehicle, $B = 23.10$, $t(13,000) = -3.58$, $p < .001$, $95\% CI [-43.60, -.03]$. For the central vision loss group, shorter actual time-to-contact led to smaller underestimations of percentage estimates of time-to-contact, while longer actual time-to-contacts led to greater underestimations of percentage time-to-contact (see Figure 14). However, the pattern of results matched what is expected from the literature; longer actual time-to-contacts have smaller percentage estimates than shorter actual time-to-contacts (Schiff & Oldak, 1990).

Figure 14

Interaction between Actual Time-to-Contact and Group Assignment on Estimated Time-to-Contact

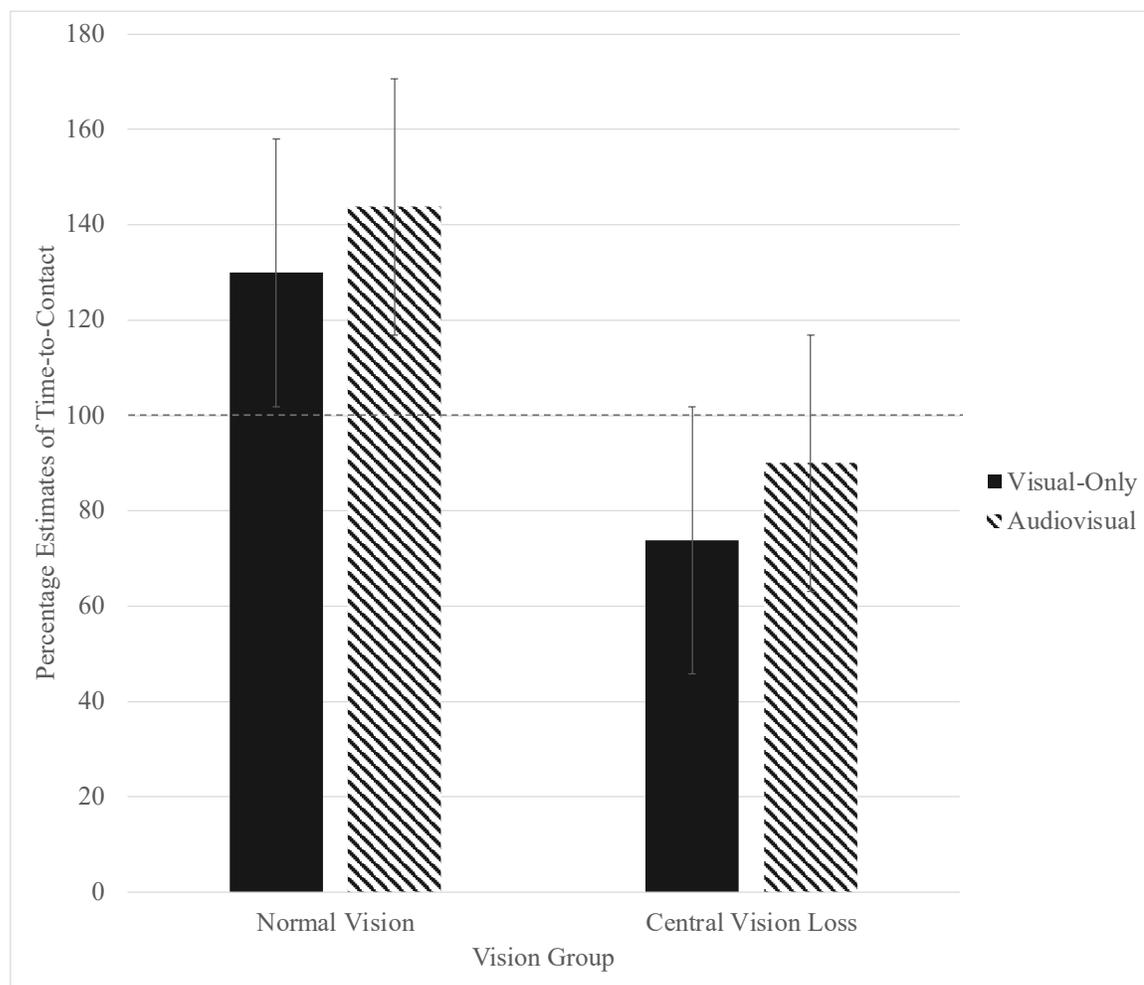


Note. The dashed line represents perfect time-to-contact estimation. Estimates above the line represent overestimations and estimates below the line represent underestimations. Error bars represent +/- 1 standard error of the mean.

There was a significant interaction between **group and modality**, $B = 17.30$, $t(13,000) = -2.47$, $p = .013$, $95\% CI [-.31, -3.60]$. For the central vision loss group, time-to-contact estimates were more accurate in the audiovisual trials versus the visual-only trials, suggesting that the addition of an auditory stimulus enhanced accuracy (see Figure 15). This effect was not observed in the control group.

Figure 15

Interaction between Modality and Group Assignment on Estimated Time-to-Contact



Note. The dashed line represents perfect time-to-contact estimation. Estimates above the line represent overestimations and estimates below the line represent underestimations.

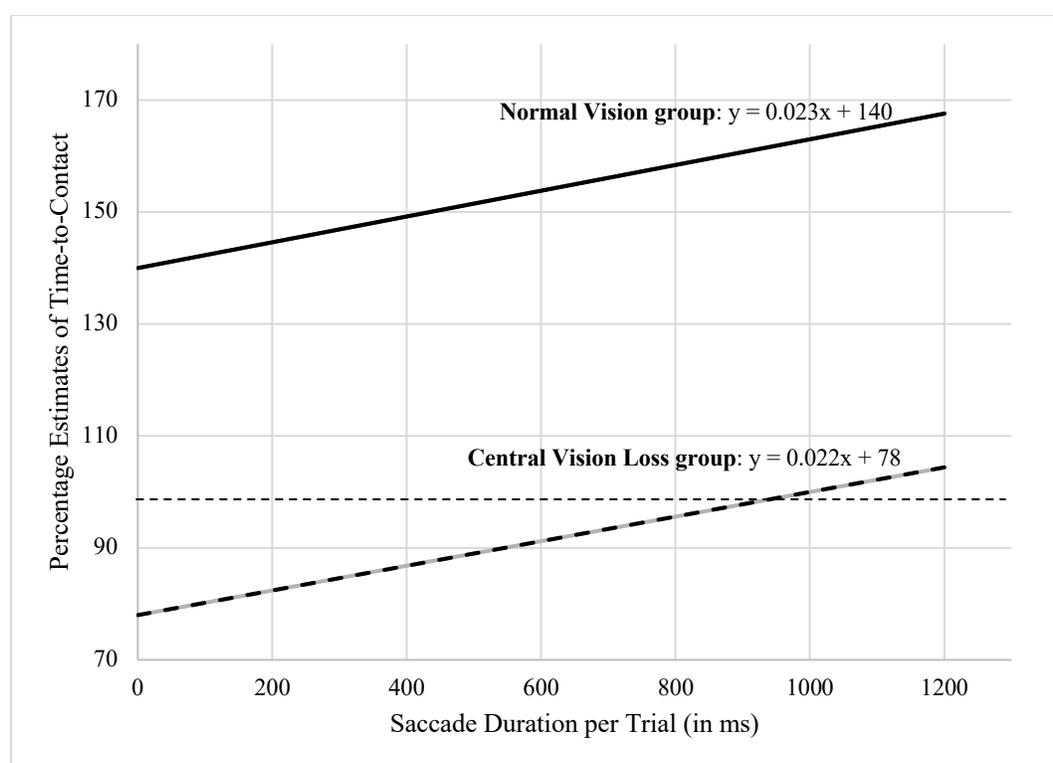
Error bars represent +/- 1 standard error of the mean.

Saccadic eye movements significantly predicted percentage estimates of time-to-contact for the central vision loss group. There was a significant interaction between **group and saccade duration**, $B = -19.30$, $t(13,000) = -2.62$, $p = .009$, $95\% CI [-34, -$

0.05]. When the central vision loss group made longer saccades, time-to-contact was less underestimated than when saccade duration was longer. The control group also saw an increase in percentage estimates of time-to-contact when saccades were longer; however, the control group overestimated time-to-contact. See Figure 16.

Figure 16

Interaction between Saccade Duration and Group Assignment on Estimated Time-to-Contact

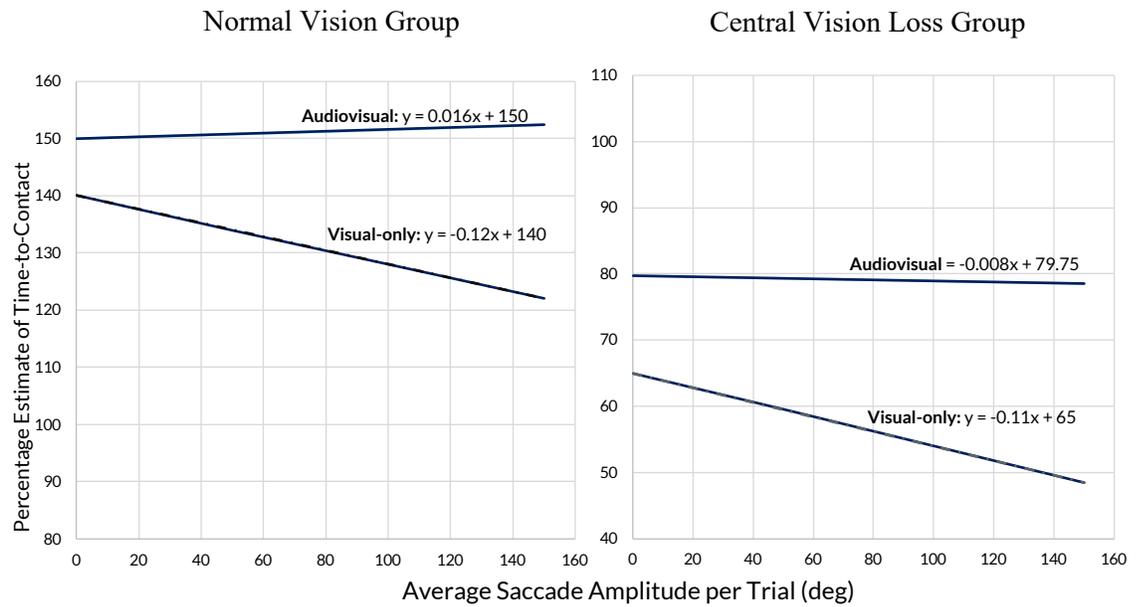


Note. The dashed line represents perfect time-to-contact estimation. Estimates above the line represent overestimations and estimates below the line represent underestimations.

There was no significant three-way interactions between saccade amplitude, group assignment and modality, $p > .05$. See Figure 17.

Figure 17

Interaction between Saccade Amplitude and Group Assignment on Estimated Time-to-Contact

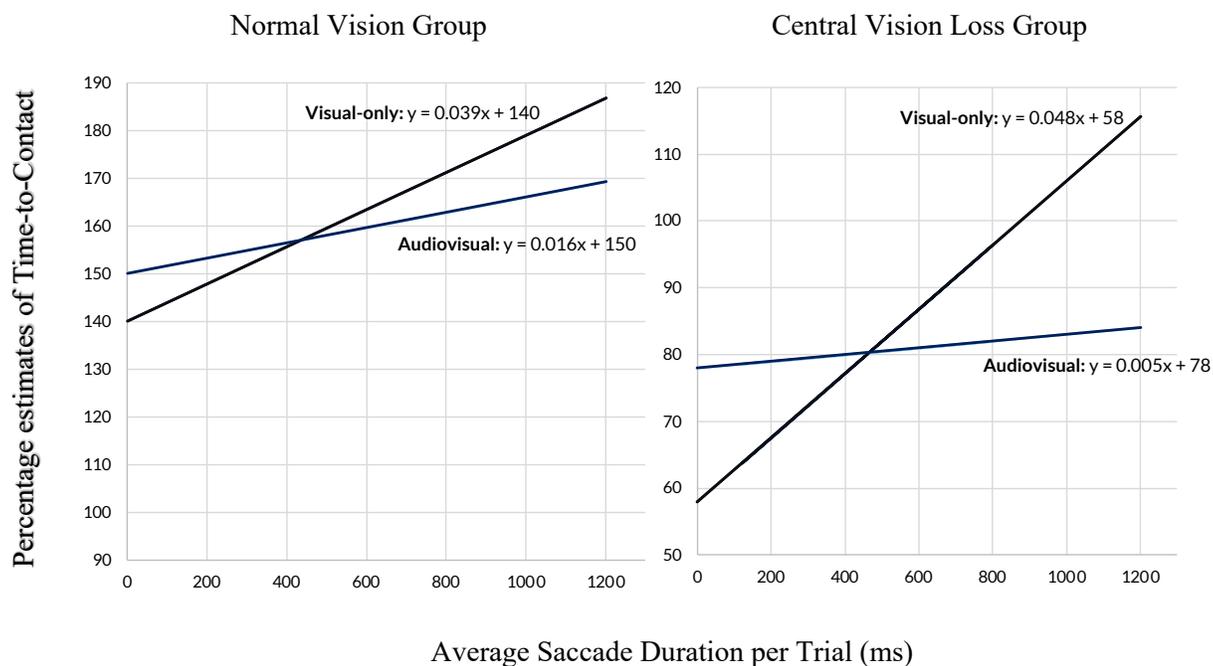


Note. The dashed line represents perfect time-to-contact estimation. Estimates above the line represent overestimations and estimates below the line represent underestimations.

There was no significant three-way interactions between saccade amplitude, group assignment and modality, $p > .05$. See Figure 18.

Figure 18

Interaction between Saccade Duration and Group Assignment on Estimated Time-to-Contact



Note. The dashed line represents perfect time-to-contact estimation. Estimates above the line represent overestimations and estimates below the line represent underestimations.

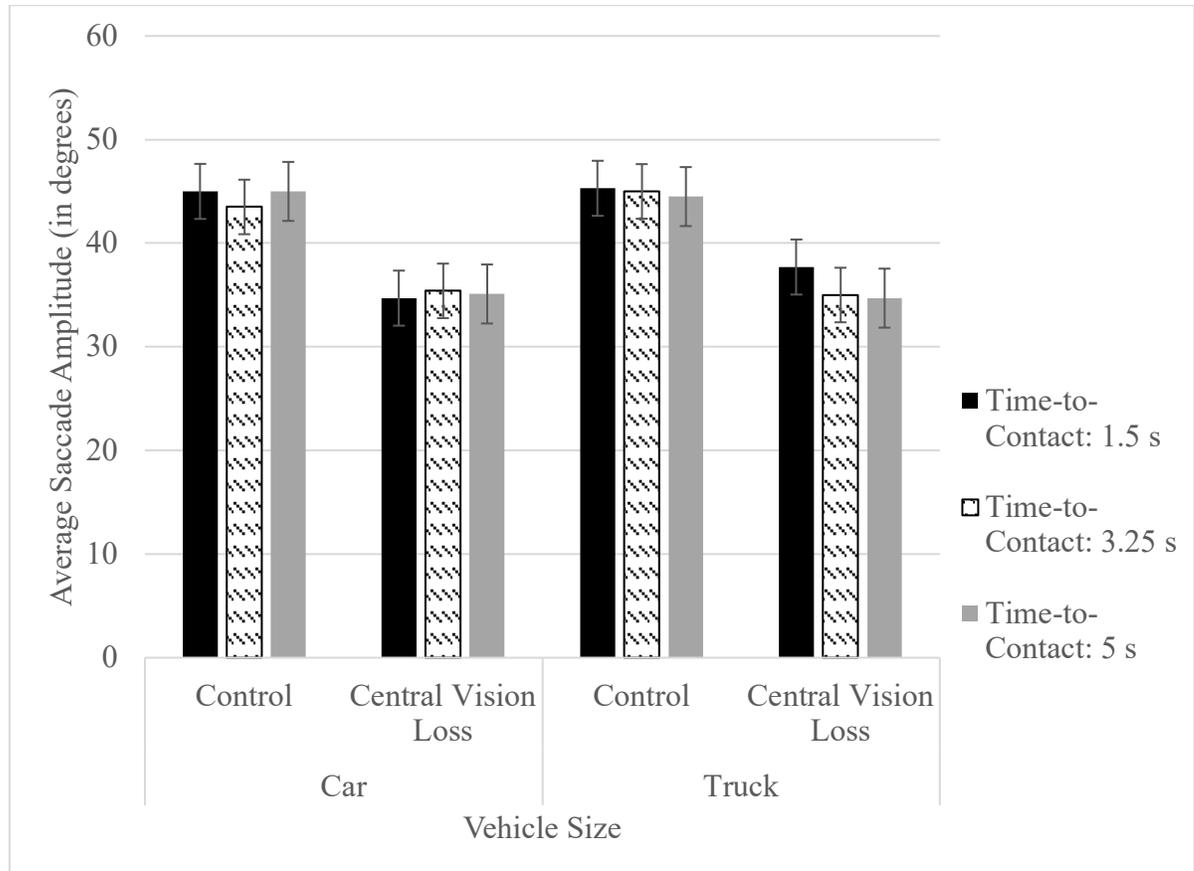
There was a significant, three-way interaction between **fixation duration, group assignment, and modality**, $B = .07$, $t(13,000) = 3.22$, $p = .001$, $95\% CI [.03, 0.12]$. For the central vision loss group, longer fixation duration led to overestimation of time-to-contact in the visual-only condition. There was no impact of fixation duration on time-to-contact estimations in the audiovisual condition. Fixation duration did not significantly impact time-to-contact estimations in the normal vision group. There was no significant interaction between group assignment, modality and saccade duration.

ANOVA Models

To determine whether the predictive power of vehicle velocity, actual TTC, vehicle size and modality on eye movements differed by group assignment, three ANOVAs were run, with different eye movements (i.e., saccade duration, saccade amplitude, fixation duration) as the dependent variable. The eye tracker did not record eye movements for certain trials for 2 control and 8 central vision loss participants. As a result, 10 participants had missing data and were excluded from the ANOVA analyses; 19 control participants and 7 central vision loss participants were included in these analyses. See Appendix D for ANOVA source tables. A 2 (velocity: 30 km/h or 50 km/h) by 3 (actual time-to-contact: 1.5 s, 3.25 s or 5 s) by 2 (vehicle size: car or truck) by 2 (modality: visual-only or audiovisual) by 3 (group: central vision loss or normal vision) mixed design ANOVA was run with **saccade amplitude** as the dependent measure. There was no significant main effect of group, $p > .05$. There was a significant interaction between actual time-to-contact, vehicle size, and group, $F(2, 48) = 3.35, p = .044, \eta^2 p = .12$. Follow-up actual time-to-contact by vehicle size ANOVAs separated by group revealed that, for the central vision loss group, a truck led to higher saccade amplitudes for a time-to-contact of 1.5 ($M = 37.8, SE = 4.7$) than a car ($M = 34.7, SE = 4.9$). There were no significant differences between vehicle size for time-to-contacts of 3.25s and 5s for either group (See Figure 19). Group by vehicle size ANOVAs at each level of actual time-to-contact, and group by actual time-to-contact at each level of vehicle size did not reveal any significant effects, $p > .05$.

Figure 19

Interaction between Vehicle Size , Actual Time-to-Contact and group Average Saccade Amplitude



Note. Error bars represent +/- 1 standard error of the mean.

A 2 (velocity: 30 km/h or 50 km/h) by 3 (actual time-to-contact: 1.5 s, 3.25 s or 5 s) by 2 (vehicle size: car or truck) by 2 (modality: visual-only or audiovisual) by 3 (group: central vision loss or normal vision) mixed design ANOVA was run with **saccade duration** as the dependent measure. There was no significant main effect of group and no significant interaction of group with modality, velocity, actual time-to-contact, and vehicle size, $p > .05$.

A 2 (velocity: 30 km/h or 50 km/h) by 3 (actual time-to-contact: 1.5 s, 3.25 s or 5 s) by 2 (vehicle size: car or truck) by 2 (modality: visual-only or audiovisual) by 3 (Group: central vision loss or normal vision) mixed design ANOVA was run with **fixation duration** as the dependent measure. There was no significant main effect of group, $p > .05$. There was a significant interaction between actual time-to-contact and group on fixation duration, $F(2, 48) = 3.49, p = .039, \eta^2p = .13$. For controls, an actual time-to-contact of 1.5s ($M = 218.1, SE = 23.3$) led to significantly shorter fixation duration than 3.25s ($M = 271.5, SE = 30.2$) and 5s ($M = 283.5, SE = 30.5$). This finding matches the main effect of actual time-to-contact found for controls in the Aim 1 analyses. No significant differences were observed between actual time-to-contact and the central vision loss group.

There was a significant interaction between vehicle velocity and group on fixation duration, $F(1, 24) = 5.84, p = .024, \eta^2p = .20$. For controls, vehicles traveling at 50 km/h ($M = 279.4, SE = 31.1$) led to longer fixation durations than vehicles traveling at 30 km/h ($M = 236.0, SE = 24.2$). This finding matches the main effect of vehicle velocity found for controls in the Aim 1 analyses. There were no significant differences between velocity and the central vision loss group. As there were no significant effects of modality on eye movements, there was not enough evidence to justify running analyses comparing sound levels in the audiovisual modality.

Discussion

The overarching goal of this thesis was to compare eye movement behaviors in judgments of collision between visual-only and audiovisual stimulus presentation.

Further, I sought to understand the difference in eye movement behaviors in judgments of

collisions between individuals with normal vision and individuals with central vision loss. This research has implications for understanding judgments of collisions as it illustrates how eye movements differ in unimodal versus multimodal stimulus presentation as well as how this difference influence judgments of collisions. This research also has implications for understanding central vision and its impact on judgments of collisions. This is especially important as it provides information that could help increase mobility in individuals with central vision loss.

The first aim of this thesis was to determine whether multimodal stimuli influenced eye movements in judgments of collision. Specifically, do eye movements change when a visual stimulus is presented alone compared to when a visual stimulus is presented concurrently with an auditory stimulus? In general, the answer to the first question is yes, eye movements do change when a visual stimulus is presented with an auditory stimulus than when it is presented alone. Saccade amplitudes and fixation durations were higher in the visual-only condition compared to the audiovisual condition. Further, results also show eye movements can influence judgments of collisions in a unimodal condition but not in a multimodal condition. In the visual-only condition, an increase in saccadic eye movements led to an increase in percentage estimates of time-to-contact. As such, eye movements also influence judgments of collisions in a time-to-contact task; however, this influence did not always lead to more accurate time-to-contact estimates.

Results established that eye movements, specifically saccadic eye movements, influence accuracy of judgments of collisions. The greater the distance traveled by the eye, the smaller the overestimation, and thus more accurate were the collision judgments.

This result makes sense within the context of existing literature. It has been shown that allowing the eyes to freely track a moving object led to more accurate judgments of collision than when the eyes maintained fixation on the arrival location (Bennet et al., 2012). As such, these results expand on this finding suggesting that longer eye movements may result in better tracking of the moving object and thus lead to more accurate judgments of collisions. Further, shorter duration eye movements led to more accurate judgments of collisions. When pursuing a moving object with the eyes, saccades can be used to adjust the eye position if the eyes no longer fall on the moving object (Fooker et al., 2021). Therefore, shorter saccade duration could indicate that smaller adjustments are needed to accurately pursue an object.

The relationship between modality, eye movement behavior and percentage estimates of time-to-contact was also investigated. Results suggest that eye movement behavior, specifically saccadic behavior, influences the time-to-contact estimates only when an object is presented visually, without an auditory stimulus. When participants had access to more information, such as the addition of an auditory stimulus, the behavior of the eye movement no longer influenced time-to-contact estimates. This suggests that eye movement behavior can predict time-to-contact estimates. The finding that saccadic eye movements predict time-to-contact estimates fits within the existing literature. Previous research has shown that the direction and distance traveled by the eyes when a moving object disappears predicted the accuracy of time-to-contact estimates. The current study showed that the overall distance travelled (i.e., saccade amplitude) predicted time-to-contact estimates. Further, this study expands upon existing results by showing that saccadic amplitude predicted time-to-contact estimates in a misspath approach trajectory

with the user acting as the target of collision rather than another object. This differs from previous research investigating saccade amplitude that used a lateral approach for their TTC task (Benguigui & Bennett, 2010; Bennett et al., 2010; Goldreich et al., 1992). Prior studies had not investigated how eye movements are affected when an auditory stimulus is added. As such, I can conclude that, though eye movement behavior certainly predicted time-to-contact estimations, the addition of an auditory stimulus reduced the influence of eye movement behavior on time-to-contact estimates. It is possible that shortcuts are employed by the brain as a result of multisensory integration, to perceive the moving stimulus, leading to eye movements not being included in the perception of the vehicle. Future research should investigate why saccadic eye movements did not predict time-to-contact estimates in audiovisual conditions.

Though participants were presented with an auditory-only condition, eye movements could not be obtained from this condition as there were no visual objects for the subjects to look at. However, previous research has shown that individuals tend to provide more accurate time-to-contact estimates in an auditory-only condition compared to a visual-only condition (Keshavarz et al., 2017). In Keshavarz et al.'s, (2017) study, participants were presented with a traffic scene with vehicles that approached them for three seconds before disappearing. Participants provided responses when they believed the approaching vehicle would have reached their location. Vehicles were presented in the visual modality, auditory modality, or both the auditory and visual modalities. Results indicated that participants were more accurate in their time-to-contact estimates when they only heard the vehicle than when they only saw the vehicle (Keshavarz et al., 2017).

Keshavarz et al. (2017) results suggest that auditory information can be used to predict time-to-contact.

The second aim of this thesis was to determine how eye movements differed between individuals with central vision loss and individuals with normal vision as well as determine whether this was associated with differences in judgments of collisions. Specifically, which factors within a scene influenced eye movements and how do they differ across visual abilities? Results showed differences in eye movement behavior between the normal vision group and the central vision loss group, specifically, saccadic eye movements, such as how long a saccade lasts (saccade duration), and the distance traveled during a saccade (saccade amplitude). Control participants had longer saccade duration and greater distance traveled by the eyes during a saccade compared to the central vision loss group. Previous research showed that individuals with central vision loss have greater difficulty with accurately tracking a moving object with their eyes, leading to to many short, corrective saccades (Janssen & Verghese, 2016). I predicted that shorter saccades would indicate greater difficulty with tracking the moving object, leading to less accurate time-to-contact estimates. As expected, the multilevel linear model revealed that longer saccade duration led to more accurate judgments of collisions for individuals with central vision loss, suggesting better control of pursuit eye movements with longer saccades.

Differences in eye movement behavior were observed between individuals with central vision loss and individuals with normal vision. Overall, individuals with central vision loss exhibited greater influence of eye movements on accuracy of judgments of collisions than individuals with normal vision, as shown through the central vision loss

group's slightly steeper regression slopes (in the multilevel linear model's output), despite the direction of the effect being the same for both groups. Importantly, the addition of an auditory stimulus removed the influence of eye movement behavior on judgments of collisions. In other words, similarly to individuals with normal vision, individuals with central vision loss's saccadic eye movements did not predict time-to-contact estimates when both visual and auditory stimuli were presented. This finding is striking as I did not expect the central vision loss group to have a similar effect of eye movements on TTC estimates as the control group. Previous research has shown that eye movements differ in individuals with central vision loss, which may impair their performance (Geruschat et al., 2006; Hassan et al., 2005). As such, I expected eye movements to influence TTC estimates differently for individuals with central vision loss compared to individuals with normal vision. One possible explanation may be that individuals with central vision loss had a visual acuity that was too good to find any differences (just under half of participants had a visual acuity of 20/60 or better in at least one eye), which may explain why performance was similar between groups. It was difficult to recruit individuals with severe visual impairments who also had good hearing.

Theoretical Implications

The overarching objective of this research was to determine the influence of eye movement behavior on judgments of collision, specifically any differences in eye movements observed between unimodal and multimodal presentation of a moving stimulus. Previous research has shown that eye movements can play a role in judgments of collisions. Individuals were more accurate at judging time-to-contact of a disappeared object when they could freely pursue the object with their eyes versus when they were

required to fixate the arrival location (Bennet et al., 2010). Further, individuals were more likely to accurately judge time-to-contact of an occluded object when their eye movements match the direction and speed of travel of the object (Bennett et al., 2010). The present research expands upon these findings by showing that eye movements only predicted time-to-contact estimates in a visual-only condition. Eye movements did not predict time-to-contact estimates in the audiovisual condition. It is possible that eye movements were used to inform time-to-contact estimates in the visual-only condition; with the addition of an auditory stimulus, higher order processes overruled eye movements. In other words, multisensory integration can permit the brain to take shortcuts when interpreting audiovisual stimuli (Török et al., 2014). As such, the brain only needs to partially interpret the auditory and visual information; eye movement may, therefore, not be interpreted in the audiovisual condition in the same way that they are interpreted in the visual-only condition. This was not tested in the current study and so it cannot be assessed using the current data. It is also possible that multisensory integration processes altered eye movements so that they no longer predict time-to-contact estimates. In other words, it is possible that the presence of an audiovisual stimulus led to different saccadic eye movements than those observed in the visual-only condition. Further research is needed to understand why eye movements did not predict time-to-contact estimates in the audiovisual condition. As stimuli for judgments of collisions rarely occur in real life as a unimodal stimulus, understanding the role of eye movements in judgments of collision when both auditory and visual stimuli are presented is of paramount importance.

Practical Implications

A secondary goal of this research was to understand how eye movements of individuals with central vision loss differ from those of individuals with normal vision in order to identify areas that could be used in vision rehabilitation training to increase mobility. Importantly, results indicated that individuals with central vision loss and individuals with normal vision had increased percentage estimates of time-to-contact when saccade amplitude and saccade duration increased; however, the central vision loss group had a greater increase of percentage estimates of time-to-contact as a result of increases in saccadic eye movement. Though there is a greater effect of saccadic eye movements on percentages estimates of time-to-contact for the central vision loss group, both groups saw an increase in time-to-contact estimates as a result of increases in saccadic eye movements. Audiovisual trials did not lead to eye movements predicting time-to-contact estimates for both groups, suggesting that an auditory stimulus may be beneficial to individuals with central vision loss when making time-to-contact judgments.

The goal of this study was to understand the impact of audiovisual stimuli in traffic environments on time-to-contact estimates to advise traffic safety organizations and develop visual aids with integrated auditory information. With the rise in electric vehicles, auditory information from a vehicle is no longer presented and could influence judgments of collisions in individuals with macular degeneration. Understanding differences in time-to-contact estimates between individuals with normal vision and individuals with macular degeneration could be used to enact new laws requiring that electric vehicles provide auditory information. Further, specific technologies could be created that transform visual approach motion into auditory approach motion

information. By doing so, individuals with macular degeneration could have an auditory stimulus along with a visual stimulus to make time-to-contact estimates. Future research needs to continue investigating time-to-contact judgments of individuals with macular degeneration so that traffic environments are safer to navigate.

Limitations and Future Directions

An important limitation of this work is the age difference between the central vision loss group and the normal vision group. Individuals with normal vision were undergraduate students and thus in their late teens or early twenties. Individuals with central vision loss were all diagnosed with age-related macular degeneration and thus were older, ranging in age from 59 to 92 years old. Despite this limitation, results for both groups showed similar direction of effects saccadic eye movements on percentage estimates of time-to-contact, suggesting that despite the age difference, individuals in both groups have a positive relationship between eye movement behavior and time-to-contact estimates. However, I plan to run this experiment with older adults with normal vision to confirm that similarities between group are replicated.

To provide converging evidence for the effects of saccadic eye movements on time-to-contact estimates, I will collect data when eye movements are controlled. If subjects don't move their eyes, time-to-contact estimates should remain constant. I will do this by having one group of participants focus on the building aligned with their location in the virtual environment, while another group will be directed to track the moving object with their eyes, similar to the methods in Bennet et al. (2010). If eye movements indeed play a role in time-to-contact estimates, discernible differences in TTC judgments should emerge between the two groups.

Conclusion

The purpose of the current research was two-fold. First, this research aimed to understand the impact of eye movement behavior on time-to-contact estimates in multimodal environments. Results suggest that eye movements do not predict time-to-contact estimates in an audiovisual task. Importantly for traffic environments, vehicles provide both auditory and visual information. Eye movements predicted time-to-contact estimates in the visual-only condition but not the audiovisual condition, meaning that results obtained from previous research focusing on visual-only information may not generalize to real traffic environments. As such, it is important to understand the limitations of previous research when generalizing results to multimodal environments.

Second, this research aimed to understand differences in eye movement in a time-to-contact task between individuals with normal vision and individuals with central vision loss. Results suggest that eye movements have a greater predictive power on time-to-contact estimates for individuals with central vision loss compared to individuals with normal vision. In other words, a one-point change in saccade amplitude or saccade duration led to greater movement in time-to-contact estimates in the central vision loss group compared to the normal vision group. Importantly, this effect was only observed in the visual-only condition; effect of eye movement on time-to-contact estimates were not observed for either vision groups in the audiovisual condition. This suggests that, though individuals with central vision loss may see greater effect of eye movements on time-to-contact estimates, the direction of the effect of saccadic eye movement on time-to-contact estimates is similar between groups. Hence, while the relationship between saccadic eye movements and time-to-contact estimates is notably more pronounced among individuals

with central vision loss than those with normal vision, it is important to emphasize that individuals with central vision loss do not exhibit entirely distinct eye movement patterns compared to their counterparts with normal vision. Both groups, in fact, demonstrate a consistent and aligned linear relationship between saccadic eye movements and time-to-contact estimates.

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Appendix A: Mixed Linear Effect Model Results for Aim One

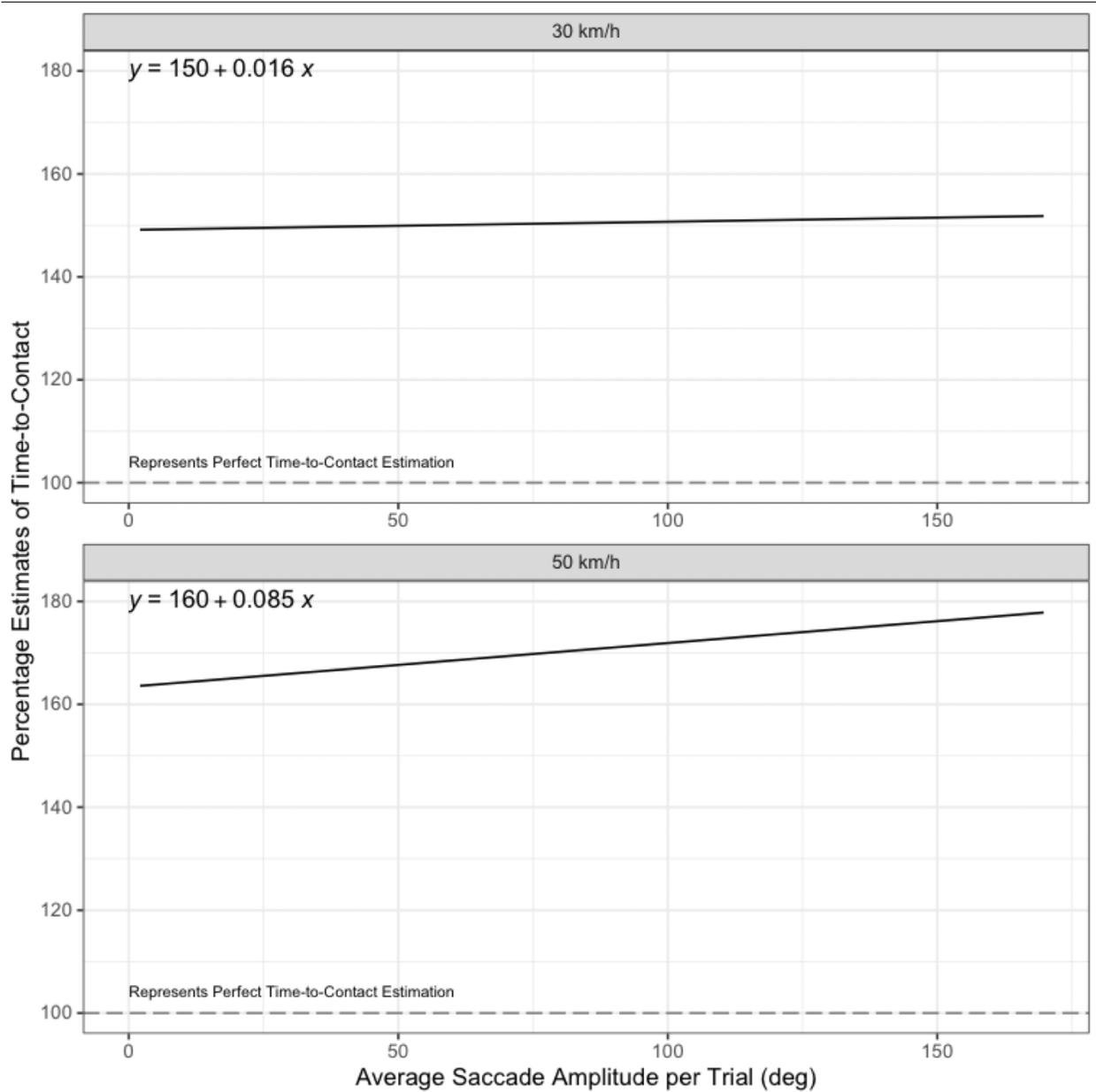
All main effects and two-way interactions from the linear mixed effect model

Main Effects and Interactions	Degrees of Freedom	Estimates (<i>B</i> value)
Saccade Amplitude	16,390	-0.25*
Fixation Duration	16,390	-6.27E-3
Saccade Duration	16,390	0.04*
Modality	16,390	8.37*
Vehicle Size	16,390	-2.24
Velocity	16,390	15.20*
Actual TTC	16,390	-23.49*
Saccade Amplitude by Modality	16,390	.22*
Saccade Amplitude by Vehicle Size	16,390	7.18E-3*
Saccade Amplitude by Velocity	16,390	.10*
Saccade Amplitude by Actual TTC	16,390	0.15*
Fixation Duration by Modality	16,390	1.32E-03
Fixation Duration by Vehicle Size	16,390	8.49E-03
Fixation Duration by Velocity	16,390	-8.87E-03
Fixation Duration by Actual TTC	16,390	.01
Saccade Duration by Modality	16,390	-0.06*
Saccade Duration by Vehicle Size	16,390	-7.91E-03

Saccade Duration by Velocity	16,390	2.91E-03
Saccade Duration by Actual TTC	16,390	-.02

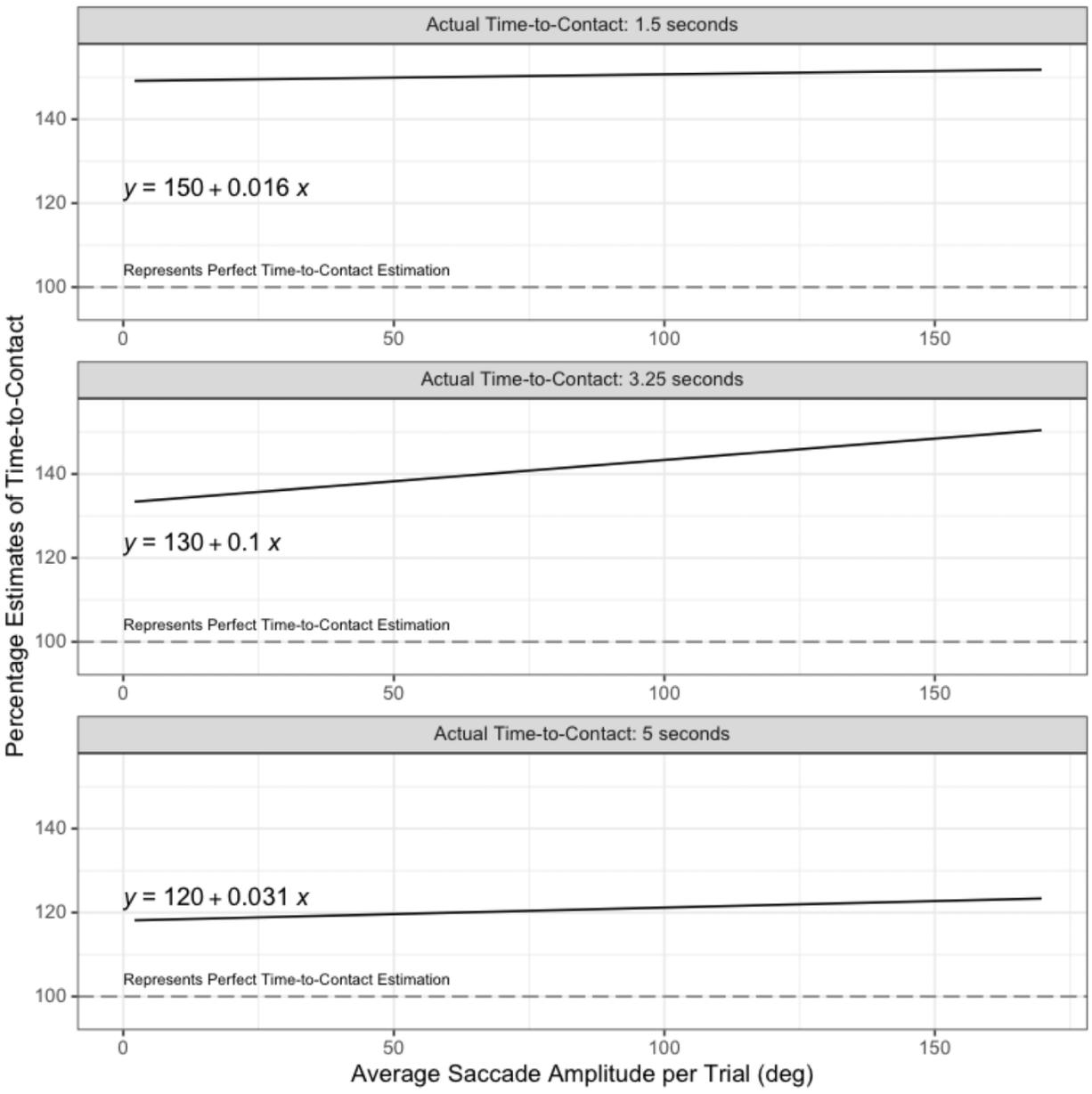
Graphs of significant results not included in results section

Interaction between Saccade Amplitudes and Vehicle Velocity on Estimated Time-to-Contact



Note. The dashed line represents perfect time-to-contact estimation. Estimates above the line represent overestimations and estimates below the line represent underestimations.

Interaction between Saccade Amplitudes and Actual Time-to-Contact on Estimated Time-to-Contact



Note. The dashed line represents perfect time-to-contact estimation. Estimates above the line represent overestimations and estimates below the line represent underestimations.

Appendix B: ANOVA Source Tables for Aim 1

Source Table for 2 (velocity: 30 km/h or 50 km/h) by 3 (actual time-to-contact: 1.5 s, 3.25 s or 5 s) by 2 (vehicle size: car or truck) within-subject ANOVA on Fixation Duration for the Visual-Only trials

Within Subjects Effects							
	Sphericity Correction	Sum of Squares	df	Mean Square	F	p	η^2_p
TTC	None	233666	2	116833	8.2258	0.001	0.314
	Greenhouse-Geisser	233666	1.82	128695	8.2258	0.002	0.314
Residual	None	511315	36	14203			
	Greenhouse-Geisser	511315	32.68	15645			
Velocity	None	143033	1	143033	15.0398	0.001	0.455
	Greenhouse-Geisser	143033	1.00	143033	15.0398	0.001	0.455
Residual	None	171185	18	9510			
	Greenhouse-Geisser	171185	18.00	9510			
Vehicle	None	4696	1	4696	1.3851	0.255	0.071
	Greenhouse-Geisser	4696	1.00	4696	1.3851	0.255	0.071
Residual	None	61026	18	3390			
	Greenhouse-Geisser	61026	18.00	3390			
TTC * Velocity	None	5272	2	2636	0.8643	0.430	0.046
	Greenhouse-Geisser	5272	1.94	2723	0.8643	0.427	0.046
Residual	None	109797	36	3050			
	Greenhouse-Geisser	109797	34.85	3151			
TTC * Vehicle	None	28789	2	14394	1.4808	0.241	0.076
	Greenhouse-Geisser	28789	1.18	24398	1.4808	0.242	0.076
Residual	None	349954	36	9721			
	Greenhouse-Geisser	349954	21.24	16477			
Velocity * Vehicle	None	5075	1	5075	1.3815	0.255	0.071
	Greenhouse-Geisser	5075	1.00	5075	1.3815	0.255	0.071
Residual	None	66130	18	3674			
	Greenhouse-Geisser	66130	18.00	3674			
TTC * Velocity * Vehicle	None	787	2	394	0.0943	0.910	0.005
	Greenhouse-Geisser	787	1.41	557	0.0943	0.844	0.005
Residual	None	150260	36	4174			
	Greenhouse-Geisser	150260	25.46	5903			

Note. Type 3 Sums of Squares

[3]

Between Subjects Effects						
	Sum of Squares	df	Mean Square	F	p	η^2_p
Residual	6.04e+6	18	335453			

Note. Type 3 Sums of Squares

Source Table for 2 (velocity: 30 km/h or 50 km/h) by 3 (actual time-to-contact: 1.5 s, 3.25 s or 5 s) by 2 (vehicle size: car or truck) within-subject ANOVA on Saccade Amplitude for the Visual-Only trials

Within Subjects Effects							
	Sphericity Correction	Sum of Squares	df	Mean Square	F	p	η^2_p
TTC	None	452.10	2	226.05	2.2069	0.125	0.109
	Greenhouse-Geisser	452.10	1.54	294.45	2.2069	0.139	0.109
Residual	None	3687.36	36	102.43			
	Greenhouse-Geisser	3687.36	27.64	133.42			
Velocity	None	725.04	1	725.04	11.9250	0.003	0.398
	Greenhouse-Geisser	725.04	1.00	725.04	11.9250	0.003	0.398
Residual	None	1094.39	18	60.80			
	Greenhouse-Geisser	1094.39	18.00	60.80			
Vehicle Size	None	7.94	1	7.94	0.0871	0.771	0.005
	Greenhouse-Geisser	7.94	1.00	7.94	0.0871	0.771	0.005
Residual	None	1640.07	18	91.12			
	Greenhouse-Geisser	1640.07	18.00	91.12			
TTC * Velocity	None	323.63	2	161.82	2.2926	0.116	0.113
	Greenhouse-Geisser	323.63	1.79	180.30	2.2926	0.122	0.113
Residual	None	2540.94	36	70.58			
	Greenhouse-Geisser	2540.94	32.31	78.65			
TTC * Vehicle Size	None	164.82	2	82.41	2.9755	0.064	0.142
	Greenhouse-Geisser	164.82	1.87	88.04	2.9755	0.068	0.142
Residual	None	997.07	36	27.70			
	Greenhouse-Geisser	997.07	33.70	29.59			
Velocity * Vehicle Size	None	57.12	1	57.12	1.7649	0.201	0.089
	Greenhouse-Geisser	57.12	1.00	57.12	1.7649	0.201	0.089
Residual	None	582.51	18	32.36			
	Greenhouse-Geisser	582.51	18.00	32.36			
TTC * Velocity * Vehicle Size	None	169.67	2	84.84	1.3454	0.273	0.070
	Greenhouse-Geisser	169.67	1.55	109.78	1.3454	0.271	0.070
Residual	None	2270.10	36	63.06			
	Greenhouse-Geisser	2270.10	27.82	81.60			

Note. Type 3 Sums of Squares

[9]

Between Subjects Effects						
	Sum of Squares	df	Mean Square	F	p	η^2_p
Residual	49355	18	2742			

Note. Type 3 Sums of Squares

Source Table for 2 (velocity: 30 km/h or 50 km/h) by 3 (actual time-to-contact: 1.5 s, 3.25 s or 5 s) by 2 (vehicle size: car or truck) within-subject ANOVA on Saccade Duration for the Visual-Only trials

Within Subjects Effects							
	Sphericity Correction	Sum of Squares	df	Mean Square	F	p	η^2_p
TTC	None	2226	2	1113	2.220	0.123	0.110
	Greenhouse-Geisser	2226	1.61	1382	2.220	0.135	0.110
Residual	None	18045	36	501			
	Greenhouse-Geisser	18045	28.99	622			
Velocity	None	397	1	397	0.166	0.689	0.009
	Greenhouse-Geisser	397	1.00	397	0.166	0.689	0.009
Residual	None	43066	18	2393			
	Greenhouse-Geisser	43066	18.00	2393			
Vehicle	None	930	1	930	0.984	0.334	0.052
	Greenhouse-Geisser	930	1.00	930	0.984	0.334	0.052
Residual	None	17000	18	944			
	Greenhouse-Geisser	17000	18.00	944			
TTC * Velocity	None	1254	2	627	1.235	0.303	0.064
	Greenhouse-Geisser	1254	1.31	956	1.235	0.292	0.064
Residual	None	18279	36	508			
	Greenhouse-Geisser	18279	23.62	774			
TTC * Vehicle	None	2352	2	1176	2.255	0.119	0.111
	Greenhouse-Geisser	2352	1.59	1477	2.255	0.132	0.111
Residual	None	18774	36	522			
	Greenhouse-Geisser	18774	28.66	655			
Velocity * Vehicle	None	794	1	794	1.983	0.176	0.099
	Greenhouse-Geisser	794	1.00	794	1.983	0.176	0.099
Residual	None	7205	18	400			
	Greenhouse-Geisser	7205	18.00	400			
TTC * Velocity * Vehicle	None	1423	2	712	1.059	0.357	0.056
	Greenhouse-Geisser	1423	1.22	1166	1.059	0.330	0.056
Residual	None	24190	36	672			
	Greenhouse-Geisser	24190	21.98	1101			

Note. Type 3 Sums of Squares

[3]

Between Subjects Effects						
	Sum of Squares	df	Mean Square	F	p	η^2_p
Residual	345542	18	19197			

Note. Type 3 Sums of Squares

Source Table for 2 (velocity: 30 km/h or 50 km/h) by 3 (actual time-to-contact: 1.5 s, 3.25 s or 5 s) by 2 (vehicle size: car or truck) by 2 (modality: visual-only or audiovisual) within-subjects ANOVA on fixation duration for the Visual and Audiovisual Trials

Within Subjects Effects						
	Sum of Squares	df	Mean Square	F	p	η^2_p
TTC	368103.6	2	184051.8	17.87708	<.001	0.498
Residual	370634.6	36	10295.4			
Velocity	214419.0	1	214419.0	23.01814	<.001	0.561
Residual	167674.0	18	9315.2			
Vehicle	12.3	1	12.3	0.00368	0.952	0.000
Residual	60169.9	18	3342.8			
Modality	41538.3	1	41538.3	1.01462	0.327	0.053
Residual	736917.9	18	40939.9			
TTC * Velocity	4576.6	2	2288.3	1.04715	0.361	0.055
Residual	78669.8	36	2185.3			
TTC * Vehicle	12005.1	2	6002.6	1.30900	0.283	0.068
Residual	165081.7	36	4585.6			
Velocity * Vehicle	1816.0	1	1816.0	0.44215	0.515	0.024
Residual	73929.3	18	4107.2			
TTC * Modality	18456.4	2	9228.2	1.20261	0.312	0.063
Residual	276245.6	36	7673.5			
Velocity * Modality	5154.9	1	5154.9	1.40431	0.251	0.072
Residual	66073.4	18	3670.7			
Vehicle * Modality	10084.1	1	10084.1	7.80562	0.012	0.302
Residual	23254.1	18	1291.9			
TTC * Velocity * Vehicle	78.0	2	39.0	0.01872	0.981	0.001
Residual	74996.1	36	2083.2			
TTC * Velocity * Modality	1316.7	2	658.4	0.20944	0.812	0.012
Residual	113165.9	36	3143.5			
TTC * Vehicle * Modality	17743.5	2	8871.7	1.45408	0.247	0.075
Residual	219645.0	36	6101.3			
Velocity * Vehicle * Modality	3380.0	1	3380.0	3.73768	0.069	0.172
Residual	16277.5	18	904.3			
TTC * Velocity * Vehicle * Modality	2347.0	2	1173.5	0.38649	0.682	0.021
Residual	109305.3	36	3036.3			

Note. Type 3 Sums of Squares

[3]

Between Subjects Effects						
	Sum of Squares	df	Mean Square	F	p	η^2_p
Residual	7.98e+6	18	443121			

Note. Type 3 Sums of Squares

Source Table for 2 (velocity: 30 km/h or 50 km/h) by 3 (actual time-to-contact: 1.5 s, 3.25 s or 5 s) by 2 (vehicle size: car or truck) by 2 (modality: visual-only or audiovisual) within-subjects ANOVA on Saccade Amplitude for the Visual and Audiovisual Trials

Within Subjects Effects

	Sum of Squares	df	Mean Square	F	p	η^2_p
TTC	63.8	2	31.9	0.3823	0.685	0.021
Residual	3006.1	36	83.5			
Velocity	807.4	1	807.4	15.7617	<.001	0.467
Residual	922.1	18	51.2			
Vehicle Size	17.2	1	17.2	0.3710	0.550	0.020
Residual	835.8	18	46.4			
Modality	11.6	1	11.6	0.0355	0.853	0.002
Residual	5888.0	18	327.1			
TTC * Velocity	152.5	2	76.2	2.1903	0.127	0.108
Residual	1253.3	36	34.8			
TTC * Vehicle Size	71.3	2	35.7	1.9151	0.162	0.096
Residual	670.4	36	18.6			
Velocity * Vehicle Size	16.5	1	16.5	0.8686	0.364	0.046
Residual	342.3	18	19.0			
TTC * Modality	538.8	2	269.4	4.6674	0.016	0.206
Residual	2077.8	36	57.7			
Velocity * Modality	93.4	1	93.4	1.5545	0.228	0.079
Residual	1081.5	18	60.1			
Vehicle Size * Modality	66.2	1	66.2	0.8763	0.362	0.046
Residual	1359.2	18	75.5			
TTC * Velocity * Vehicle Size	134.8	2	67.4	2.0892	0.139	0.104
Residual	1161.3	36	32.3			
TTC * Velocity * Modality	471.0	2	235.5	4.4854	0.018	0.199
Residual	1890.1	36	52.5			
TTC * Vehicle Size * Modality	125.6	2	62.8	2.4943	0.097	0.122
Residual	906.4	36	25.2			
Velocity * Vehicle Size * Modality	43.9	1	43.9	1.4687	0.241	0.075
Residual	537.7	18	29.9			
TTC * Velocity * Vehicle Size * Modality	179.0	2	89.5	1.8543	0.171	0.093
Residual	1738.0	36	48.3			

Note. Type 3 Sums of Squares

[3]

Between Subjects Effects

	Sum of Squares	df	Mean Square	F	p	η^2_p
Residual	80156	18	4453			

Note. Type 3 Sums of Squares

Source Table for 2 (velocity: 30 km/h or 50 km/h) by 3 (actual time-to-contact: 1.5 s, 3.25 s or 5 s) by 2 (vehicle size: car or truck) by 2 (modality: visual-only or audiovisual) within-subjects ANOVA on Saccade Duration for the Visual and Audiovisual Trials

Within Subjects Effects

	Sum of Squares	df	Mean Square	F	p	η^2_p
TTC	1472.9	2	736.4	1.7643	0.186	0.089
Residual	15026.5	36	417.4			
Velocity	26.1	1	26.1	0.0204	0.888	0.001
Residual	23067.9	18	1281.5			
Vehicle	411.5	1	411.5	0.8672	0.364	0.046
Residual	8541.4	18	474.5			
Modality	223.2	1	223.2	0.0662	0.800	0.004
Residual	60696.4	18	3372.0			
TTC * Velocity	522.5	2	261.2	1.2204	0.307	0.063
Residual	7706.1	36	214.1			
TTC * Vehicle	375.3	2	187.7	0.7162	0.495	0.038
Residual	9433.4	36	262.0			
Velocity * Vehicle	674.6	1	674.6	2.3194	0.145	0.114
Residual	5235.1	18	290.8			
TTC * Modality	1042.6	2	521.3	1.8467	0.172	0.093
Residual	10162.8	36	282.3			
Velocity * Modality	532.1	1	532.1	0.3949	0.538	0.021
Residual	24252.2	18	1347.3			
Vehicle * Modality	521.3	1	521.3	0.6740	0.422	0.036
Residual	13920.4	18	773.4			
TTC * Velocity * Vehicle	520.0	2	260.0	0.9143	0.410	0.048
Residual	10237.9	36	284.4			
TTC * Velocity * Modality	1074.1	2	537.0	1.4285	0.253	0.074
Residual	13534.2	36	376.0			
TTC * Vehicle * Modality	2445.1	2	1222.6	2.9809	0.063	0.142
Residual	14765.0	36	410.1			
Velocity * Vehicle * Modality	192.3	1	192.3	0.8272	0.375	0.044
Residual	4185.3	18	232.5			
TTC * Velocity * Vehicle * Modality	1287.1	2	643.5	1.2338	0.303	0.064
Residual	18777.6	36	521.6			

Note. Type 3 Sums of Squares

[3]

Between Subjects Effects

	Sum of Squares	df	Mean Square	F	p	η^2_p
Residual	504744	18	28041			

Note. Type 3 Sums of Squares

Source Table for a 2 (velocity: 30 km/h or 50 km/h) by 3 (actual time-to-contact: 1.5 s, 3.25 s or 5 s) by 2 (vehicle size: car or truck) by 2 (gain: soft or loud) within-subjects ANOVA on Fixation Duration for the Audiovisual trials only

Within Subjects Effects						
	Sum of Squares	df	Mean Square	F	p	η^2_p
Gain	12813	1	12813.1	1.8365	0.192	0.093
Residual	125584	18	6976.9			
TTC	306634	2	153316.9	19.5158	<.001	0.520
Residual	282818	36	7856.1			
Velocity	158459	1	158459.4	25.0002	<.001	0.581
Residual	114090	18	6338.3			
Vehicle	11364	1	11364.0	4.9840	0.039	0.217
Residual	41042	18	2280.1			
Gain * TTC	1473	2	736.5	0.3219	0.727	0.018
Residual	82382	36	2288.4			
Gain * Velocity	2977	1	2977.1	0.8286	0.375	0.044
Residual	64672	18	3592.9			
TTC * Velocity	1648	2	824.0	0.1789	0.837	0.010
Residual	165787	36	4605.2			
Gain * Vehicle	351	1	350.8	0.2484	0.624	0.014
Residual	25417	18	1412.1			
TTC * Vehicle	2524	2	1262.2	0.5364	0.589	0.029
Residual	84705	36	2352.9			
Velocity * Vehicle	250	1	250.2	0.0777	0.784	0.004
Residual	57993	18	3221.8			
Gain * TTC * Velocity	5969	2	2984.3	1.2325	0.304	0.064
Residual	87166	36	2421.3			
Gain * TTC * Vehicle	146	2	73.2	0.0211	0.979	0.001
Residual	125149	36	3476.4			
Gain * Velocity * Vehicle	1820	1	1820.2	0.9507	0.342	0.050
Residual	34463	18	1914.6			
TTC * Velocity * Vehicle	4468	2	2234.0	1.0858	0.348	0.057
Residual	74069	36	2057.5			
Gain * TTC * Velocity * Vehicle	1657	2	828.3	0.4206	0.660	0.023
Residual	70900	36	1969.5			

Note. Type 3 Sums of Squares

[3]

Between Subjects Effects						
	Sum of Squares	df	Mean Square	F	p	η^2_p
Residual	5.49e+6	18	305143			

Note. Type 3 Sums of Squares

Source Table for a 2 (velocity: 30 km/h or 50 km/h) by 3 (actual time-to-contact: 1.5 s, 3.25 s or 5 s) by 2 (vehicle size: car or truck) by 2 (gain: soft or loud) within-subjects ANOVA on Saccade Amplitude for the Audiovisual trials only

Within Subjects Effects						
	Sum of Squares	df	Mean Square	F	p	η^2_p
Gain	251.601	1	251.601	4.56775	0.047	0.202
Residual	991.475	18	55.082			
TTC	332.729	2	166.364	2.04099	0.145	0.102
Residual	2934.422	36	81.512			
Velocity	371.893	1	371.893	3.74211	0.069	0.172
Residual	1788.852	18	99.381			
Vehicle	146.935	1	146.935	2.42974	0.136	0.119
Residual	1088.527	18	60.474			
Gain * TTC	21.040	2	10.520	0.36123	0.699	0.020
Residual	1048.392	36	29.122			
Gain * Velocity	92.967	1	92.967	5.87512	0.026	0.246
Residual	284.829	18	15.824			
TTC * Velocity	597.973	2	298.987	8.82951	<.001	0.329
Residual	1219.040	36	33.862			
Gain * Vehicle	63.591	1	63.591	1.88423	0.187	0.095
Residual	607.478	18	33.749			
TTC * Vehicle	60.429	2	30.215	0.88195	0.423	0.047
Residual	1233.327	36	34.259			
Velocity * Vehicle	12.638	1	12.638	0.39907	0.536	0.022
Residual	570.024	18	31.668			
Gain * TTC * Velocity	4.100	2	2.050	0.06519	0.937	0.004
Residual	1131.968	36	31.444			
Gain * TTC * Vehicle	46.205	2	23.102	0.67259	0.517	0.036
Residual	1236.543	36	34.348			
Gain * Velocity * Vehicle	0.156	1	0.156	0.00663	0.936	0.000
Residual	422.622	18	23.479			
TTC * Velocity * Vehicle	262.691	2	131.345	4.11265	0.025	0.186
Residual	1149.728	36	31.937			
Gain * TTC * Velocity * Vehicle	7.469	2	3.734	0.09523	0.909	0.005
Residual	1411.728	36	39.215			

Note. Type 3 Sums of Squares

[3]

Between Subjects Effects						
	Sum of Squares	df	Mean Square	F	p	η^2_p
Residual	73502	18	4083			

Note. Type 3 Sums of Squares

Source Table for a 2 (velocity: 30 km/h or 50 km/h) by 3 (actual time-to-contact: 1.5 s, 3.25 s or 5 s) by 2 (vehicle size: car or truck) by 2 (gain: soft or loud) within-subjects ANOVA on Saccade Duration for the Audiovisual trials only

Within Subjects Effects

	Sum of Squares	df	Mean Square	F	p	η^2_p
Gain	1003.34	1	1003.34	2.5878	0.125	0.126
Residual	6979.07	18	387.73			
TTC	785.52	2	392.76	0.9180	0.408	0.049
Residual	15401.79	36	427.83			
Velocity	357.85	1	357.85	0.7640	0.394	0.041
Residual	8431.37	18	468.41			
Vehicle	19.60	1	19.60	0.0336	0.857	0.002
Residual	10505.28	18	583.63			
Gain * TTC	197.29	2	98.64	0.4516	0.640	0.024
Residual	7863.37	36	218.43			
Gain * Velocity	507.07	1	507.07	1.9222	0.183	0.096
Residual	4748.32	18	263.80			
TTC * Velocity	839.33	2	419.66	2.3718	0.108	0.116
Residual	6369.71	36	176.94			
Gain * Vehicle	285.14	1	285.14	1.5058	0.236	0.077
Residual	3408.67	18	189.37			
TTC * Vehicle	940.97	2	470.48	1.3262	0.278	0.069
Residual	12771.67	36	354.77			
Velocity * Vehicle	91.01	1	91.01	0.3467	0.563	0.019
Residual	4725.74	18	262.54			
Gain * TTC * Velocity	190.93	2	95.46	0.2476	0.782	0.014
Residual	13878.46	36	385.51			
Gain * TTC * Vehicle	457.30	2	228.65	0.4055	0.670	0.022
Residual	20301.31	36	563.93			
Gain * Velocity * Vehicle	9.79	1	9.79	0.0275	0.870	0.002
Residual	6407.75	18	355.99			
TTC * Velocity * Vehicle	739.96	2	369.98	1.3063	0.283	0.068
Residual	10196.41	36	283.23			
Gain * TTC * Velocity * Vehicle	1991.75	2	995.87	1.8622	0.170	0.094
Residual	19252.53	36	534.79			

Note. Type 3 Sums of Squares

[3]

Between Subjects Effects

	Sum of Squares	df	Mean Square	F	p	η^2_p
Residual	441112	18	24506			

Note. Type 3 Sums of Squares

Appendix C: Mixed Linear Effect Model Results for Aim Two

Complete table of results

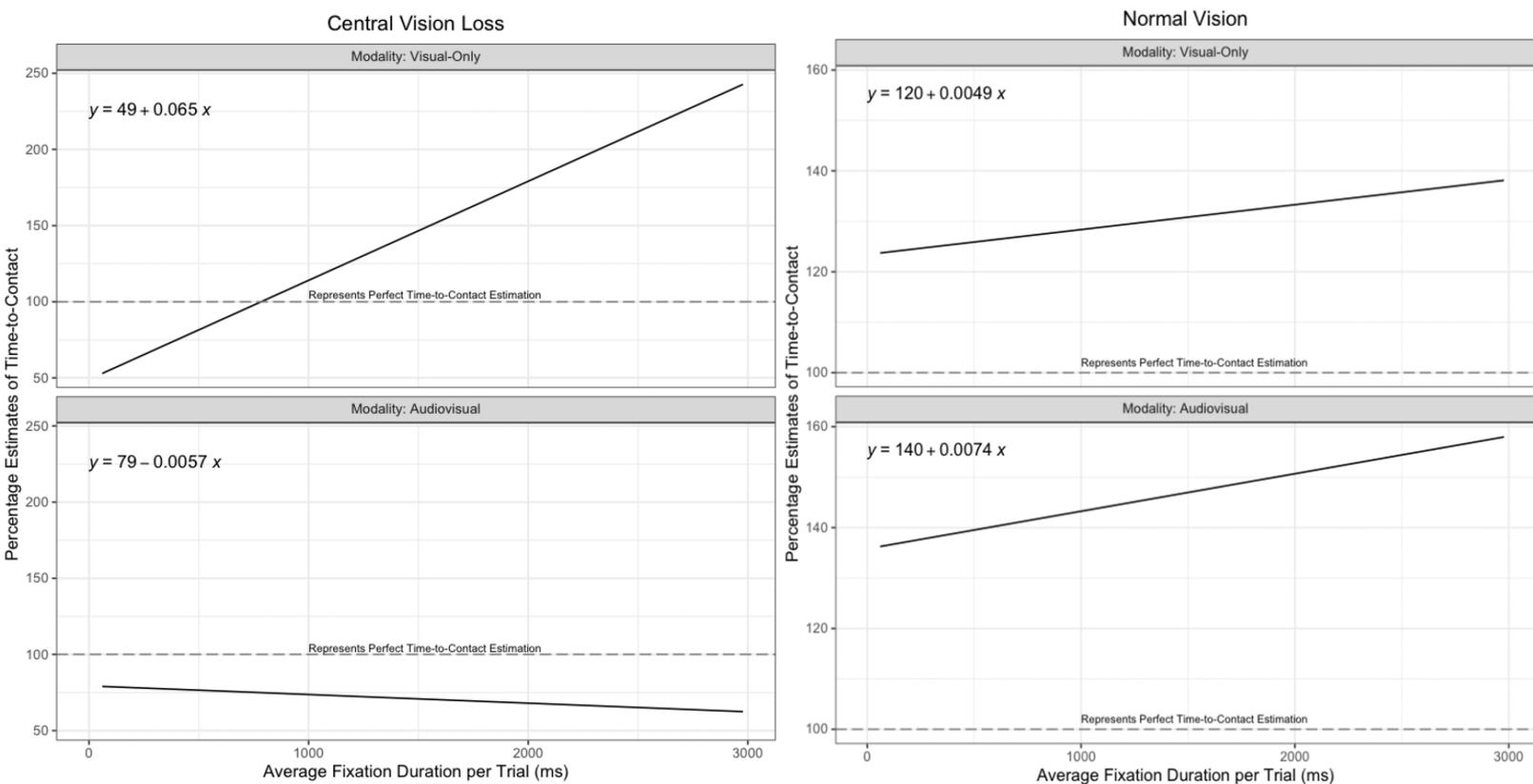
All two-way and three-way interactions from the linear mixed effect model

Interactions	Degrees of Freedom	Estimates (<i>B</i> values)
Group by Modality	13,000	-17.29*
Group by Velocity	13,000	-23.10*
Group by Vehicle Size	13,000	.51
Group by Actual Time-to-Contact	13,000	-35.20*
Group by Saccade Amplitude	13,000	-.44*
Group by Fixation Duration	13,000	-.04*
Group by Saccade Duration	13,000	-.19*
Group by Modality by Saccade Amplitude	13,000	-.04
Group by Vehicle Size by Saccade Amplitude	13,000	.10
Group by Velocity by Saccade Amplitude	13,000	-.04
Group by Actual Time-to-Contact by Saccade Amplitude	13,000	.49*
Group by Modality by Fixation Duration	13,000	.07*
Group by Vehicle Size by Fixation Duration	13,000	-.10
Group by Velocity by Fixation Duration	13,000	6.60E-03
Group by Actual Time-to-Contact by Fixation Duration	13,000	-4.34E-03
Group by Modality by Saccade Duration	13,000	.20
Group by Vehicle Size by Saccade Duration	13,000	-2.60E-03
Group by Velocity by Saccade Duration	13,000	-.05
Group by Actual Time-to-Contact by Saccade Duration	13,000	.30*

Note. * denotes a significant value of $p < .05$.

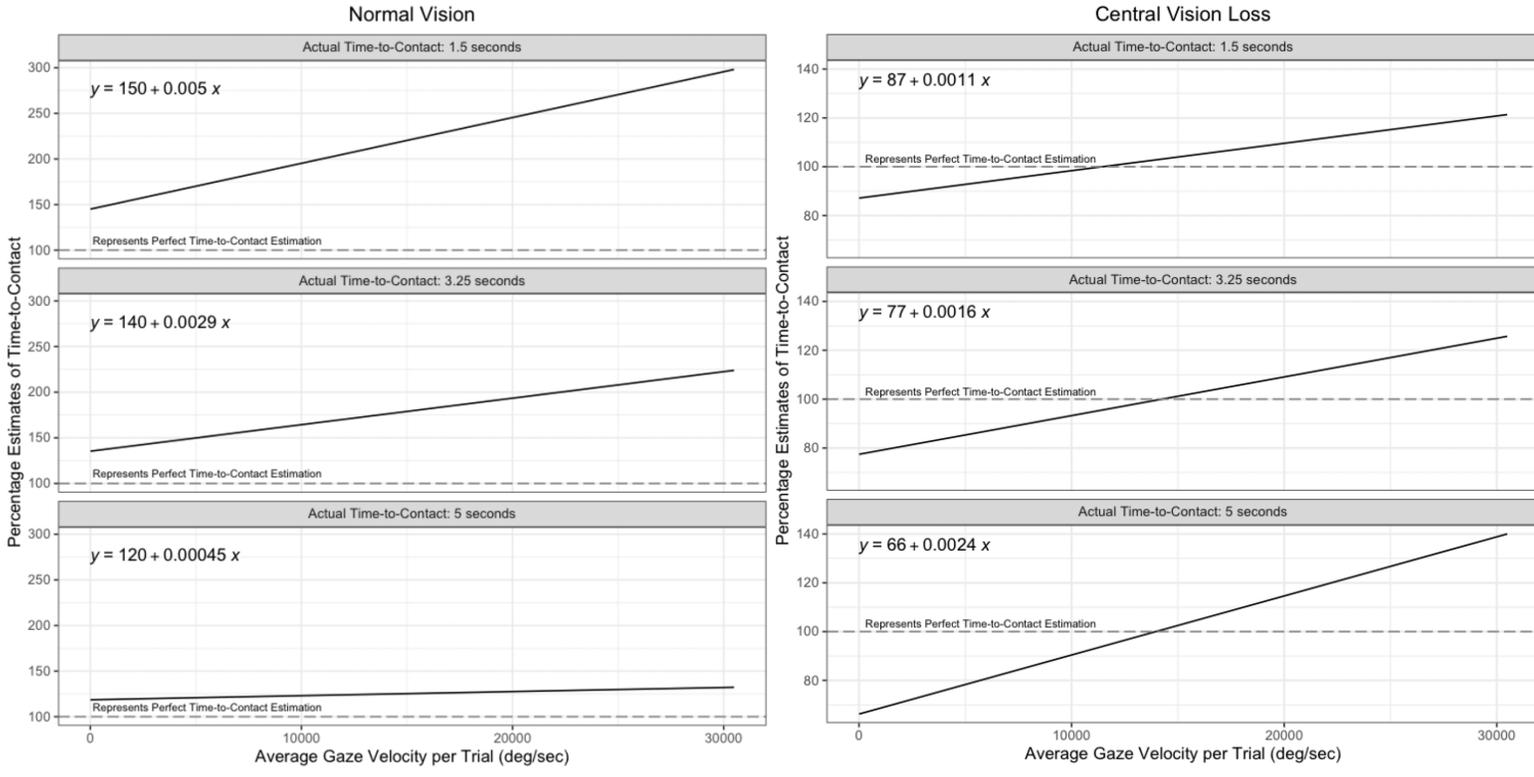
Graphs of significant results not included in results section

Interaction between Saccade Duration, Actual Time-to-Contact and Group Assignment on Estimated Time-to-Contact



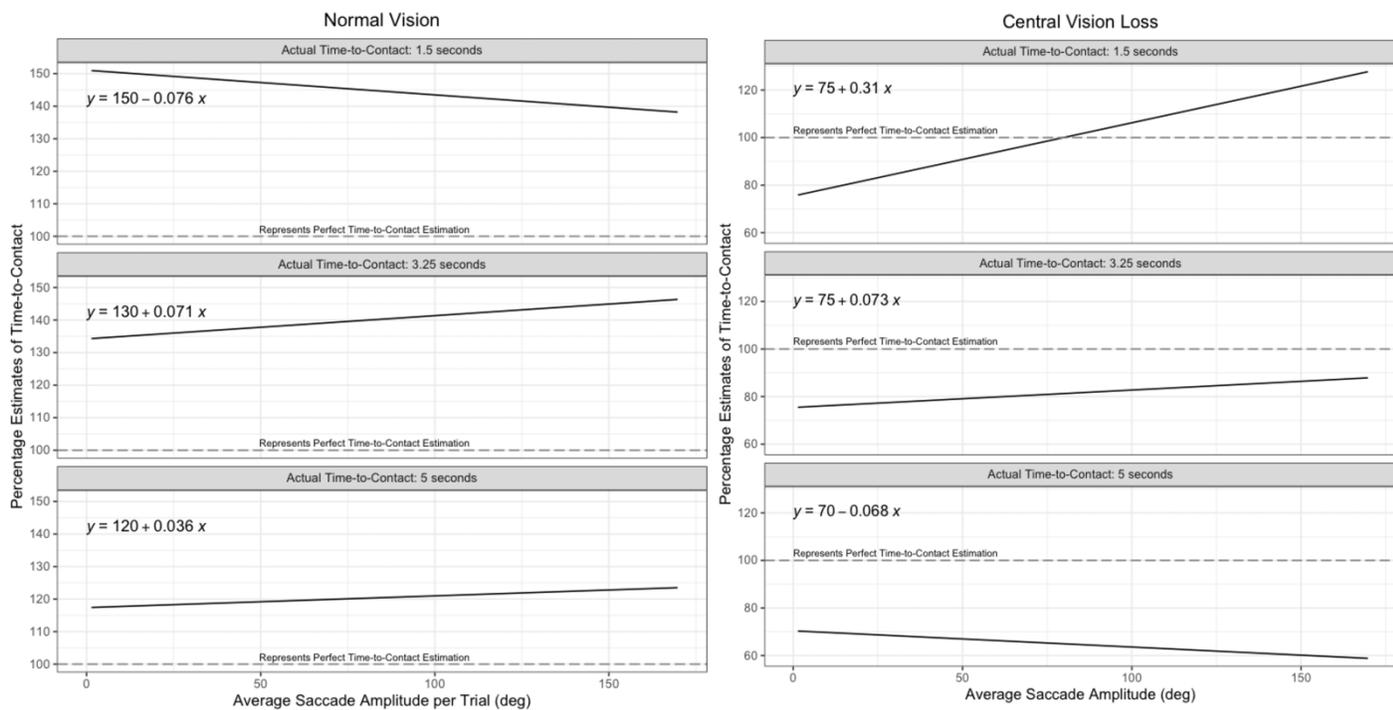
Note. The dashed line represents perfect time-to-contact estimation. Estimates above the line represent overestimations and estimates below the line represent underestimations.

Interaction between Gaze Velocity, Actual Time-to-Contact and Group Assignment on Estimated Time-to-Contact



Note. The dashed line represents perfect time-to-contact estimation. Estimates above the line represent overestimations and estimates below the line represent underestimations.

Interaction between Saccade Amplitude, Actual Time-to-Contact and Group Assignment on Estimated Time-to-Contact



Note. The dashed line represents perfect time-to-contact estimation. Estimates above the line represent overestimations and estimates below the line represent underestimations.

Appendix D: ANOVA Source Tables for Aim 2

Source Table for 2 (velocity: 30 km/h or 50 km/h) by 3 (actual time-to-contact: 1.5 s, 3.25 s or 5 s) by 2 (vehicle size: car or truck) by 2 (modality: visual-only or audiovisual) by 3 (group: central vision loss or normal vision) mixed design ANOVA on saccade amplitude for the control and central vision loss groups

Within Subjects Effects						
	Sum of Squares	df	Mean Square	F	p	η^2_p
Modality	82.7644	1	82.7644	0.15387	0.698	0.006
Modality * group	30.9237	1	30.9237	0.05749	0.813	0.002
Residual	12909.3296	24	537.8887			
Actual TTC	92.3362	2	46.1681	0.57937	0.564	0.024
Actual TTC * group	18.6820	2	9.3410	0.11722	0.890	0.005
Residual	3824.9308	48	79.6861			
Velocity	927.3368	1	927.3368	17.06135	<.001	0.416
Velocity * group	0.9300	1	0.9300	0.01711	0.897	0.001
Residual	1304.4738	24	54.3531			
Vehicle	40.5197	1	40.5197	1.07148	0.311	0.043
Vehicle * group	4.2360	1	4.2360	0.11201	0.741	0.005
Residual	907.6013	24	37.8167			
Modality * Actual TTC	676.1487	2	338.0744	5.61734	0.006	0.190
Modality * Actual TTC * group	11.2989	2	5.6495	0.09387	0.911	0.004
Residual	2888.8357	48	60.1841			
Modality * Velocity	148.1626	1	148.1626	2.96503	0.098	0.110
Modality * Velocity * group	4.5915	1	4.5915	0.09189	0.764	0.004
Residual	1199.2814	24	49.9701			
Actual TTC * Velocity	139.5012	2	69.7506	2.11254	0.132	0.081
Actual TTC * Velocity * group	10.4950	2	5.2475	0.15893	0.854	0.007
Residual	1584.8394	48	33.0175			
Modality * Vehicle	51.4250	1	51.4250	0.84694	0.367	0.034
Modality * Vehicle * group	1.6148	1	1.6148	0.02659	0.872	0.001
Residual	1457.2498	24	60.7187			
Actual TTC * Vehicle	91.9053	2	45.9527	2.72230	0.076	0.102
Actual TTC * Vehicle * group	113.0636	2	56.5318	3.34902	0.043	0.122
Residual	810.2446	48	16.8801			
Velocity * Vehicle	19.6323	1	19.6323	1.32062	0.262	0.052
Velocity * Vehicle * group	0.0454	1	0.0454	0.00306	0.956	0.000
Residual	356.7836	24	14.8660			
Modality * Actual TTC * Velocity	303.8061	2	151.9031	3.12984	0.053	0.115
Modality * Actual TTC * Velocity * group	26.2009	2	13.1004	0.26992	0.765	0.011
Residual	2329.6238	48	48.5338			
Modality * Actual TTC * Vehicle	39.9056	2	19.9528	0.97858	0.383	0.039
Modality * Actual TTC * Vehicle * group	89.1733	2	44.5866	2.18674	0.123	0.084
Residual	978.6986	48	20.3896			
Modality * Velocity * Vehicle	28.9813	1	28.9813	1.23506	0.277	0.049
Modality * Velocity * Vehicle * group	2.2210	1	2.2210	0.09465	0.761	0.004
Residual	563.1723	24	23.4655			
Actual TTC * Velocity * Vehicle	114.2579	2	57.1289	2.10922	0.132	0.081
Actual TTC * Velocity * Vehicle * group	135.3693	2	67.6847	2.49894	0.093	0.094
Residual	1300.0948	48	27.0853			
Modality * Actual TTC * Velocity * Vehicle	11.4526	2	5.7263	0.12612	0.882	0.005
Modality * Actual TTC * Velocity * Vehicle * group	115.6348	2	57.8174	1.27344	0.289	0.050
Residual	2179.3269	48	45.4026			

Note. Type 3 Sums of Squares

[3]

Between Subjects Effects

	Sum of Squares	df	Mean Square	F	p	η^2_p
group	10611	1	10611	2.46	0.130	0.093
Residual	103559	24	4315			

Note. Type 3 Sums of Squares

Source Table for 2 (velocity: 30 km/h or 50 km/h) by 3 (actual time-to-contact: 1.5 s, 3.25 s or 5 s) by 2 (vehicle size: car or truck) by 2 (modality: visual-only or audiovisual) by 3 (group: central vision loss or normal vision) mixed design ANOVA on saccade duration for the control and central vision loss groups

Within Subjects Effects

	Sum of Squares	df	Mean Square	F	p	η^2_p
Modality	1285.282	1	1285.282	0.3933	0.536	0.016
Modality * group	414.017	1	414.017	0.1267	0.725	0.005
Residual	78421.677	24	3267.570			
Actual TTC	1403.257	2	701.628	1.2468	0.297	0.049
Actual TTC * group	3459.643	2	1729.822	3.0738	0.055	0.114
Residual	27012.447	48	562.759			
Velocity	124.484	1	124.484	0.1016	0.753	0.004
Velocity * group	34.236	1	34.236	0.0279	0.869	0.001
Residual	29411.985	24	1225.499			
Vehicle	132.157	1	132.157	0.3498	0.560	0.014
Vehicle * group	91.313	1	91.313	0.2417	0.627	0.010
Residual	9067.816	24	377.826			
Modality * Actual TTC	1189.273	2	594.636	1.7977	0.177	0.070
Modality * Actual TTC * group	26.147	2	13.074	0.0395	0.961	0.002
Residual	15876.933	48	330.769			
Modality * Velocity	156.996	1	156.996	0.1327	0.719	0.005
Modality * Velocity * group	130.128	1	130.128	0.1100	0.743	0.005
Residual	28397.973	24	1183.249			
Actual TTC * Velocity	698.882	2	349.441	1.5545	0.222	0.061
Actual TTC * Velocity * group	138.645	2	69.322	0.3084	0.736	0.013
Residual	10790.011	48	224.792			
Modality * Vehicle	593.233	1	593.233	0.9891	0.330	0.040
Modality * Vehicle * group	0.440	1	0.440	7.34e-4	0.979	0.000
Residual	14394.336	24	599.764			
Actual TTC * Vehicle	221.827	2	110.913	0.4358	0.649	0.018
Actual TTC * Vehicle * group	742.301	2	371.151	1.4585	0.243	0.057
Residual	12214.903	48	254.477			
Velocity * Vehicle	30.876	1	30.876	0.1255	0.726	0.005
Velocity * Vehicle * group	457.795	1	457.795	1.8605	0.185	0.072
Residual	5905.417	24	246.059			
Modality * Actual TTC * Velocity	737.951	2	368.975	1.1121	0.337	0.044
Modality * Actual TTC * Velocity * group	48.176	2	24.088	0.0726	0.930	0.003
Residual	15924.930	48	331.769			
Modality * Actual TTC * Vehicle	903.051	2	451.525	1.3530	0.268	0.053
Modality * Actual TTC * Vehicle * group	1057.907	2	528.954	1.5850	0.215	0.062
Residual	16019.128	48	333.732			
Modality * Velocity * Vehicle	9.904	1	9.904	0.0489	0.827	0.002
Modality * Velocity * Vehicle * group	126.445	1	126.445	0.6243	0.437	0.025
Residual	4860.994	24	202.541			
Actual TTC * Velocity * Vehicle	45.612	2	22.806	0.0929	0.911	0.004
Actual TTC * Velocity * Vehicle * group	587.652	2	293.826	1.1964	0.311	0.047
Residual	11788.666	48	245.597			
Modality * Actual TTC * Velocity * Vehicle	102.652	2	51.326	0.1227	0.885	0.005
Modality * Actual TTC * Velocity * Vehicle * group	830.868	2	415.434	0.9931	0.378	0.040
Residual	20079.152	48	418.316			

Note. Type 3 Sums of Squares

[3]

Between Subjects Effects

	Sum of Squares	df	Mean Square	F	p	η^2_p
group	4201	1	4201	0.190	0.667	0.008
Residual	530860	24	22119			

Note. Type 3 Sums of Squares

Source Table for 2 (velocity: 30 km/h or 50 km/h) by 3 (actual time-to-contact: 1.5 s, 3.25 s or 5 s) by 2 (vehicle size: car or truck) by 2 (modality: visual-only or audiovisual) by 3 (group: central vision loss or normal vision) mixed design ANOVA on fixation duration for the control and central vision loss groups

Within Subjects Effects

	Sum of Squares	df	Mean Square	F	p	η^2_p
Modality	34025.5	1	34025.5	1.0433	0.317	0.042
Modality * group	731.3	1	731.3	0.0224	0.882	0.001
Residual	782705.2	24	32612.7			
Actual TTC	151692.4	2	75846.2	9.0023	<.001	0.273
Actual TTC * group	58732.0	2	29366.0	3.4855	0.039	0.127
Residual	404407.4	48	8425.2			
Velocity	70042.0	1	70042.0	8.7731	0.007	0.268
Velocity * group	46603.9	1	46603.9	5.8373	0.024	0.196
Residual	191610.2	24	7983.8			
Vehicle	650.4	1	650.4	0.2181	0.645	0.009
Vehicle * group	849.4	1	849.4	0.2849	0.598	0.012
Residual	71565.9	24	2981.9			
Modality * Actual TTC	2275.5	2	1137.8	0.1889	0.829	0.008
Modality * Actual TTC * group	15118.1	2	7559.1	1.2548	0.294	0.050
Residual	289153.9	48	6024.0			
Modality * Velocity	3198.8	1	3198.8	0.9028	0.351	0.036
Modality * Velocity * group	322.2	1	322.2	0.0909	0.766	0.004
Residual	85033.8	24	3543.1			
Actual TTC * Velocity	7102.2	2	3551.1	1.4882	0.236	0.058
Actual TTC * Velocity * group	895.1	2	447.6	0.1876	0.830	0.008
Residual	114537.0	48	2386.2			
Modality * Vehicle	3290.2	1	3290.2	3.0447	0.094	0.113
Modality * Vehicle * group	2194.9	1	2194.9	2.0311	0.167	0.078
Residual	25935.1	24	1080.6			
Actual TTC * Vehicle	3918.4	2	1959.2	0.5433	0.584	0.022
Actual TTC * Vehicle * group	3656.6	2	1828.3	0.5070	0.605	0.021
Residual	173098.8	48	3606.2			
Velocity * Vehicle	514.2	1	514.2	0.1596	0.693	0.007
Velocity * Vehicle * group	464.3	1	464.3	0.1441	0.708	0.006
Residual	77335.0	24	3222.3			
Modality * Actual TTC * Velocity	1765.7	2	882.9	0.3197	0.728	0.013
Modality * Actual TTC * Velocity * group	1060.1	2	530.1	0.1920	0.826	0.008
Residual	132546.6	48	2761.4			
Modality * Actual TTC * Vehicle	7534.5	2	3767.2	0.7792	0.464	0.031
Modality * Actual TTC * Vehicle * group	2717.2	2	1358.6	0.2810	0.756	0.012
Residual	232061.1	48	4834.6			
Modality * Velocity * Vehicle	4384.9	1	4384.9	5.0039	0.035	0.173
Modality * Velocity * Vehicle * group	34.6	1	34.6	0.0395	0.844	0.002
Residual	21031.0	24	876.3			
Actual TTC * Velocity * Vehicle	902.1	2	451.0	0.2595	0.772	0.011
Actual TTC * Velocity * Vehicle * group	435.8	2	217.9	0.1254	0.882	0.005
Residual	83421.6	48	1738.0			
Modality * Actual TTC * Velocity * Vehicle	1576.8	2	788.4	0.3176	0.729	0.013
Modality * Actual TTC * Velocity * Vehicle * group	3402.2	2	1701.1	0.6852	0.509	0.028
Residual	119169.3	48	2482.7			

Note. Type 3 Sums of Squares

[3]

Between Subjects Effects

	Sum of Squares	df	Mean Square	F	p	η^2_p
group	595251	1	595251	1.72	0.202	0.067
Residual	8.30e+6	24	346032			

Note. Type 3 Sums of Squares