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Cyclists' eye movements and crossing judgments at uncontrolled intersections: An eye-tracking study using animated video clips

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ABSTRACT

Research indicates that crashes between a cyclist and a car often occur even when the cyclist must have seen the approaching car, suggesting the importance of hazard anticipation skills. This study aimed to analyze cyclists' eye movements and crossing judgments while approaching an intersection at different speeds. Thirty-six participants watched animated video clips with a car approaching an uncontrolled four-way intersection and continuously indicated whether they would cross the intersection first. We varied (1) car approach scenario (passing, colliding, stopping), (2) traffic complexity (one or two approaching cars), and (3) cyclist's approach speed (15, 25, or 35 km/h). Results showed that participants looked at the approaching car when it was relevant to the task of crossing the intersection and posed an imminent hazard, and they directed less attention to the car after it had stopped or passed the intersection. Traffic complexity resulted in divided attention between the two cars, but participants retained most visual attention to the car that came from the right and had right of way. Effects of cycling speed on cyclists' gaze behavior and crossing judgments were small to moderate. In conclusion, cyclists' visual focus and crossing judgments are governed by situational factors (i.e., objects with priority and future collision potential), whereas cycling speed does not have substantial effects on eye movements and crossing judgments.

1. Introduction

Naturalistic cycling studies and accident data analyses indicate that cyclists are particularly at risk when encountering a car at an intersection (Akhtar et al., 2010; Dozza et al., 2016; Schepers et al., 2011; Summala et al., 1996). Contributory factors to bicycle-car collisions at intersections include the driver's failure in perceiving the cyclist and the cyclist's incorrect anticipation of the driver's intentions (Räsänen and Summala, 1998). Similarly, analyses of car-car and motorcycle-car intersection crashes have found that not only perceptual errors, but also false assumptions about the other's future actions are frequent causes of crashes (Choi, 2010; Najm et al., 1994; Pai, 2011).

The importance of 'knowing what is going on' in the environment can be captured by the construct of situation awareness, comprising three levels (Endsley, 1995). Level 1 is the perception of individual elements of the scene, Level 2 involves the comprehension of their meaning and importance, and at Level 3 the road user anticipates future events, such as a car driver's intentions. Researchers have identified several factors that are associated with perceptual errors at intersections, such as information processing limitations and perceptual filtering (e.g., Crundall et al., 2008; Herslund and Jørgensen, 2003; Scott et al., 2013; Werneke and Vollrath, 2012). However, less empirical evidence exists concerning the mechanisms responsible for road users' failures in comprehension and anticipation of other road users' intentions.

Several studies have used time-to-arrival judgments tasks to examine participants' anticipation of the future location of other road users (e.g., Caird and Hancock, 1994; Hancock and Manster, 1997; Van Loon et al., 2010), gap acceptance or interception tasks to investigate under which conditions individuals cross an intersection (e.g., Chihak et al., 2010; Grechkin et al., 2013; Lobjois et al., 2013; Louveton et al., 2012; Simpson et al., 2003), and judgment tasks to examine the perceived risk associated with crossing the intersection in front of an approaching car (e.g., Ebbesen et al., 1977). Stimuli for these tasks included cars approaching intersections at constant speeds while the participant was either stationary or moving toward the intersection.

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Chihak et al. (2010) used a bicycle simulator to investigate how children and adult cyclists adjust their approach speed to successfully pass through a gap in crossing traffic. Their results indicated that instead of cycling with a constant speed, cyclists used a two-stage interception strategy where they slowed down first, and accelerated when being close to the intersection (approximately 4–6 s). A possible reason why cyclists adjust their approach speed is that it allows them to improve the timing of the entry into the gap while minimizing the amount of time spent in the path of the oncoming traffic. Traditionally, the emphasis has been on how accurately people make judgments about potential collisions and on the probability/timing of crossing the intersection, whereas relatively little attention has been paid to what sources of visual information humans use in such tasks.

Early work on fixation allocation using pictures has indicated that viewers do not look randomly at the scene but gaze predominantly to informative areas of the picture (Buswell, 1935; Mackworth and Morandi, 1967). In a traffic environment, informative areas are those where hazards can arise from as well as objects in the visual field relevant to the performed task (e.g., a vehicle having priority). In an eye-tracking experiment by Van Loon et al. (2010), observers watched animated video clips while making relative timing judgments about approaching vehicle at a T-junction. Results showed that drivers made saccadic movements between the road ahead and the approaching car while spending the most viewing time (37%) on the approaching car. Eye-tracking studies conducted among car drivers have shown that hazardous events reduce saccadic activity (i.e., reduced spread of search) and increase fixation durations on the hazardous object, which may reflect in-depth information processing (Crundall et al., 1999, 2002; Chapman and Underwood, 1998; Velichkovsky et al., 2002). Perceptual narrowing in traffic may be similar to the 'weapon focus' phenomenon whereby observers fixate more often and for a longer duration on a threatening object than on a neutral object (Loftus et al., 1987; Underwood et al., 2003). At intersections, it can be expected that road users shift their attention between potentially hazardous objects while allocating most visual attention to high-value information sources (Werneke and Vollrath, 2012; Wickens et al., 2001).

Humans have evolved to perform ambulatory tasks up to 10 km/h, whereas driving and cycling occur at considerably higher speeds, posing challenges for safety and human information processing (Rumar, 1985). Driving simulator studies have shown that drivers reduce their horizontal gaze variance as driving speed increases (Rogers et al., 2005; Van Leeuwen et al., 2015). When driving at a low speed, road users have more time for perceptual and cognitive processing, whereas at higher speeds they look farther ahead and become more selective in their attention allocation (Summala and Räsänen, 2000).

Formal traffic rules (e.g., the right-hand rule) help road users act in a safe manner (Åberg, 1998). However, road users' behavior is not only governed by formal traffic rules (Özkan and Lajunen, 2005). For example, a driver may let a cyclist cross first, even when the driver has right of way. One explanation for bicycle-car collisions when a cyclist must have seen the car is that the cyclist anticipates that the driver will yield if slowing down, while in fact, that driver is preparing to make a turn and has not seen the cyclist (Summala and Räsänen, 2000). Thus, it is important that cyclists detect relevant information that can be used for confirming or updating preliminary decisions (Näätänen and Summala, 1974).

In the present study, participants were asked to watch animated video clips from the viewpoint of a cyclist. In these video clips, the cyclist encountered different types of car approach scenarios while cycling towards an uncontrolled four-way intersection. We recorded participants' eye movements while participants were tasked to indicate continuously whether they believed they or the car(s) would cross the intersection first, by respectively pressing or releasing the spacebar. The aim of this paper is to investigate how cyclist's eye movements and 'I will cross the intersection first' judgments differ as a function of car approach scenario (passing, collision, stopping), traffic complexity (one vs. two approaching cars), and cycling speed (15, 25, or 35 km/h). The questions addressed in this study are as follows:

1. How do cyclists' eye movements and their crossing judgments differ between car approach scenarios at the same four-way intersection?

Based on previous research (e.g., Chapman and Underwood, 1998; Loftus et al., 1987), we hypothesized that when approaching the intersection, participants focus on a car if the car is relevant to their task of crossing the intersection, while gazing less to the car if it is irrelevant and does not pose an imminent hazard. Further, we expected that crossing judgment continuously changes while approaching an intersection based on traffic rules (i.e., the initial appearance of the car) and visual information (i.e., particular approach scenario). To address this research question, three approach scenarios with one car were created: (a) a car coming from the right and passing in front of the cyclist, (b) impending collision with a car coming from the right, (c) a car coming from the right and stopping.

2. How do cyclists' eye movements and their crossing judgments change when traffic complexity increases?

Based on Werneke and Vollrath (2012) and Wickens et al. (2001), we hypothesized that if traffic complexity increases (i.e., more cars approach the intersection), participants divide their attention between the cars relevant to their task. To investigate this research question, a scenario with two cars was added: a car coming from the right and stopping (same as in approach scenario c) together with a car coming from the left that is also stopping. We hypothesized that crossing judgment is done based on the car that has higher task relevance (in this case the car from the right) and, thus, there will be no difference in crossing judgments between scenarios with one or two cars.

3. How do cyclists' eye movements and their crossing judgments differ between three cycling speeds?

We expected visual tunneling whereby cyclists are more likely to glance at the task-relevant sources of information (i.e., an approaching car) if the cycling speed is higher (Summala and Räsänen, 2000; Rogers et al., 2005; Van Leeuwen et al., 2015). Cycling speeds (15, 25, and 35 km/h) were chosen based on previous experiments showing that conventional, electric, and racing bicycles users differ in their speed choice (Hendriksen et al., 2008; Methorst et al., 2011; Schleinitz et al., 2017).

2. Methods

2.1. Participants

Thirty-seven cyclists (6 females, 31 males) recruited from the Delft University of Technology took part in this study. The age range was 18–27 years (M = 21.0, SD = 2.0). All participants reported normal or corrected-to-normal vision. Thirty-four participants possessed a driving license (M = 3.0 years; SD = 1.6). The participants had started cycling at the age of 3–6 years and 32 of them cycled frequently (i.e., at least 3 days per week). The research was approved by the Human Research Ethics Committee of the Delft University of Technology (Ethics application no. 34, 2016), and all participants provided written informed consent. Participants were financially compensated for their time.

2.2. Apparatus

Participants sat approximately 95 cm in front of a 24-inch monitor and rested their head on an adjustable head support. The horizontal field of view (i.e., the size of the screen from the participant's perspective) was approximately 31 degrees. The eye tracker was placed at 60 cm in front of the participants with the lens centered at the right eye. Viewing was binocular, but only the right eye movements were tracked, at a sampling rate of 2000 Hz using the EyeLink 1000 Plus Eye Tracker (SR Research, Canada). Participants used a keyboard to provide input about whether or not they would cross the intersection first. No sounds were provided during the experiment.