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The role of driver's situational awareness on right-hook bicycle-motor vehicle crashes

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ABSTRACT

Objective: The objective was to explore the effect of driver Situational Awareness (SA) on "right-hook" bicycle-motor vehicle crashes involving right turns into adjacent bicyclists.
Background: Previous literature suggests that improper allocation of motorists' visual attention, inadequate surveillance, and poor SA are contributing factors to bicycle-motor vehicle crashes in other types of encounters.
Method: Fifty-one participants completed this driving simulator study. Right-turning motorists' SA was measured using the SAGAT technique in the presence of a through-moving bicyclist in an adjacent bicycle lane during the latter portion of the green phase at a signalized intersection using a three (bicyclist's relative position) by two (presence of oncoming left-turning vehicle) within-subject factorial design. Each participant made 21 right turns, nine of which were immediately followed by SA queries, and crash avoidance behavior was measured at the last intersection, which involved a crash-likely scenario.
Results: The bicyclist's position significantly influenced motorists' overall SA ($p < 0.05$) and Level 2 SA (comprehension) ($p < 0.05$). Level 1 SA (perception) degraded when oncoming vehicles were present and the bicyclist was approaching from behind ($p < 0.05$). Level 3 SA (projection) degraded when the bicyclist was ahead of the motorist and oncoming vehicles were present ($p < 0.05$). Level 1 SA and crash occurrence were negatively correlated ($r_{pbi} = -0.3$, $p < 0.05$).
Conclusion: Motorists focused more attention on cars in front of them and less attention on bicycles in the peripheral vision. A common cause of observed crashes in the simulator was detection error. The bicyclist approaching from behind the motorist is the most vulnerable to a right-turning motorist.

1. Introduction

As U.S. cities have made investments in non-motorized transportation infrastructure, bicycling has become a meaningful alternative mode of transportation for activities such as commuting to school or work, shopping, and recreation (Pucher et al., 1999, 2011; SAFETEA-LU Section 1807, 2012). However, research has shown that safety is a primary concern for many people in the decision to use a bicycle for transportation. The National Highway Traffic Safety Administration (NHTSA) reports that there were 840 fatal bicycle-related crashes in 2016, which accounted for 2.2% of transportation-related fatalities in the U.S. (NHTSA, 2018). The majority of these fatal bicycle crashes (60%) occur in urban areas with 40% of them at intersections. At intersections without space for both a separate right-turn and bicycle lane, bicyclists are often to the right of motorists as they approach an intersection. This configuration sets up the "right-hook" bicycle-motor vehicle type crash where right-turning vehicles and through-moving bicycles conflict. These crashes occur frequently and can sometimes be severe. They can happen either (1) at the start-up period (the onset of the green or departing from a stop sign) or (2) during the "moving" phase after the signal turns green and the standing queue has cleared (i.e. the latter part of the green phase). In the second case, the approach speeds of the right-turning motorist and the through-moving bicyclist are higher, and their relative positions are more variable. It is important to note that the motor vehicle operating laws in U.S. states vary and in the study location (Oregon), drivers may not encroach in the bicycle lane unless in the process of making a turn.

Although the subject of right-turning vehicle crashes with bicycles appears in the literature with some frequency (Summala, 1988; Weigand, 2008), little substantive research on the crash causation mechanism has been conducted. In addition to the fact that crashes are rare events, police-reported crash records sometimes lack robust information on the behavior of road users and presence or status of other traffic hazards during the crash. It can be difficult to infer the awareness and behavior of each party (perceptions, decision making, and trajectories) from these data.

A safe right-turning maneuver requires that the motorist complete at least two tasks: (i) look and detect the bicyclist, (ii) make the appropriate decision based on that information and corresponding conditions at the intersection. In this regard, the Situational Awareness (SA) of motorists can help explain their behavior with reference to several key factors: anticipation, attention, perception, expectations,

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and risk (Endsley, 1998). SA is the term given to the awareness that a person has of a situation and an operator's dynamic understanding of 'what is going on' (Endsley, 1995a). It has been shown to influence both decision-making and task performance of the operator during the tasks of driving and flying. While the issue with SA is obviously important in the aviation domain, other complex real-time tasks such as driving also suffer the consequence of poor SA.

Motorists' behaviors in crash events are difficult to systematically analyze in large numbers due to the low frequency of crashes and the variety of external factors that must be considered and controlled. In this regard, driving simulation and eye-tracker technology have emerged as useful research tools for exploring the contribution of human driving behavior to traffic crashes (Durkee, 2010). Driving simulators can place motorists into crash-likely scenarios from the relative safety of the laboratory.

This research used a high-fidelity driving simulator to investigate the causal factors of right-hook crashes related to motorist behavior. This paper presents the results of an experiment designed to determine motorist's SA during right-turn maneuvers at signalized intersection in the presence of a through-moving bicyclist in an adjacent bicycle lane. Although SA is key to decision making in a dynamic environment, it does not necessarily guarantee successful task performance (Salmon, 2009). Therefore, in addition to the explicit recall measures of SA, it is also important to assess operator's SA with indirect performance-based measures (Gugerty, 1997), so in this case motorist's performance was measured through the global performance measure of crash avoidance. Finally, this experiment analyzed if there is any correlation between motorist's SA and crash avoidance behavior. The overarching research objective of this experiment was to assess if right-turning motorists have the necessary knowledge for safely executing a right-turning maneuver during the latter portion of the green phase, which is important to avoid a potential RH crash with an adjacent bicyclist.

2. Theoretical background

2.1. Crash factors attributable to the motorist

Vehicle collisions often result from the lack of attention or a failure to detect the other party or, sometimes, the loss of control by one or more of the parties involved (Korve and Niemeier, 2002; Summala, 1988; Summala et al., 1996; Räsänen et al., 1998; Rumar, 1990). The first thorough investigation of the contributing factors for crashes was conducted in the 1970s by a research team from Indiana University for NHTSA, and is known as the Tri-Level Study of Accident Causes (Treat et al., 1979). This study investigated 2,258 different types of police-reported crashes. Results from this study reported that improper lookout and inattention, which are two important aspects of SA, were the two leading direct human causes of those crashes. Improper lookout or inadequate surveillance consisted both of "failed to look" and "looked but failed to see" behaviors (Treat, 1980). Gugerty found that improper lookout and inattention were cited as causes of more crashes than factors related to decision making (e.g., excessive speed) and psychomotor ability (e.g., improper driving technique) (Gugerty, 2011). More recently, NHTSA conducted a study to examine the general characteristics of motor-vehicle traffic crashes at intersections using the National Motor Vehicle Crash Causation Survey (NMVCCS) from 2005 to 2007 (NHTSA, 2010). Among those records, there were 756,570 intersection-related crashes; the most frequently assigned critical reason (44.1%) was found to be inadequate surveillance. This failure can occur at an intersection when the motorist looks at the required direction before making a turn, but fails to see the approaching traffic (Dingus et al., 2006).

Specifically for bicycle motor vehicle crashes, Summala et al. found that improper allocation of a motorist's visual attention while making turns at an intersection and failure to detect the bicyclist was a contributing factor to many crashes (Summala et al., 1996).

2.2. Situational awareness

Perception and attention are very important factors for safe driving (Castro, 2008; Gugerty, 2011). Therefore it is essential to measure motorists' attention correctly to gain insight into the driving task (Gugerty, 2011). Suggesting that motorists' SA is similar to motorists' attention, Gugerty has defined SA as, "the updated, meaningful knowledge of an unpredictably-changing, multifaceted situation that operators use to guide choice and action when engaged in real-time multitasking" (Gugerty, 2011). In the context of the driving task, this meaningful knowledge can include the motorists' route location, roadway alignment, location of nearby traffic and pedestrians, fuel level, and other information. Gugerty also categorized the perceptual and cognitive processes required to maintain SA into three levels:

- Level 1: automatic, a preattentive process that occurs unconsciously and places almost no demands on cognitive resources;
- Level 2: recognition-primed, a decision process that may be conscious for brief periods (< 1 s) and place few demands on cognitive resources; and
- Level 3: conscious, a controlled process that place heavy demands on cognitive resources (Gugerty, 2011).

In the context of driving, Gugerty described vehicle control, such as maintaining speed and lane position as mostly an automated process, but other tasks requiring some regular conscious decisions during driving, such as lane changing or stopping at a red light, are recognition-primed processes. At the final level, he described hazard anticipation and making navigational decisions in an unfamiliar environment during heavy traffic as requiring a controlled, conscious process (Gugerty, 2011).

To safely accomplish the driving task, motorists need to perceive, identify, and correctly interpret the elements of the current traffic situation, including immediately adjacent traffic, road signs, route direction, and other inputs, while being vigilant for obstacles and making predictions of near-future traffic conditions to maintain control, guidance, and navigation of the vehicle (Baumann et al., 2007). Endsley's definition of SA incorporates the great variability of information that needs to be processed in dynamic real time tasks such as driving, air traffic control, or flying. Endsley states that, "Situation awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1988). Endsley's definition of SA was expanded into three hierarchical phases:

- Level 1 SA involves the *perception* of the elements in the environment;
- Level 2 SA is the *comprehension* of the current situation by integrating various pieces of data and information collected in Level 1 SA in conjunction with operator goals; and
- Level 3 SA involves the *projection* of future status from the knowledge of the elements and comprehension of the situation achieved in Level 1 and Level 2 SA. Level 3 SA allows the motorist to perform timely and effective decision making (Endsley, 1995b).

Although the two models are conceptually different, Gugerty has compared his three levels of perceptual and cognitive processes with Endsley's three levels of SA in the way that perceiving the elements of a situation (Endsley's Level 1 SA) is mostly highly automated, while comprehension and projection (Level 2 and 3) mostly use recognition-primed and controlled processes (Gugerty, 2011; Endsley, 1995a,b).

The above discussion underlines the importance of SA, which is required for hazard anticipation and safe driving. A high degree of SA generally helps motorists to accomplish these goals as well as provide a basis for subsequent decision making and good performance in the driving task. In the context of right-hook crash scenarios, a high degree