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Situational influences on response time and maneuver choice: Development of time-critical scenarios

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ABSTRACT

Findings concerning drivers' response times to sudden events vary considerably across studies due to different experimental setups and situational characteristics, such as expectancy of an event and urgency to react. While response times are widely reported in the literature, understanding of drivers' choice of maneuvers in time-critical situations is limited. Standardized test scenarios could enhance the comparability of studies and help in attaining a better understanding of driver behavior in these situations.

In an effort to achieve these improvements, three driving simulator studies (N = 131) were conducted to investigate drivers' response time and maneuver choice under a range of situational conditions. Each study took place in a specific environmental setting (urban, rural, and highway) and incorporated one unexpected and 12 subsequent events (increased expectancy). Four different time-critical scenarios were used to evoke different driver responses. In three scenarios, obstacles suddenly entered the roadway (braking, steering, or both possible). A fourth scenario comprised the sudden braking of a leading vehicle (only braking possible). Half of the drivers performed a cognitive secondary task. To validate the findings, results from an additional field test (N = 14) were compared to the results from the simulated urban environment.

As expected, response choice was influenced by scenario characteristics (available braking distance and room for evasive maneuvers). Braking maneuvers were more frequent in settings with lower speed limits (urban) while steering maneuvers were found at higher speed limits (highway). Responses to suddenly appearing obstacles were fastest in the urban setting at 540–680 ms; these responses were 200–300 ms slower in the rural and highway settings. Response times increased by 100–200 ms when drivers responded to braking leading vehicles rather than obstacles. Braking responses were 200–350 ms slower and steering responses were 90–200 ms slower when drivers responded to an unexpected event rather than subsequent events. The cognitive secondary task had no significant effect. The simulated environment and the field test produced comparable response behavior.

The current study provides reference numbers that help to establish a set of standardized test scenarios for future studies. On basis of this study, nine scenarios are recommended for the context of time-critical crash avoidance maneuvers. Such standardized test scenarios could improve the comparability of future studies on response time and maneuver choice.

1. Introduction

1.1. Driving performance and response times

Driver errors are one of the most frequent causes of crashes (e.g., Vollrath, 2010). When considering driver safety and crash prevention, one of the most important aims is to improve the driver's behavior. Improvements include preventing critical situations by assisting drivers in behaving adequately before a situation becomes dangerous. Even more importantly, driver assistance systems, such as a forward collision warning, help drivers avoid crashes in a situation that has become critical. To evaluate the effectiveness of such systems in a critical situation, a measure of driving performance is needed.

Overall, driving performance can be seen as a general term for how effectively a driver's behavior matches situational requirements (e.g., Fuller, 2005). As Dunn et al's. (2014) crash trifecta concept indicates, crashes require the simultaneous presence of the following factors: (1) unsafe pre-incident behavior, (2) transient driver inattention, and (3) an unexpected traffic event. The final element requires a fast and adequate response to avoid a crash. An essential measure of driver behavior in these critical situations is response time: the time that elapses between the start of the unexpected traffic event to the actual

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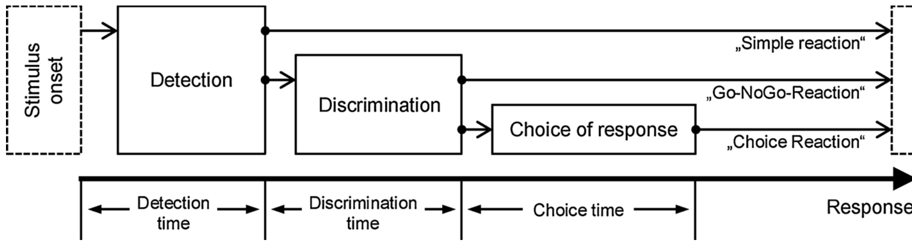

Fig. 1. The authors' visualization of the response process according to the stages proposed by Donders (1969).

adaption of the driving behavior. Driver assistance systems should help drivers to respond adequately (e.g. steering instead of braking) and as quickly as possible. A human factors evaluation of these systems should measure reaction type and response time.

A driver's response includes multiple stages (e.g., Boff and Lincoln, 1988). To respond to a time-critical event, a driver needs to detect relevant cues in the environment, distinguish safety-relevant cues from irrelevant cues in the ongoing situation, choose an appropriate maneuver, and execute on this choice. Early laboratory research on response times has identified several mental processes (e.g., Donders, 1969). As Fig. 1 illustrates, the stages of detection, discrimination, and response choice can be examined using different reaction time tasks. Donders (1969) described a method to estimate the duration of the single stages based on the assumption that these stages are independent of each other. For example, the discrimination time can be estimated by subtracting the response times for a simple response task from those for a similar Go-NoGo task (see Fig. 1). This subtraction method is similar to a baseline correction and is also used in other fields of research such as functional neuroimaging.

While other methods have been proposed (see Sternberg, 1969) and evidence of the validity of the independence assumption is mixed (see Miller and Low, 2001; Danek and Mordkoff, 2011), Donders' (1969) early work illustrates that even if the motor response (e.g., button press) and target stimuli are held constant, due to different cognitive processes, the actual onset of an observable behavioral response varies depending on the task in question.

1.2. Response times and situational factors

Returning to response times in traffic, a large body of literature examines the speed at which drivers respond to various traffic situations (reviews given by Green, 2000; Sohn and Stepleman, 1998; Young and Stanton, 2007). Average braking response times range from 0.4 s to 2.5 s. In some situations, response times have been found to be as long as 4.1 s (Adell et al., 2011). In his review of 40 studies on braking response times, Green (2000) found that response times varied considerably due to the different experimental setups of the studies and variations in the factors such as expectancy, urgency of the situation, cognitive load, and age and gender of the driver. The most important factor was expectancy, as in expected situations, response times were around 0.7 s. In unexpected but common situations, response times were around 1.25 s and in surprising situations (unexpected and uncommon) response times were around 1.5 s (Green, 2000).

Summala (2000) has criticized these values because of the aggregation of situations with different urgencies. According to Summala (2000) drivers want to hold a constant speed as long as possible, and they decelerate only if required by a situation. This effect would result in a biased estimation of drivers' ability to react to critical events if the critical events were not *time-critical* enough to require a fast response. The aggregation of different situations raises the question of whether the response times found by Green (2000) are estimates of how fast drivers *can* possibly respond or of how fast drivers *prefer* to respond considering the perceived requirements of a situation. To compare reaction times in critical situations, the situation characteristics may be the most prominent influencing factors.

Naturally, when evaluating a driver assistance system to determine whether it improves response times, it is sufficient to compare use and non-use of the system in identical test situations, e.g. by means of a driving simulator and a between-subjects design. However, to create or select test situations and estimate the generalizability of the findings, it is beneficial to know the extent to which situational factors influence response times. With this need in mind, the first aim of the current study was to examine the influence of basic situational factors such as road type and typical driving speed on the road.

1.3. Beyond response times: maneuver choice

While not reported as frequently as response times, maneuver choice is also a relevant feature of driver behavior. How fast a driver must react in a specific situation to avoid a collision can be easily determined by the basic parameters of the situation, including distance to the collision object, current speed, and anticipated deceleration rate. Whether a chosen response is the most appropriate for a situation is a more sophisticated question.

A review of crash avoidance strategies (Adams, 1994) revealed that in critical situations, drivers tended to choose braking maneuvers (39–91%) more often than steering maneuvers (9–24%). However, steering maneuvers tended to have higher success rates in terms of avoiding crashes and were effective even when the distance to an obstacle was very short. A crash analysis conducted by Ferrandez, Fleury, and Lepesant (1984, cited after Malaterre et al., 1988) found that in 31 out of 72 cases, a crash could have been avoided if the driver had chosen an appropriate maneuver. In two thirds of the cases, a steering maneuver would have been the appropriate choice. Using videos of critical situations, Malaterre et al. (1988) asked 12 subjects to indicate what maneuver they would have selected in a given situation and the reason for the choice. The results indicated that drivers tended to choose sideways maneuvers more frequently when (1) the distance to the obstacle was short; (2) the driver was certain of the obstacle's trajectory; and (3) visibility was strong. Since the answers did not match data found in crash analyses, the authors suggested that in actual critical situations, drivers do not rely on refined perceptual judgments and tend to follow simplified strategies.

Crash analyses have also revealed that drivers often fail to execute crash avoidance maneuvers (Kaplan and Prato, 2012, 2015; Harb et al., 2009). For example, in a study by Kaplan and Prato (2012), a steering maneuver that would have resulted in lower crash severity was performed only in 13% of the cases. While this finding seems alarming, it must be stated that the data was naturally biased towards unsuccessful crash avoidance behavior, since the studies only analyzed police-reported crash data and did not consider successful avoidance maneuvers in near-crash situations. However, the drivers' tendency to brake was also found in naturalistic driving (Dozza, 2013). In 66% of 493 near-crash events, the driver chose a braking maneuver; steering maneuvers were chosen in about 25% of the cases.

Overall, it seems that choosing the adequate response in critical situations may be even more important than responding as quickly as possible. Similar to the large range of response times between studies,