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Judging arrival times of incoming traffic vehicles is not a prerequisite for safely crossing an intersection: Differential effects of vehicle size and type in passive judgment and active driving tasks

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ABSTRACT

Using a fixed-base driving simulator we compared the effects of the size and type of traffic vehicles (i.e., normal-sized or double-sized cars or motorcycles) approaching an intersection in two different tasks. In the perceptual judgment task, passively moving participants estimated when a traffic vehicle would reach the intersection for actual arrival times (ATs) of 1, 2, or 3 s. In line with earlier findings, ATs were generally underestimated, the more so the longer the actual AT. Results revealed that vehicle size affected judgments in particular for the larger actual ATs (2 and 3 s), with double-sized vehicles then being judged as arriving earlier than normal-sized vehicles. Vehicle type, on the other hand, affected judgments at the smaller actual ATs (1 and 2 s), with cars then being judged as arriving earlier than motorcycles. In the behavioral task participants actively drove the simulator to cross the intersection by passing through a gap in a train of traffic. Analyses of the speed variations observed during the active intersection-crossing task revealed that the size and type of vehicles in the traffic train did not affect driving behavior in the same way as in the AT judgment task. First, effects were considerably smaller, affecting driving behavior only marginally. Second, effects were opposite to expectations based on AT judgments: driver approach speeds were smaller (rather than larger) when confronted with double-sized vehicles as compared to their normal-sized counterparts and when confronted with cars as compared to motorcycles. Finally, the temporality of the effects was different on the two tasks: vehicle size affected driver approach speed in the final stages of approach rather than early on, while vehicle type affected driver approach speed early on rather than later. Overall, we conclude that the active control of approach to the intersection is not based on successive judgments of traffic vehicle arrival times. These results thereby question the general belief that arrival time estimates are crucial for safe interaction with traffic.

1. Introduction

According to the European Road Safety Observatory (www.erso.eu), during the year 2013 26,000 people were killed (and over a million injured) in road traffic accidents within the European Union. >5300 fatalities (i.e., over 20%) were due to accidents at traffic junctions. The more accident-prone scenarios (representing nearly 30% of the traffic-junction fatalities) involved straight crossing paths, with other vehicles coming from either or both sides of the intersection. Factors associated with such accidents have been reported (e.g., Caird & Hancock, 2002) to include not only characteristics of the driver (such as age and gender) and the environment (such as setting and layout of the intersection), but also the perceptual and motor mechanisms implicated in driving tasks. Our work aims to provide a better understanding of these latter mechanisms when drivers perform an intersection-crossing task in the presence of incoming traffic.

As already noted by Louveton, Bootsma, Guerrin, Berhelon, and Montagne (2012), the vast majority of work performed so far has focused on the capacity of drivers to judge when an approaching vehicle will reach a given location (e.g., Berthelon & Mestre, 1993; Caird & Hancock, 1994) or to decide when a safe manoeuver can be initiated (e.g., Dewing, Duley, & Hancock, 1993; Hancock, Caird, Shekhar, & Vercruyssen, 1991). Experimentally, such judgments or decisions are typically obtained in settings requiring participants to provide a discrete response after viewing part of an approach event involving one or more vehicles. Several authors (e.g., Caird & Hancock, 1994; Gray & Regan, 2005) have advocated the need for paradigms with higher ecological validity, allowing to preserve the natural links between perception and action that characterize the unfolding of the majority of driving maneuvers. There is in fact no guarantee that the results obtained using

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discrete-response motion-extrapolation paradigms can indeed be transferred to driving tasks in which the continuous perceptual-motor dialog underlying the unfolding of the action is preserved. More precisely, adoption of these paradigms rests on the hypothesis that predictive assessment of an arrival time or a temporal gap is a prerequisite for safe behavioral interaction with the approaching vehicle(s). In this light, determining the capacity of a driver to make such predictive assessments under a wide range of conditions is then presumed to reveal not only the adequacy of the underlying mechanisms, but also the specific conditions leading to their deterioration. Following this line of reasoning, a large body of work has allowed identification of the main factors underlying poor prediction of a forthcoming event (e.g., Dewing et al., 1993; Hancock et al., 1991). However, contrary to discrete judgment or decision tasks, the control of a time-evolving action is not necessarily based on some form of predictive assessment. Indeed, a large number of studies, notably in the domain of interception, have revealed that the control of action can be based on prospective information. Rather than relying on predictions about when a moving object will be where, interceptive actions may be regulated with respect to particular current states of the agent-environment interaction that guarantee (i.e., are lawfully related to) the future achievement of the goal (e.g., McLeod & Dienes, 1993; Lenoir et al., 1999; see Montagne, 2005 for a review). One can wonder to what extent the same kind of information could be used when drivers intercept an inter-vehicular gap.

Whereas the *discrete-response motion-extrapolation paradigm* has been used in many studies to better understand the underlying perceptual processes, to our knowledge only a few studies decided to preserve the perceptual-motor dialog when studying intersection-crossing behavior. The work of Chihak et al. (2010), Chihak, Grechkin, Kearney, Cremer, and Plumert (2014) and that of Louveton, Bootsma, et al. (2012) and Louveton, Montagne, Berthelon, and Bootsma (2012) constitute rather isolated attempts to study intersection-crossing behavior without separating the perceptual-motor mechanisms involved. While the former were interested in the perceptual-motor developmental changes accompanying the intersection-crossing behavior of cyclists, the latter focused on the mechanisms underlying the intersection-crossing behavior of adult drivers. Calling upon the same type of virtual environment technology, the tasks studied required participants to regulate their speed of approach to an intersection so as to safely pass through an incoming traffic gap. Both groups shared the idea that, rather than trying to isolate particular components, intersection-crossing behavior should be studied as a whole in order to reveal the underlying mechanisms. A general finding of these studies was that functional (i.e., situation-appropriate) speed changes were observed over the entire approach phase, allowing participants to cross the inter-vehicular gap near its center, at a position slightly shifted towards the lead vehicle (e.g., Chihak et al., 2010; Louveton, Bootsma, et al., 2012). While consistent with an on-line, prospective control of the approach to the intersection, the observed gradual and functional speed adjustments seem to fit less well with expectations derived from arrival time (AT) judgments. Indeed, not only do AT judgments generally give rise to underestimations of actual AT, but the magnitude of the underestimation is known to be larger for longer actual ATs (e.g., Caird & Hancock, 1994; Schiff & Detwiler, 1979). Thus, even during an approach to an intersection that does not require a change in speed to ensure safe crossing (that is, passing near the center of a gap between two incoming traffic vehicles), early estimates of time remaining until arrival of the traffic vehicles at the intersection would be considerably shorter than the actual ATs. Such underestimations of actual AT would be expected to give rise to an increase in speed. As actual AT decreases over the course of the approach, judgments would become more precise (less underestimated) and speed would therefore be expected to gradually decrease to more appropriate levels. The speed profiles described by Chihak et al. (2010, 2014), Louveton, Bootsma, et al. (2012) and Louveton, Montagne, et al. (2012) did not show such characteristics.

Moreover, several studies have demonstrated that perceptual processes operate more accurately within a perceptual-motor task than in a purely perceptual task (e.g., Bootsma, 1989; Gray & Regan, 2005; Mann, Abernethy, & Farrow, 2010; Oudejans, Michaels, & van Dort, 1996). In the study by Bootsma (1989) participants experienced more difficulties (i.e., larger variability) in judging arrival time of a moving ball than in initiating a movement to strike it. Comparably, Gray and Regan (2005) reported more appropriate decisions when drivers overtook a moving vehicle than when they had to judge the opportunity to initiate a safe overtaking maneuver. Thus, the magnitude of underestimation generally observed in AT judgment tasks may be attenuated during an active intersection-crossing task. Of course, such an attenuation effect may already have consequences for the generality of the conclusions drawn from the often-used judgment tasks.

The present contribution builds on the framework developed by Chihak et al. (2010, 2014), Louveton, Bootsma, et al. (2012) and Louveton, Montagne, et al. (2012), with the ambition to more directly test the hypothesis that the perceptual substrate underlying judgments of arrival time of a vehicle moving towards an intersection is (at least partly) distinct from the perceptual substrate underlying the active control of one's own approach to that same intersection. For that purpose, we compared the influence of a given set of experimental manipulations (specifically, the size and type of the vehicles encountered at the intersection) on both perceptual (i.e., AT judgment, Experiment 1) and perceptual-motor (i.e., active intersection crossing, Experiment 2) tasks. Vehicle size is known to affect AT judgments: larger vehicles are judged to arrive earlier than smaller vehicles (e.g., Eberts & MacMillan, 1985; De Lucia, 1991; Dewing et al., 1993; De Lucia & Warren, 1994; Caird & Hancock, 1994, 2002; see De Lucia, 2013 for a review). If active intersection crossing would (at least partly) share the perceptual substrate underlying AT judgments, the size of the vehicles encountered should affect behavior on both tasks in similar ways. However, before further examining the effects expected, a closer look at the way size has been experimentally manipulated is warranted.

Indeed, many of the studies attributing the observed increase in AT underestimation to increases in vehicle size in fact manipulated vehicle type at the same time. In the experiment by Horswill, Helman, Ardiles, and Wann (2005), for example, participants were asked to make AT judgments for different vehicles approaching a junction. The different vehicles examined included a small motorbike, a large motorcycle, a car and a van. The larger AT underestimations recorded for both the car and the van, in comparison to the motorbikes, were said to result from the increase in size of the approaching vehicle. Unfortunately, the simultaneous variation of two dimensions (i.e., vehicle size and vehicle type) does not allow their respective effects to be disambiguated. This methodological confounding of size and type is all the more worrisome as recent experiments have indicated that the type per se of an approaching object influences AT judgments: Brendel, De Lucia, Hecht, Stacy, and Larsen (2012) demonstrated that threatening pictures were judged as arriving earlier than neutral pictures, but also that ATs of angry faces were underestimated (see Brendel, Hecht, De Lucia, & Gamer (2014), for a discussion focusing on the underlying mechanisms). As a consequence, the type of vehicle approaching an intersection is likely to affect AT estimates as well as the vehicle's size. There is a need to control these factors experimentally to disambiguate their respective effects.

Our study therefore has two objectives. The main objective is to test whether the perceptual substrate underlying AT judgments is comparable to the perceptual substrate underlying active intersection crossing tasks. The second related objective, is to examine the influence of both the size and the type of the vehicles encountered on the two tasks (i.e., perceptual vs. perceptual-motor tasks), with the objective of disambiguating the role of these factors.

Based on the previous work described above, the following hypotheses can be formulated. In the judgment task of Experiment 1 arrival time of the vehicles encountered should generally be underestimated