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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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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Highlights

- Participants were confronted with traffic vehicles approaching an intersection.
- Arrival time judgments were affected by traffic vehicle size and type.
- Intersection crossing behavior did not reflect biases observed in judgments
- Active approach to intersection is not based on arrival time judgments

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 larger (rather than smaller) 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.

Key-words: *arrival time, judgment, driving, speed, perception, control*

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. More than 5,300 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 et al. (2012a), 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., Caird & Hancock, 1994; Berthelon & Mestre, 1993) or to decide when a safe manoeuver can be initiated (e.g., Dewing et al., 1993; Hancock et al., 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 *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., Hancock et al, 1991; Dewing et al., 1993). 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 dialogue when studying intersection-crossing behavior. The work of Chihak et al. (2010, 2014) and that of Louveton et al. (2012a, 2012b) 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 et al., 2012a). 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) and Louveton et al. (2012a, 2012b) 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; Oudejans, Michaels & van Dort, 1996; Mann, Abernethy & Farrow, 2010). 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) and Louveton (2012a, 2012b), 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 et al. (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 et al. (2012) demonstrated that threatening pictures were judged as arriving earlier than neutral pictures, but also that ATs of angry faces were underestimated (see Brendel et al., 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 and the underestimation should be greater for longer actual ATs. More importantly for the present purposes, both the size and the type of the vehicles encountered should influence AT judgments. The underestimation in AT judgments should be greater for larger-sized vehicles (size effect) and for more threatening vehicles (type effect). If the active intersection-crossing task of Experiment 2 were to rely on a perceptual substrate similar to that of the AT judgment task, equivalent manipulations of size and type of the vehicles encountered should influence driving speed during approach to the intersection in a predictable way. The use of successive AT estimates to control speed to pass through an inter-vehicular gap should lead the participants to adopt somewhat higher speeds when confronted with larger-sized and/or more threatening vehicles. The phase of approach expected to be most affected by the size and type manipulations depends on the relations between the magnitude of each of these effects on AT estimates and actual AT. Experiment 1 will allow determining the time-dependence of these effects.

On the other hand, the perceptual substrate underlying the two tasks (i.e., AT judgment and active intersection crossing) could in fact be different and the use of prospective information during active intersection crossing should favor the appearance of functional speed changes. In the case predictive information (i.e., AT estimates) would not be involved in the speed regulation process, there is no reason to expect the type of adjustments described above. Gradual functional speed changes should appear when necessary. In this perspective effects of vehicle size and type might still occur (affecting, for instance, the position in the inter-vehicular gap chosen for crossing) but, if at all existent, would not be expected to demonstrate the same time-dependency as observed in the AT judgment task.

General Methods

Participants

Fourteen young adults, six women and eight men (26.7 ± 3.8 years old; *M* ± *SD*) with normal or corrected to normal vision, volunteered for participation in both experiments. They all held a driver's license for at least three years. Participants provided written consent prior to the study, which was conducted according to IFSTTAR regulations and the Declaration of Helsinki.

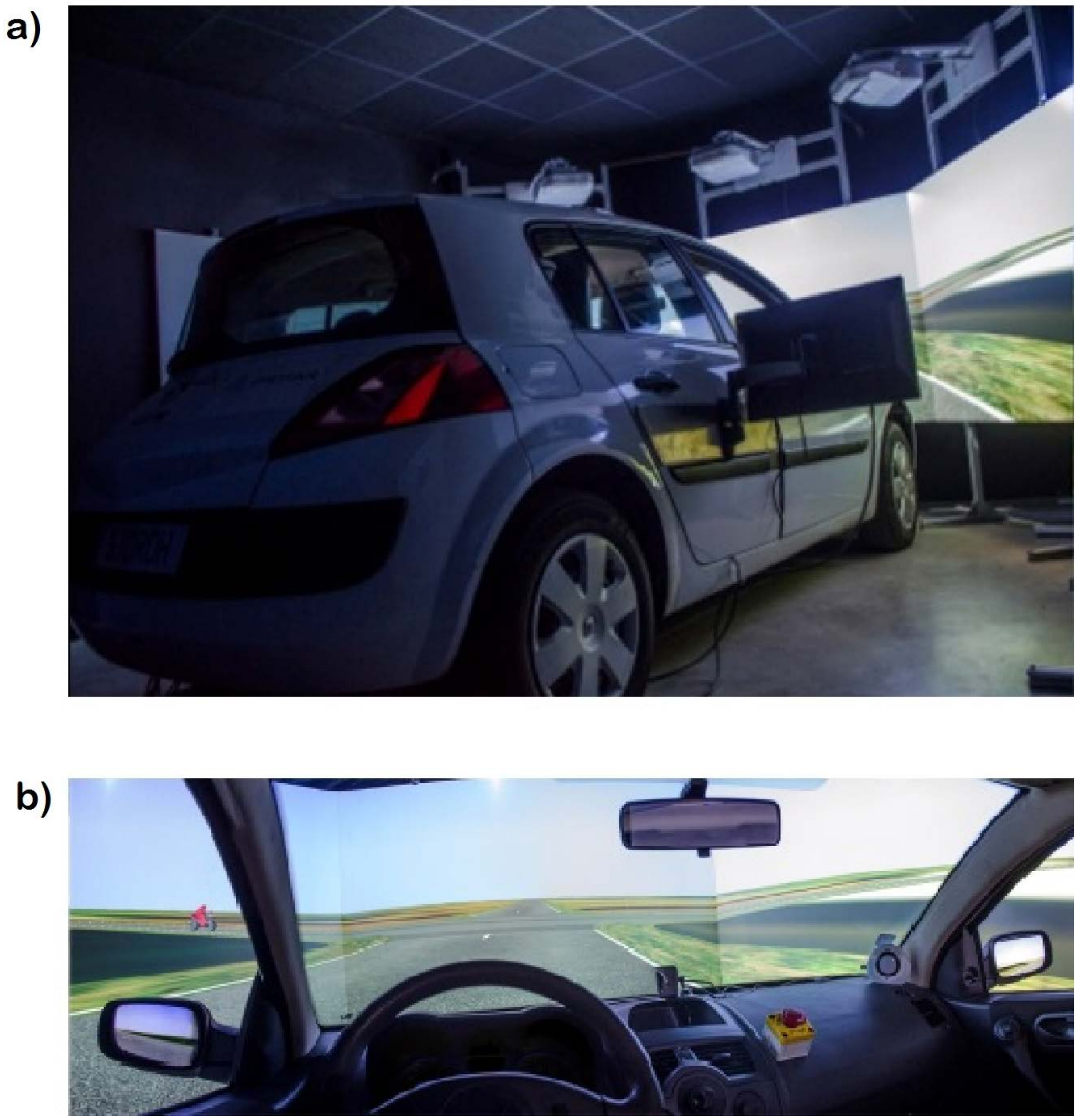

Figure 1: Illustration of the exterior view of the driving simulator with the three projectors and screens (a) and participant view from inside the simulator (b). The visual scene is presented on the three screens as well as in the side and rear-view mirrors. The task was to estimate when the approaching motorcycle would have arrived at the intersection after disappearance of the visual scene.

Apparatus and visual environment

In both experiments participants sat in the driver seat of a fixed-base SIDROH driving simulator, based on a Renault Megane II (see Fig. 1, top panel). They could interact with the car using its standard equipment, including the steering wheel and a set of clutch, footbrake and accelerator pedals. The driving simulator implemented an automatic transmission so that participants did not have to shift gears while driving. The audio-visual environment was generated using the ARCHISIM traffic model (Espie & Auberlet, 2007). Using three Epson 485W projectors operating at 60 Hz, the visual scene was presented on three planar (1.8-m high by 1.35-m wide) screens with the left and right screens oriented inward so as to sustain a total horizontal visual angle of 150° for a vertical visual angle of 40°. In order to improve immersion in the scene, the virtual environment was also presented in the side and rear-view mirrors. The participant’s viewpoint was situated 1.2 m above the ground at a distance of 2.2 m from the frontal projection screen. A quadriphonic sound system presented sounds from inside (e.g., engine, tires, start engine) and outside (e.g., engines of crossed vehicles) the car.

The simulated environment consisted of a straight textured road, with two lanes for opposing traffic separated by intermittent white lines, running through a flat rural environment (see Fig. 1, bottom panel). The road followed by the participant was orthogonally intersected by a similar second road over which a single vehicle (Experiment 1) or a train of vehicles (Experiment 2) could approach the intersection from the left. In Experiment 1 the participant was passively transported towards the intersection and had to judge when the other vehicle would reach the intersection. In Experiment 2 the participant actively drove the simulator car so as to cross the intersection by passing through a gap in the train of traffic. Each participant completed the two experiments within the same half day, with experimental sessions being separated by a 15 min rest period . Each experiment consisted of both a familiarization phase (3 min for Experiment 1, 8 min for Experiment 2) and an experimental phase (30 min for both experiments). The order of passage of the two experiments was counterbalanced over participants, such that 7 participants performed Experiment 1 before Experiment 2 and 7 others performed Experiment 2 before Experiment 1. In both Experiments each trial started with the participant moving at a speed 16 m/s, from initial distances of 72, 88, and 104 m from the intersection. Participants always moved in the right lane of the road. Data were collected at a 60 Hz sampling frequency.

Experiment 1: Judging vehicle arrival time

Task and experimental design

During passive approach to the intersection, the participant was confronted with a vehicle approaching the intersection *via* the other road. After an exposure duration depending on the experimental conditions, the full visual scene disappeared and all screens became blank. The participant's task was to estimate when the approaching vehicle would have arrived at the intersection (precisely, at the midline of the participant's road) by pulling the horizontal lever protruding from the left side of the steering column (normally used for flashing the lights).

In order to study the effects of vehicle type and vehicle size independently, we created 3D models of a car and a motorcycle-with-driver of identical physical outline dimensions. The normal-sized vehicles were 2.4 m long, 1.27 m wide and 1.7 m high. The double-sized vehicles were twice as large, 4.8 m long, 2.54 m wide and 3.4 m high. Both vehicles were colored red except for the wheels and tires that were respectively grey and black[1].

Moving at 10 m/s the stimulus vehicle could start at distances of either 40 or 50 m from the intersection, corresponding to vehicle travel durations to the intersection of 4 or 5 s. Moving at 16 m/s participants could start at distances of either 72, 88, or 104 m from the

[1] Note that the dimensions of the normal sized-vehicles used here corresponded quite closely to the dimensions of small cars (e.g., smart) and 'classical' motorbikes. As the double-sized vehicles did not have such direct correspondence with daily life, we questioned each participant after completion of the experiments about several aspects of the scenario used and in particular about the different experimental manipulations they had identified. Interestingly, not a single participant mentioned the size of the approaching vehicle(s). Conversely, they all cited the type of vehicle(s), but also variables that were in fact not manipulated, such as the speed of the train of vehicles.

intersection, corresponding to participant travel durations to the intersection of 4.5, 5.5, or 6.5 s. The approach to the intersection was visible during either 2 or 3 s. The stimulus vehicle was thus at distances of 30, 20, or 10 m from the intersection when the visual scene disappeared. For the constant vehicle speed of 10 m/s, these distances corresponded to 3, 2, and 1 s until arrival at the intersection. The initial and final visual eccentricities of the stimulus vehicle with respect to the participant's direction of motion varied over conditions, due to the combination of different stimulus vehicle starting distances (2), different exposure durations (2) and different participant starting distances (3).

Procedure

During a short familiarization phase prior to the experiment proper both the participant and the stimulus vehicle moved at speeds of 12 m/s. In the first two familiarization trials the stimulus vehicle remained visible over the full period of approach to the intersection and the participant had to pull the lever when the stimulus vehicle's front bumper crossed the center of the intersection. In the following two familiarization trials, the stimulus vehicle disappeared 0.5 s before reaching the intersection and the participant had to pull the lever when s/he estimated that the stimulus vehicle would have arrived at the same location. Performance on these familiarization tasks was quite precise: Participants pulled the lever on average -0.02 ± 0.08 s before the actual arrival time of the vehicle in the full-visibility condition and 0.02 ± 0.15 s after the actual arrival time of the vehicle in the 0.5-s disappearance condition.

During the experimental phase participants performed five blocks of trials, for a total of 240 trials. In each block of trials all 48 experimental conditions, resulting from the combination of the factors vehicle type (2), vehicle size (2), initial vehicle distance (2), exposure duration (2) and initial participant distance (3), were presented once in a randomized order. Only initial stimulus vehicle distance and exposure duration influenced the actual time remaining (1, 2, or 3 s) until the stimulus vehicle reached the intersection.

Data analysis

For each trial the difference between the actual moment of arrival of the stimulus vehicle at the intersection and the participant's estimation of this moment, indicated by activation of the lever command, was determined. For each modality of stimulus vehicle arrival time (1, 2, and 3 s) we calculated, for each participant under each of the four vehicle type and size combinations separately, average estimated arrival time as well as the constant, absolute and variable estimation errors (Schmidt & Lee, 1988). The latter dependent variables were analyzed using repeated-measures ANOVAs with factors Vehicle Type (car or motorcycle), Vehicle Size (normal-sized or double-sized) and Arrival Time (1, 2, or 3 s). When Mauchly's test revealed violations of the sphericity assumption, Greenhouse-Geisser corrections were applied. Significance level was set at $\alpha = .05$. When appropriate, post-hoc analyses were performed using Scheffé tests.

Results

Figure 2 presents the average arrival time judgments as a function of actual stimulus vehicle arrival time. Visual inspection revealed that AT was generally underestimated for occlusion durations exceeding 1 s, with longer actual ATs (i.e., longer occlusion durations) giving rise to larger underestimations as well as more variability in the judgments. Furthermore, both the size and the type of stimulus vehicle appeared to influence the AT judgments (although vehicle size affected judgments more strongly than vehicle type): Participants underestimated AT to a larger extent when confronted with double-sized vehicles than when confronted with normal-sized vehicles and participants underestimated AT to a lesser extent when confronted with a motorcycle than when confronted with a car. These observations were corroborated by the statistical analyses of the constant, absolute and variable judgment errors.

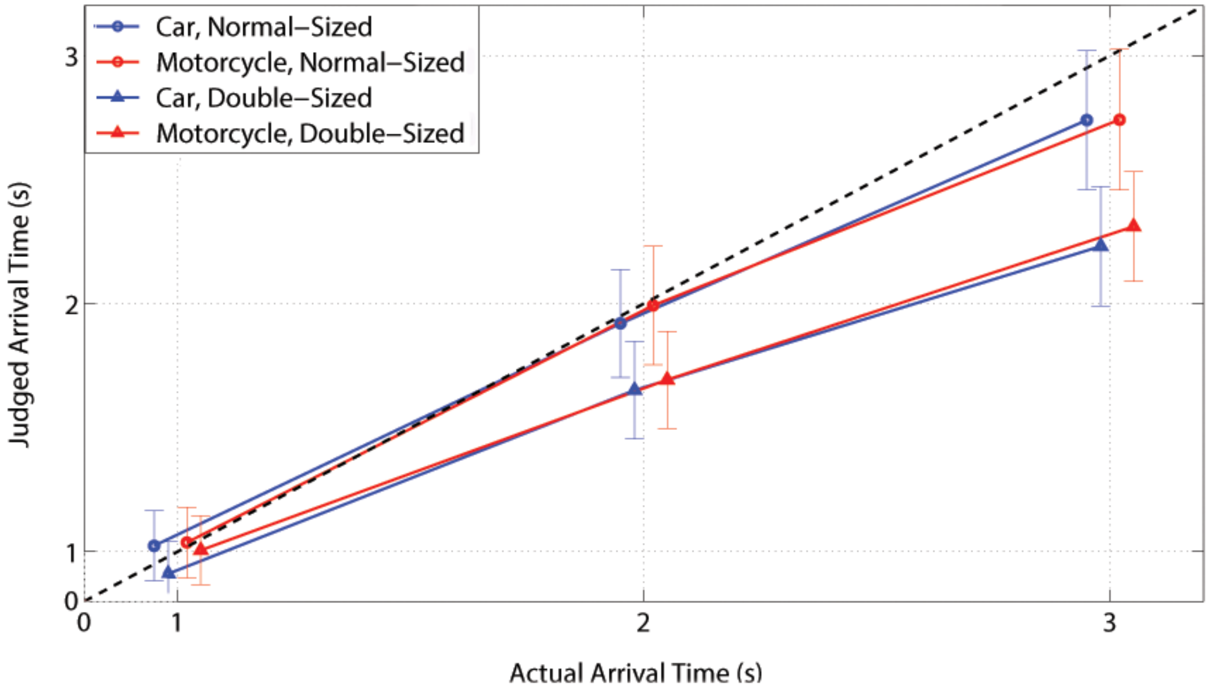

Figure 2: Average judged arrival time as a function of actual arrival time for the four vehicle size and vehicle type conditions. The dotted black line indicates equivalence. Error bars indicate average within-participant standard deviations.

Constant error

The ANOVA on constant error (CE) in the participant's estimation of vehicle arrival time revealed significant main effects of the factors Arrival Time ($F(1.37, 17.87) = 53.07$, $p < .001$, $\eta^2_p = .80$), Vehicle Type ($F(1, 13) = 12.78$, $p < .01$, $\eta^2_p = .50$) and Vehicle Size ($F(1, 13) = 121.57$, $p < .001$, $\eta^2_p = .90$), a first-order interaction between Vehicle Size and Arrival Time ($F(1.44, 18.68) = 37.05$, $p < .001$, $\eta^2_p = .74$), as well as a second-order interaction between Vehicle Type, Vehicle Size and Arrival Time ($F(1.90, 24.65) = 3.45$, $p < .05$, $\eta^2_p = .21$). This complex pattern of results indicated that both Vehicle Type and Vehicle Size affected CE but not in the same way for each Arrival Time (Fig. 3A). We therefore ran separate ANOVAs with factors Vehicle Type and Vehicle Size at each level of Arrival Time.

For an Arrival Time of 1 s, significant main effects were observed for Vehicle Type ($F(1, 13) = 13.21$, $p < .01$, $\eta^2_p = .50$) and Vehicle Size ($F(1, 13) = 17.92$, $p < .001$, $\eta^2_p = .58$) together with a significant interaction between Vehicle Type and Vehicle Size ($F(1, 13) = 6.63$, $p < .05$, $\eta^2_p = .34$). Post-hoc analysis of the interaction indicated that the normal-sized car gave rise to a slight overestimation of arrival time while the double-sized car gave rise to a slight underestimation ($p < .05$). No such an effect of Vehicle Size was observed for the motorcycle, with both sizes leading to CE's similar to that observed for the normal-sized car. For an Arrival Time of 2 s, significant main effects were observed for both Vehicle Type ($F(1, 13) = 9.11$, $p < .01$), $\eta^2_p = .41$) and Vehicle Size ($F(1, 13) = 79.33$, $p < .001$), $\eta^2_p = .86$). The interaction was not significant ($p > .1$, $\eta^2_p = .07$). The normal-sized vehicles gave rise to, respectively, a small underestimation of arrival time for the car and a very slight overestimation for the motorcycle. A similar difference in CE's was observed for the double-sized vehicles, with larger underestimations for the car than for the motorcycle. For an Arrival Time of 3 s, arrival time was systematically underestimated (all CE's negative) and revealed a significant main effect of Vehicle Size only ($F(1, 13) = 78.92$, $p < .001$, $\eta^2_p = .86$; other effects all $p > .1$ and, $\eta^2_p < .03$). For both the car and the motorcycle, double-sized vehicles gave rise to larger underestimations of arrival time than their normal-sized counterparts.

Absolute Error

The ANOVA on absolute error (AE) in the participant's estimation of vehicle arrival time revealed significant main effects of the factors Arrival Time ($F(1.14, 14.83) = 59.33$, $p < .001$, $\eta^2_p = .82$) and Vehicle Size ($F(1, 13) = 6.17$, $p < .05$, $\eta^2_p = .32$), first-order interactions between Vehicle Size and Arrival Time ($F(1.78, 23.15) = 15.75$, $p < .001$, $\eta^2_p = .55$) and Vehicle Type and Vehicle Size ($F(1, 13) = 5.21$, $p < .05$, $\eta^2_p = .29$), as well as a second-order interaction between Vehicle Type, Vehicle Size and Arrival Time ($F(1.89, 24.55) = 4.38$, $p < .05$, $\eta^2_p = .25$). As for CE, this complex pattern of results indicated that both Vehicle Type and

Vehicle Size affected AE but not in the same way for each Arrival Time (Fig. 3B). To clarify the effects of Vehicle Type and Vehicle Size we therefore again ran separate ANOVAs with factors Vehicle Type and Vehicle Size at each level of Arrival Time.

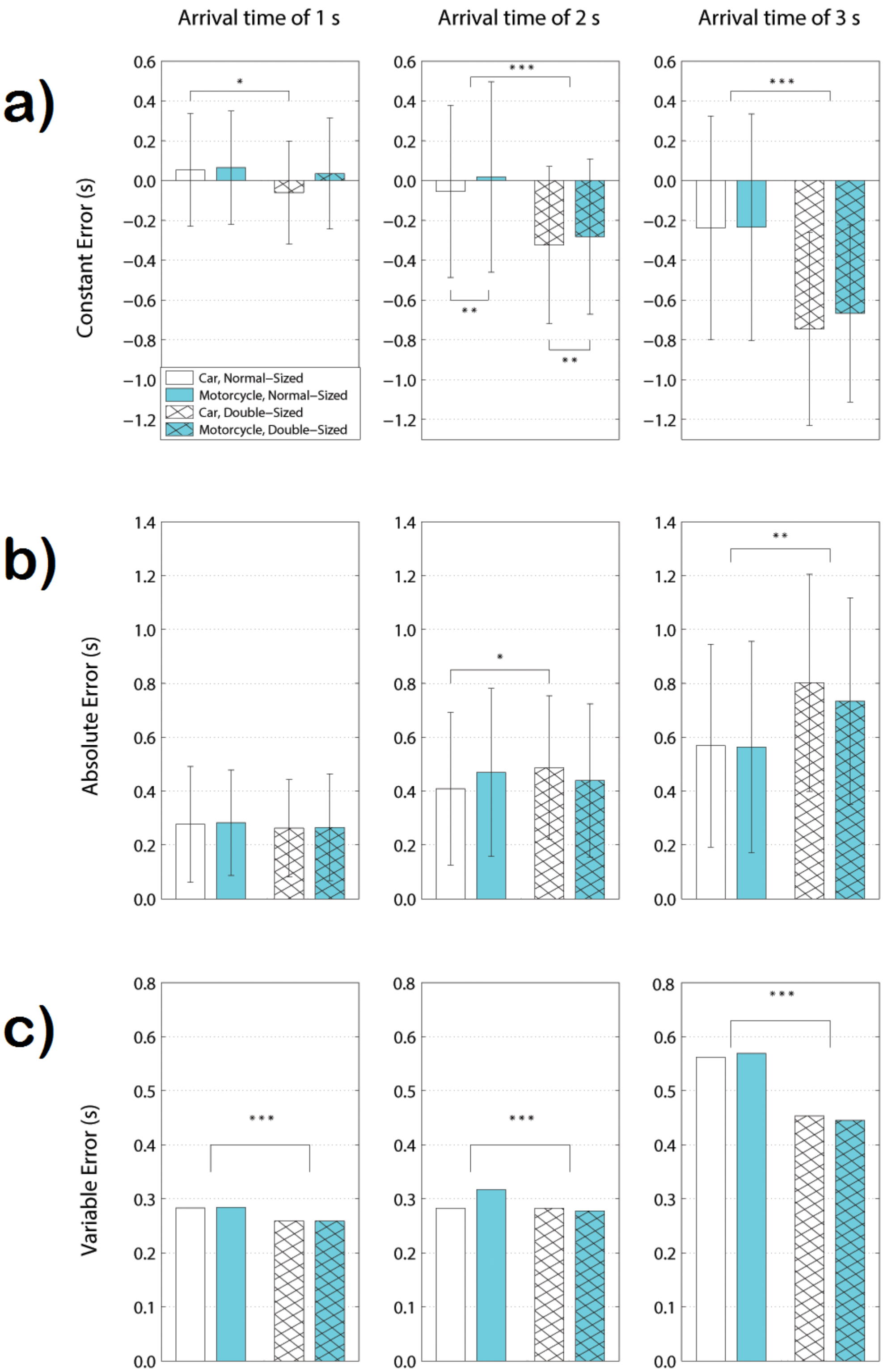

Figure 3: Constant Error (a), Absolute Error (b) and Variable Error (c) in participants' estimates of vehicle arrival time for the 1-s (left column), 2-s (middle column and 3-s (right column) arrival time conditions. ***p < .001, **p < .01 and *p < .05 significant differences. Error bars indicate average within-participant standard deviations.

For an Arrival Time of 1 s, no effects on AE of Vehicle Type or Vehicle Size ($p > .1$, $\eta^2_p < .05$) were observed. For an Arrival Time of 2 s, the interaction between Vehicle Type and Vehicle Size was significant ($F(1, 13) = 16.21$, $p < .01$, $\eta^2_p = .55$). Post-hoc analysis of the interaction revealed that AE was larger for the double-sized car than for the normal-sized car ($p < .05$). No such size-effect was observed for the motorcycle. AE tended ($p = .051$) to be larger for the normal-sized motorcycle than for the normal-sized car. For an Arrival Time of 3 s, AE was influenced by Vehicle Size only ($F(1, 13) = 15.96$, $p < .01$, $\eta^2_p = .55$; other effects all $p > .1$ and $\eta^2_p < .11$). AE was larger for both the double-sized car and motorcycle than for their normal-sized counterparts.

Variable error

The ANOVA on variable error (VE) in the participant's estimation of vehicle arrival time revealed significant main effects of the factors Arrival Time ($F(1.38, 17.93) = 55.97$, $p < .001$, $\eta^2_p = .81$) and Vehicle Size (2, 26) = 42.61, $p < .001$, $\eta^2_p = .77$). No other effects reached significance (all $p > .1$ and $\eta^2_p < .18$). Post-hoc analysis of the Arrival Time effect revealed that VE was larger ($p < .001$) for an Arrival Time of 3 s than for Arrival Times of 1 s and 2 s (Fig. 3C). Moreover, VE was larger for both the normal-sized car and motorcycle than for their double-sized counterparts.

Discussion

The aim of this first experiment was to disambiguate and qualify the effects of actual AT, vehicle size and vehicle type on AT judgments. We will first examine the influence of actual AT on the participants' judgments, before analyzing the respective impact of the variables of interest (i.e., size and type) on the perceptual task.

Actual AT effects. Longer ATs were judged with less precision, as evidenced by the increase in AE with increasing actual AT (on average, 0.27, 0.45, and 0.68 s for actual ATs of 1, 2, and 3 s, respectively). In line with the literature (e.g., Schiff & Detwiler, 1979; McLeod & Ross, 1983; Cavallo & Laurent, 1988; Schiff & Oldak, 1991) this effect resulted from the combination of both an increasing underestimation (CE) and an increasing variability (VE) in the judgments of longer actual ATs. While the interpretation of these results in terms of interval timing falls outside the scope of the present contribution (see Gibbon, 1977, and Mattel and Meck, 2000), we note that the similarity of the results obtained in our study, in comparison with the results reported in the literature, is an important methodological step in validating our protocol. We can now address the influence of vehicle size and vehicle type on AT judgments.

Size and Type effects. The size of the approaching vehicle was found to systematically affect AT judgements. Double-sized vehicles gave rise to larger errors than normal-sized vehicles, in particular for the larger actual AT's (i.e., 2 and 3 s). In these conditions, compared to their normal-sized counterparts, double-sized vehicles led participants to underestimate AT by an extra 0.28 s in the 2-s AT condition and an extra 0.50 s in the 3-s AT condition. The size of the approaching vehicle also affected variable error, with normal-sized vehicles giving rise to larger errors than double-sized vehicles. This pattern of results confirms the influence of the size of the approaching vehicle on perceptual judgments reported in the literature on numerous occasions (cf., De Lucia, 2013). While previous studies confounded the effects of vehicle size and type (e.g., Dewing et al., 1993; Caird & Hancock, 1994, 2002; Horswill et al., 2005), our experimental protocol, designed to disambiguate these effects, allowed us to ascertain that it was the size of the approaching vehicle *per se* that influenced the judgments of the participants. It also allowed us to highlight the influence of the type of approaching vehicle on the judgment of the participants. While not present in the 3-s AT condition, an effect of vehicle type appeared in the 2-s AT condition, characterized by a systematically larger AT underestimation for cars than for motorbikes. The observation that the average difference was a modest 0.06 s indicates that the effect of the type of vehicle is not as strong as the effect of the size of the vehicle. Finally our results also demonstrated that in the shorter AT conditions size and type interacted, with size affecting judgments for cars but not for motorcycles (for AE in 2-s AT condition and for CE in 1-s AT condition).

Overall, the present results therefore confirmed that the precision of AT judgments decreases (i.e., increasing underestimation and larger variability) when actual AT increases. Most interestingly for the present purposes, both the size and the type of an approaching vehicle were found to influence perceptual judgments of its arrival time, but not in the same way. Vehicle size affected AT judgments more for larger actual ATs. Thus, under the hypothesis that the regulation of approach to the intersection during active intersection crossing is (at least partly) related to successive AT judgments, early on during the approach drivers would be expected to adopt a somewhat higher speed when confronted with larger-sized incoming vehicles than when confronted with normal-sized incoming vehicles. This vehicle-size effect on driver speed should gradually diminish over the course of the approach, as AT judgments become less and less affected by vehicle size with decreasing actual AT. As expected (Brendel et al., 2012, 2014), vehicle type was also found to affect AT judgments, albeit overall to a lesser extent than vehicle size. Contrary to the effect of vehicle size, no effect of vehicle type was observed at the largest (3-s) actual AT tested; its influence only appeared at the shorter actual ATs, with cars generally being judged to arrive earlier than motorcycles. Thus, according to the same logic as developed for the expected effects of vehicle size, during the last seconds of active approach to an intersection drivers should adopt slightly higher speeds when confronted with incoming cars than when confronted with incoming motorcycles. In Experiment 2, we tested these hypotheses by analyzing the influence of vehicle size and type on an active intersection-crossing task.

Experiment 2: Passing through a gap in a train of traffic

Task and experimental design

In Experiment 2 the participant actively drove the simulator. The task and procedure were similar to that of Louveton et al. (2012a, 2012b), except that in the present experiment the simulator had a larger accelerative capacity. In Louveton et al.’s parameterization of the simulator reaching a speed of 100 km/h required 15.7 s of full acceleration. Here it required only 5.1 s, providing participants with a larger range of speed regulation capabilities. In order to familiarize the participants with the simulator, they first performed a following task, consisting of attempting to remain at a constant distance (corresponding to two segments of the intermittent central lane division markings) behind a car moving in front. The latter changed speed regularly, moving at 13.9, 16.7 or 19.4 m/s (corresponding to 50, 60 or 70 km/h) during 4, 6, or 8 s periods. Speed levels and durations were randomly combined into a sequence of eight minutes. This exercise forced participants to accelerate, decelerate and maintain a constant speed, thereby allowing them to discover the action capabilities of the simulated vehicle driven. Following this familiarization phase and a short break, the experimental phase was started.

In the experimental phase, the participants' task was to safely cross the intersection. During approach to the intersection, the participant was confronted with a four-vehicle traffic train coming from the left and moving at a constant speed of 10 m/s. This traffic train consisted of a truck, two red vehicles and another truck (see Fig. 4, lower panel).

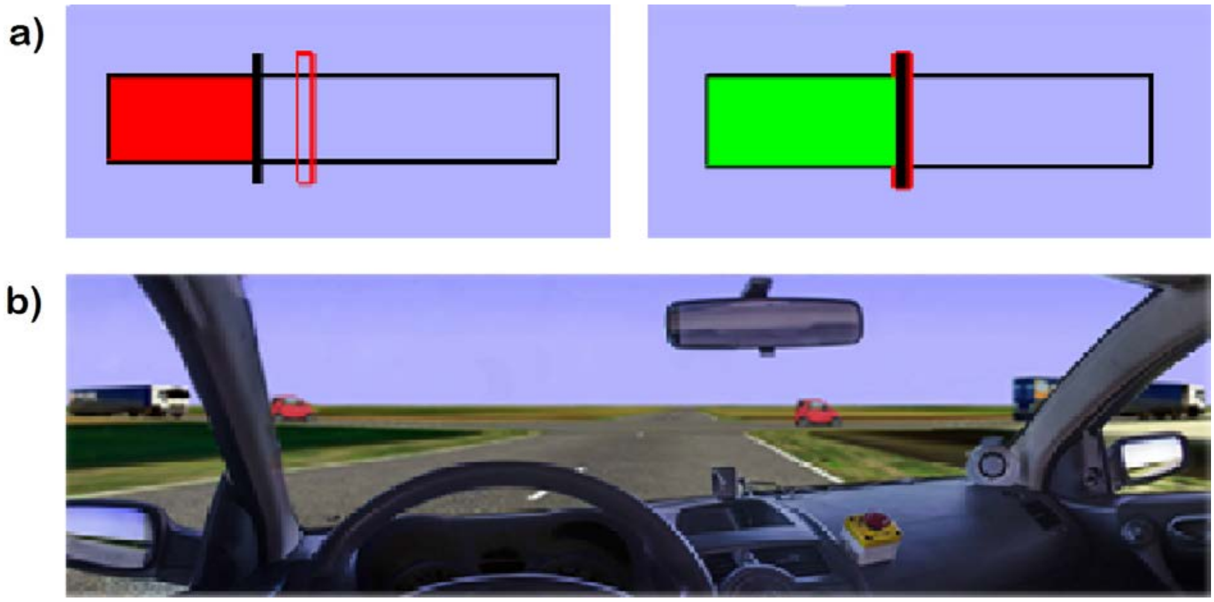

Figure 4: Illustration of the speed gauge displayed in the center of the visual field to help participants stabilize speed prior to onset of the intersection crossing scenario (a). The gauge presented on the left indicates that current speed is too low, while the gauge presented on the right indicates that current speed is within the required zone. Participant’s view of the intersection with the traffic train consisting of two trucks surrounding two red vehicles (here two cars) separated by a 27-m gap (b).

Participants were to cross the intersection using the 27-m (i.e., 2.7-s) gap between the two red vehicles. In the absence of any traffic signs, no information with respect to priority was provided. The four-vehicle traffic train always moved in such a way that the center of the traffic gap (between the two red vehicles as measured by the distance between the lead vehicle's rear end and the trail vehicle's front end) arrived at the middle of the driver's lane 5.5 s after the beginning of the intersection scenario. In the rare case that the driver collided with one of the traffic vehicles a large red triangle was presented.

Three aspects of the situation were experimentally manipulated: the type of vehicle in the traffic train, the size of the vehicles in the traffic train and the initial position of the participant driving the simulator. Vehicle Type and Vehicle Size corresponded to those used in Experiment 1: Vehicles could be cars or motorcycles and vehicles could be normal-sized or doubled-sized.

The participant's initial distance from the intersection was manipulated so as to create an offset between the anticipated moment of arrival at the intersection of the participant and the moment of arrival of the center of the traffic gap. To this end, the distance remaining to the intersection was set to 72, 88, or 104 m at the moment the participant had stabilized the car's speed (see below). Continuing at the stabilized speed of 16 m/s would have the participant arrive at the intersection with a temporal offset of +1 s (Early Offset), 0 s (No Offset), or −1 s (Late Offset) with respect to the center of the traffic gap. Note that the early and late offsets still allowed safely passing the intersection, as lead and trail vehicles were separated by a 2.7-s time gap.

At the beginning of each trial, participants were parked in the middle of their lane, without any other vehicles in sight. They started the car's engine and operated the pedals in order to attain the required velocity of 16 m/s indicated by a horizontally-oriented speedometer placed directly in front of them. Their current speed was indicated by the position of a black vertical line on a speed gauge and the required speed by a vertically-elongated rectangular zone, without any numerical information being provided (Fig. 4, upper panel). When the car’s speed was within the delimited zone the gauge was green; when it was outside the delimited zone the gauge was red. Speed had to be stabilized within the indicated zone. An 80-m long stretch of empty road was available for the initial acceleration and subsequent stabilization of speed. If the participant's car speed remained within the delimited zone (corresponding to 16.0 ± 0.55 m/s = 57.6 ± 2.0 km/h) over the last 20 m of the 80-m stretch, the speed gauge disappeared and the intersection scenario was started, with the four-vehicle traffic train appearing on the left. If not, the trial was restarted. Note that the presence of the gauge during the preparatory phase was in fact a methodological stratagem allowing us to standardize the initial conditions from trial to trial (at the onset of the intersection scenario) while at the same time providing the participants with active control of their speed.. Because the gauge disappeared when the intersection scenario was started it cannot have interfered with the driver's behavior during the approach to the intersection.

During the experimental phase participants performed five blocks of trials for a total of 60 trials. In each block of trials all 12 experimental conditions, resulting from the combination of the factors vehicle type (2), vehicle size (2) and the initial position of participant driving simulator (3), were presented once in a randomized order.

Data analysis

Intersection crossing was analyzed *via* the position of the participant within the traffic gap at the moment of crossing. Taking the center of the gap as the reference, a negative crossing position indicated crossing after the center of the gap (i.e., closer to the trail vehicle) while a positive crossing position indicated crossing before the center of the gap (i.e., closer to the lead vehicle). In order to examine the nature of the speed adjustments effected during approach to the intersection, we analyzed the time course of participant's speed and its instantaneous effect on future passing position within the traffic gap, allowing a functional interpretation of the observed speed adjustments. The latter was operationalized through the current deviation (CD) from the traffic gap center, calculated as the time (distance) from the center of the traffic gap at which the participant would pass the intersection if the current speed were to remain constant from thereon. In the No Offset condition, continuing at the initial (stabilized) speed would lead the participant to pass right in the center of the traffic gap. Thus, at the start of a No Offset trial, the temporal (spatial) CD was equal to 0 s (0 m). In the Late Offset condition, continuing at the initial speed would lead the participant to pass 1 s (10 m) behind the center of the traffic gap. Thus, at the start of a Late Offset condition CD was −1 s (−10 m). In the Early Offset condition, continuing at the initial speed would lead the participant to pass 1 s (10 m) in front of the center of the traffic gap. Thus, at the start of an Early Offset trial CD was +1 s (+10 m).

The time courses of speed and current deviation were analyzed in time steps, by averaging each of these variables over 1-s intervals synchronized with the final moment of passing the intersection. Given the relatively high speeds adopted by the participants in the present study, they often reached the intersection within less than 5 s. Average speeds and current deviations could therefore only be calculated over four time steps (i.e., 1-s intervals around 3.5, 2.5, 1.5, and 0.5 s before the participant arrived at the intersection).

Statistical analyses were performed using repeated-measures ANOVAs. The temporally-defined position in the traffic gap at the moment the participant crossed the intersection was analyzed with the factors Vehicle Type (cars or motorcycles), Vehicle Size (normal-sized or double-sized) and Offset (early, no, late). For speed and temporally-defined current deviation similar 3-way ANOVAs were conducted at each Time Step (3.5, 2.5, 1.5 or 0.5 s before crossing) in order to facilitate interpretation of the results. When Mauchly's test revealed violations of the sphericity assumption, Greenhouse-Geisser corrections were applied. Significance level was set at $\alpha = .05$. When appropriate post-hoc analyses were performed using Scheffé tests.

Results

Gap crossing position

The ANOVA on gap crossing position revealed significant main effects of the factors Offset ($F(1.26, 16.42) = 55.19$, $p < .001$, $\eta^2_p = .81$) and Vehicle Size ($F(1, 13) = 14.43$, $p < .01$, $\eta^2_p = .53$). The main effect of Vehicle Type was not significant ($p > .1$, $\eta^2_p = .15$), nor were any of the interactions (all $p > .1$ and $\eta^2_p < .10$).

As can be seen from Fig. 5, participants crossed the intersection at a position ahead of the center of the traffic gap under all conditions. Gap crossing position was systematically a little (0.06 s on average) closer the center of the traffic gap when participants were confronted with the double-sized vehicles as compared to the normal-sized vehicles. Post-hoc analysis of the main effect of Offset demonstrated that, compared to the no-offset condition, an early offset gave rise to crossing the intersection further ahead of the center of the traffic gap ($p < .01$) while a late offset gave rise to crossing the intersection closer to the center of the traffic gap ($p < .01$). The persistence, up to the point of intersection crossing, of an effect of offset in the participant's initial distance to the intersection was also reported by Louveton et al. (2012a, 2012b). As in these earlier studies, however, this finding did not imply that participants continued to drive at the initial speed, without implementing functional speed regulations during approach to the intersection: At the time of crossing the initial (+1 s) difference between early and no offset conditions had been reduced to +0.19 s and the initial (−1 s) difference between late and no offset conditions had been reduced to −0.18 s, on average. These changes correspond to average final crossing positions of +0.65, +0.46, and +0.28 s for the early (+1 s), no (0 s), and late (−1 s) offset conditions, respectively.

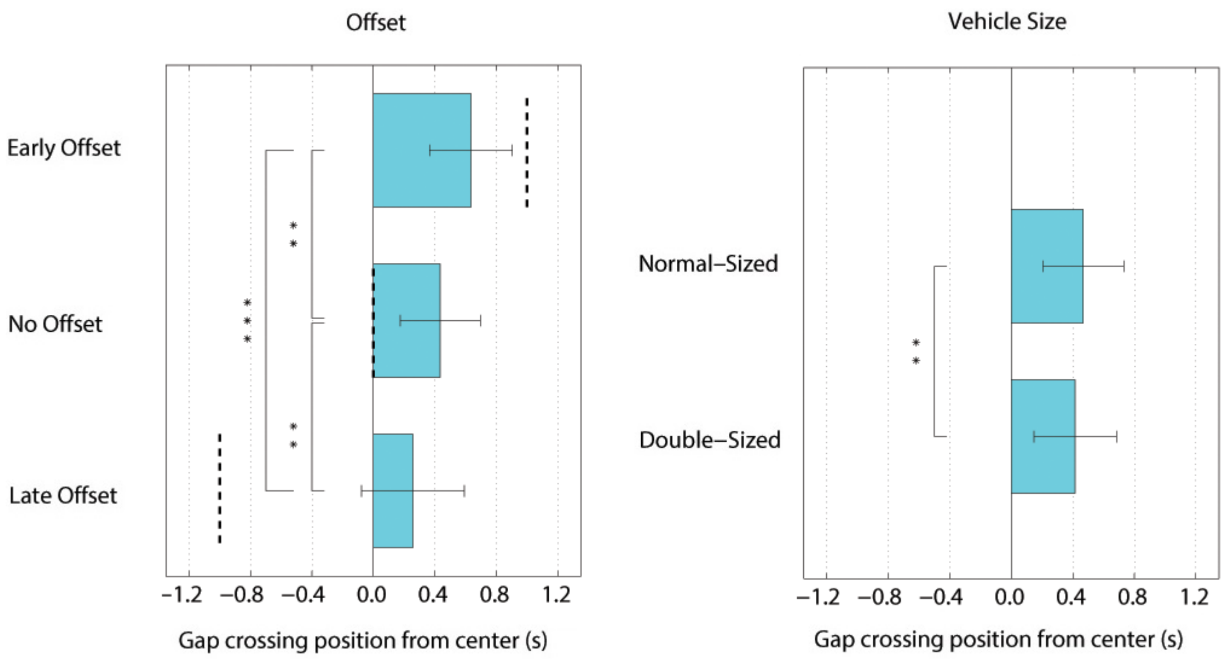

Figure 5: Average gap crossing position as a function of initial offset (left panel) and traffic vehicle size (right panel). Vertical dotted black line segments indicate the position where participants would have crossed the intersection if they had maintained the initial speed over the full duration of the trial. The gap's trail and lead vehicles were respectively located at -1.35 s and +1.35 s from the gap center. ***p < .001 and **p < .01 significant differences. Error bars indicate average within-participant standard deviations.

Speed profiles

As already indicated by the results on gap crossing position, participants did not simply maintain their initial speed notwithstanding the fact that this would have allowed them to cross the intersection without colliding with the traffic vehicles. The speed profiles presented in Fig. 6A indicated that in the early offset conditions participants appeared to have decelerated early on during the approach, as speed was already well below its initial value at 3.5 s before reaching the intersection. They continued to decelerate up to 2.5 s before reaching the intersection before reaccelerating during the final phase of approach. In the no offset conditions, participants appeared to have almost fully maintained their initial speed during the initial phase of approach: at 3.5 s before reaching the intersection participant speed was only slightly below 16 m/s. From there on they began to accelerate and continued to do so up to the moment of intersection crossing. In the late offset conditions participants appeared to have accelerated early on during the approach, as speed was already well above its initial value at 3.5 s before reaching the intersection. They continued to accelerate up to the moment of intersection crossing. This general pattern of speed regulation as a function of offset condition was observed whether the traffic vehicles were cars or motorcycles and whether they were normal-sized or large-sized. As demonstrated by the statistical analyses, the size and type characteristics of the vehicles in the traffic train did however bring about subtle but systematic variations in this general pattern.

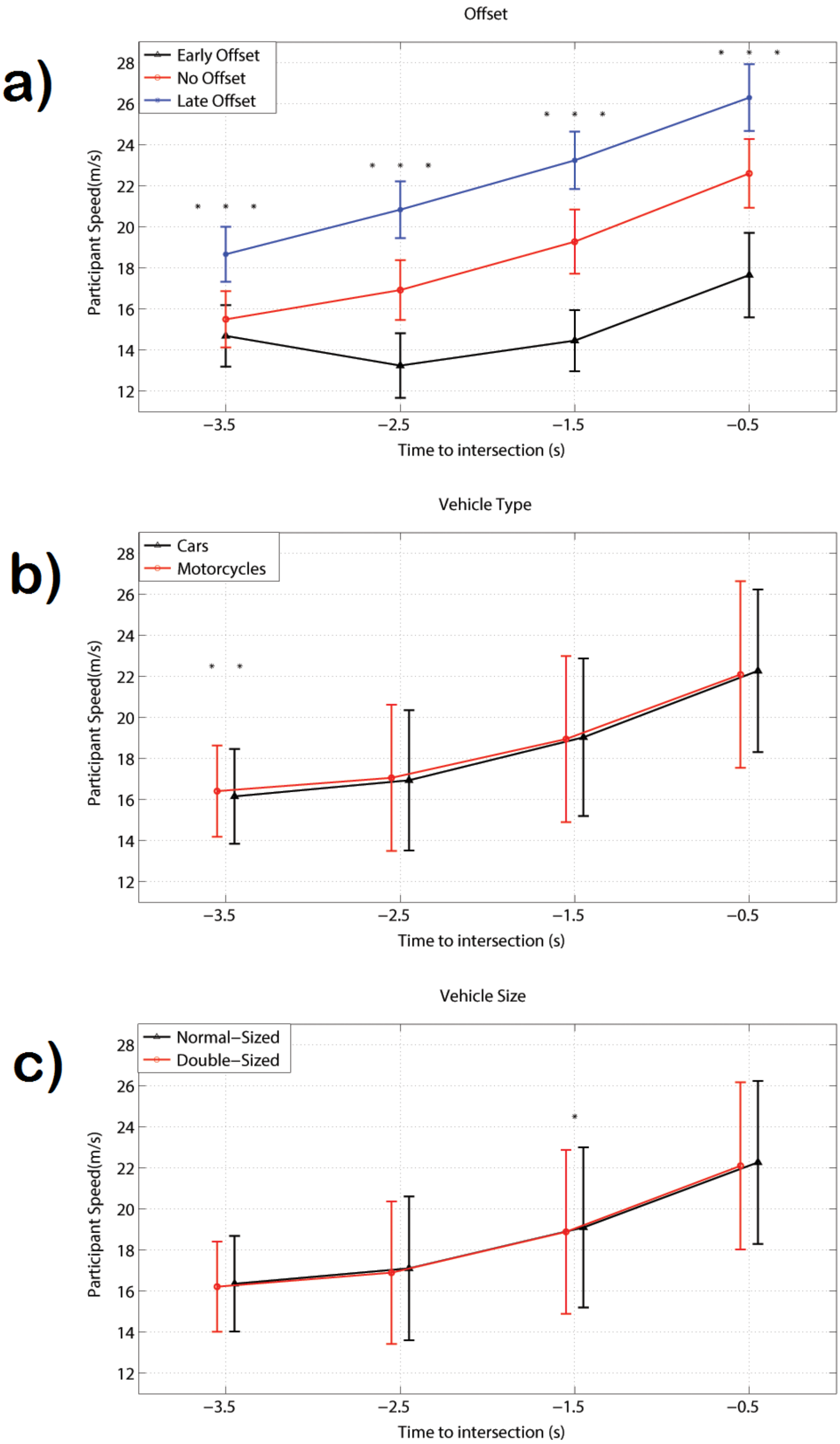

Figure 6: Average participant speed as a function time before crossing the intersection for each offset (a), vehicle type (b) and vehicle size (c). ***p < .001, **p < .01 and *p < .05 significant differences. Error bars indicate average within-participant standard deviations.

Since we already observed differences in participant speed at the earliest Time Step analyzed (i.e., at 3.5 s before reaching the intersection), we first assessed the participants' initial reaction to the different experimental conditions by analyzing the speed after having been exposed to the intersection-crossing scenario for 1 s (i.e., around 4 s before arrival at the intersection). An ANOVA on participant speed at 1 s after the beginning of the approach to the intersection revealed significant main effects of factors Offset ($F(1.98, 25.77) = 21.90$, $p < .001$, $\eta^2_p = .63$) and Vehicle Type ($F(1, 13) = 10.92$, $p < .01$, $\eta^2_p = .45$). While none of the interactions approached significance (all $p > .1$ and $\eta^2_p < .13$), the factor Vehicle Size tended towards significance ($F(1, 13) = 3.44$, $p = .09$, $\eta^2_p = .21$). Nevertheless, because the speed difference between the normal-sized and double-sized vehicles was less than 0.1 m/s, the possible early effect of Vehicle Size could be considered negligible. On average speed after 1 s of exposure was lower under the early offset conditions than under the no offset conditions (15.5 m/s vs. 15.8 m/s, $p < .01$) and higher under the late offset conditions than under the no offset conditions (16.0 m/s vs. 15.8 m/s, $p < .05$). Thus, the different offset conditions evoked quite rapid, offset-specific reactions. Of particular interest for the present purposes was that different vehicle types also evoked such rapid reactions: On average participant speed after 1 s of approach to the intersection was lower when the traffic train contained cars as compared to motorcycles (15.7 m/s vs. 15.9 m/s).

As was to be expected from the observation of an influence of offset conditions on the final gap crossing position, Offset effects on participant speed persisted throughout the approach to the intersection (at each Time Step: $F > 300$, $p < .001$, $\eta^2_p > .98$). More interesting for the present purposes was the finding that the effect of Vehicle Type (already observed at 1 s into the scenario) was still present at 3.5 s before reaching the intersection before washing out over the course of the approach to the intersection (see Table 1 and Fig. 6B). At 3.5 s before reaching the intersection the effect of Vehicle Size, characterized by η^2_p =

.17, was not significant (p > .1), nor were any of the interactions (all p > .1 and η^2_p < .10). While Vehicle size did not affect participant speed in the early stages of the approach (i.e., at 1 s after the start and at 3.5 s before reaching the intersection), traffic trains containing double-sized vehicles were found to give rise to slightly but systematically lower participant speeds at 2.5 s (p = .084, η^2_p = .21) and 1.5 s (p < .05, η^2_p = .13) as compared to traffic trains containing normal-sized vehicles (see Table 1 and Fig. 6C). This effect of Vehicle Size on participant speed was no longer significant shortly before the intersection was crossed.

Table 1: Effects of Vehicle Type and Vehicle Size on participant speed at different times before arrival at the intersection.

	Vehicle Type				Vehicle Size			
TTI (s)	Diff. Mot-Car (m/s)	F (1, 13)	p	η^2_p	Diff. Nor-Dble (m/s)	F (1, 13)	p	η^2_p
3.5	0.25	9.76	< .01	.43	0.14	2.61	> .1	.17
2.5	0.12	1.50	> .1	.10	0.21	3.50	< .1	.21
1.5	-0.09	0.65	> .1	.02	0.21	6.72	< .05	.13
0.5	-0.18	2.18	> .1	.14	0.17	2.31	> .1	.15

TTI: Time to intersection. Diff. Mot-Car: Average difference in participant speed between traffic trains containing motorcycles and traffic trains containing cars. Diff. Nor-Dble: Average difference in participant speed between traffic trains containing normal-sized vehicles and traffic trains containing double-sized vehicles.

Current deviation

Continuously extrapolating the current state of affairs to the future moment of passing the intersection, the variations over time of the current deviation (CD) from the center of the traffic gap allow a functional interpretation of the speed regulations described in the previous section.

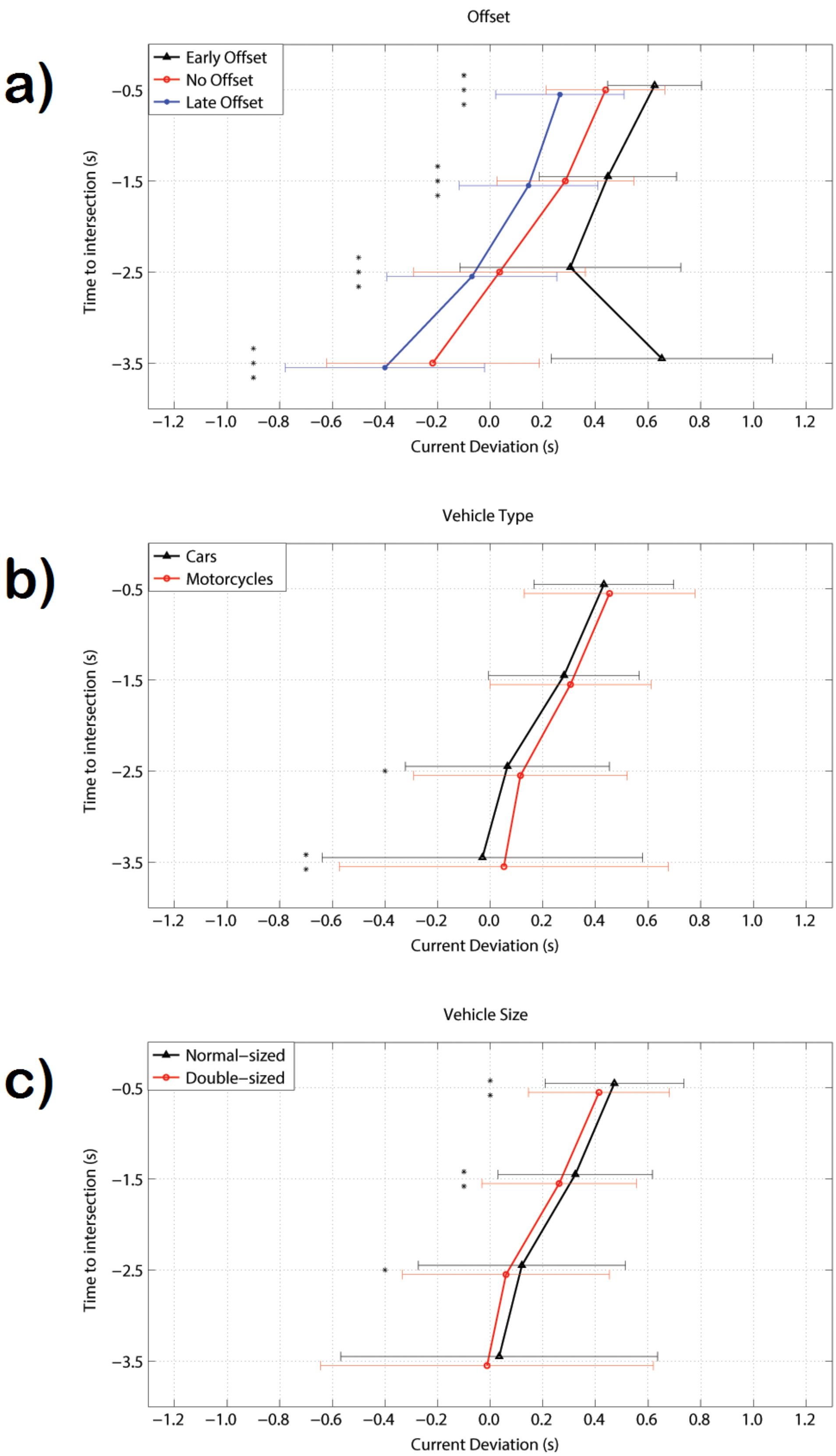

Figure 7: Average current deviation as a function time before crossing the intersection for each offset (a), vehicle type (b) and vehicle size (c). The gap's trail and lead vehicles were

respectively located at -1.35 s and +1.35 s from the gap center. ***$p < .001$, **$p < .01$ and *$p < .05$ significant differences. Error bars indicate average within-participant standard deviations.

As can be seen from Fig. 7A, at 3.5 s before reaching the intersection the initial early (+1 s) and late (-1 s) offsets had already been reduced, as a result of the early change in speed discussed in the previous section. For the no-offset conditions, CD was only slightly below 0 s, as a result of participants largely maintaining their initial speed. Speed regulations continued to reduce CD under all conditions up to 2.5 s before reaching the intersection. From there on the acceleration observed under all conditions (see Fig. 6A) gave rise to a systematic increase in CD, leading participants to cross the intersection at positions ahead of the center of the traffic gap (see Fig. 5).

As was to be expected from the observation of an influence of offset conditions on the final gap crossing position, Offset effects persisted throughout the approach to the intersection (at each Time Step: $F > 30$, $p < .001$, $\eta^2_p > .70$). More interestingly for the present purposes was the observation of an early effect of Vehicle Type on current deviation. Participants' current deviation at 3.5 s before reaching the intersection was slightly (0.08 s) but systematically larger when the traffic train contained motorcycles rather than cars. This initial effect of Vehicle Type gradually disappeared over the approach to the intersection (see Table 2 and Fig. 7B). The washing out of the Vehicle Type effect over the course of the approach to the intersection (η^2_p decreasing from .53, to .17, see Table 2) is consistent with the absence of such an effect at the moment the participants crossed the intersection. The effect of Vehicle Size, on the other hand, did not reach significance in the earliest stage of approach ($p = .065$, $\eta^2_p = .24$), but became significant thereafter (η^2_p increasing from .24 to .55, see Table 2), consistent with the finding that participants crossed the intersection closer to the lead vehicle for normal-sized cars than for double-sized cars (see Fig. 7C).

Table 2 : Effects of Vehicle Type and Vehicle Size on current deviation at different times before arrival at the intersection.

	Vehicle Type				Vehicle Size			
TTI (s)	Diff. Mot-Car (s)	F (1, 13)	p	η^2_p	Diff. Nor-Dble (s)	F (1, 13)	p	η^2_p
3.5	0.08	14.56	< .01	.53	0.05	4.06	< .1	.24
2.5	0.05	6.58	< .05	.34	0.06	5.18	< .05	.28
1.5	0.02	3.52	< .1	.21	0.06	11.04	< .01	.46
0.5	0.02	2.63	> .1	.17	0.06	15.73	< .01	.55
0	0.02	2.37	> .1	.15	0.06	14.43	< .01	.53

TTI: Time to intersection. Diff. Mot-Car: Average difference in temporal current deviation between traffic trains containing motorcycles and traffic trains containing cars. Diff. Nor-Dble: Average difference in temporal current deviation between traffic trains containing normal-sized vehicles and traffic trains containing double-sized vehicles. TTI = 0 s corresponds to the moment the participants crossed the intersection.

Discussion

The aim of the second experiment was to analyze the influence of both the size and the type of vehicles in a traffic train on drivers' approach and intersection crossing behavior. We will first analyze the time course of participant speed changes when confronted with different offsets, before examining more precisely to what extent the two variables of interest (size and type) modified the way they accomplished the intersection crossing task.

Patterns of speed change at each offset. Offset manipulations were introduced to encourage participants to actively control their speed during approach to the intersection so as to ensure a safe crossing. The results obtained in the ±1-s offset conditions revealed functional speed changes spread over the course of approach to the intersection allowing the participants to cross the inter-vehicular gap near its center, with a small bias towards early arrival in all conditions. Two additional adjustment characteristics are worth noting. First of all, the participants were shown to detect the need for producing speed changes early on during the approach, with offset-related functional speed changes already being present 1 s after the appearance of the train of vehicles. This strategy allowed the participants to distribute speed adjustments over the entire approach, rather than producing large, and probably not optimal, last second adjustments. The second characteristic is related to the fact that participants did not fully compensate for the initial offsets; the final crossing positions were still different among the three offsets (see Louveton et al., 2012a, 2012b, and Chihak et al., 2010, 2014, for similar results). Taken together, these results speak to the operation of an information-driven type of control allowing functional adjustments to take place all along the approach.

Effects of size and type. Both the size and the type of the approaching vehicles only gave rise to subtle but nevertheless systematic adjustments. Double-sized vehicles gave rise to lower participant speeds (≈ 0.2 m/s) during the intermediate part of the approach resulting in slightly smaller current deviations in comparison with normal-sized vehicles. As a consequence, the gap was crossed a little further from the lead vehicle (≈ 0.06 s) when approaching vehicles were double-sized as compared to normal-sized. The type of approaching vehicle affected intersection crossing behavior in a different way, according to a different temporality. The type of vehicle encountered affected participant speed early on (i.e., soon after the vehicles appeared) while this influence subsequently washed out over the course of the approach. More precisely, during the first seconds following the appearance of the vehicles, participant speed was lower when the traffic train contained cars as compared to motorbikes (≈ 0.2 m/s). These very early adjustments were not only limited in magnitude but also not functional, in the sense that they did not influence the final intersection crossing locations.

Overall, the results of the second experiment indicated a systematic thought limited influence of both the size and the type of the approaching vehicles on participants' intersection crossing behavior. The type effect coincided with the appearance of the train of vehicles and vanished during the second part of the approach. Conversely, the size effect appeared later and was maintained until the end of the approach, giving rise to distinct intersection crossing positions.

General Discussion

In this contribution we addressed the widely-shared conviction that negotiating traffic is based on (punctual) predictive assessments of the situation and that insight into the perceptual-motor mechanisms underlying a road-user's safe or risky behavior can be derived from understanding the factors influencing the predictive assessment of supposedly critical variables, such as the estimated time until arrival of a traffic vehicle at a designated location or the estimated size of a gap in a train of traffic (e.g., Caird & Hancock, 1992, 1994; Dewing et al., 1993; DeLucia, 2013). More specifically, we examined the ensuing hypothesis that the active control of approach to an intersection with incoming traffic is influenced by estimations of the arrival times of traffic vehicles approaching the intersection, because both tasks would rely on a similar perceptual substrate. To this end, we assessed the influences of actual AT as well as the size and the type of approaching vehicle(s) on AT judgments (using the standard *discrete-response motion-extrapolation* paradigm, Experiment 1) and active intersection-crossing behavior (using a driving simulator, Experiment 2). Overall, the results obtained in the two experiments do not provide evidence in favor of reliance on a common perceptual substrate in the two tasks. Neither the effects of actual AT nor the effects of the size or type of approaching vehicles observed in the AT judgments of Experiment 1 gave rise to the expected corresponding effects in speed regulation during the active approach to the intersection of Experiment 2.

In line with earlier studies (Schiff & Detwiller, 1979; McLeod & Ross, 1983; Cavallo & Laurent, 1988), AT judgments revealed systematic underestimations for the longer actual

ATs. Use of successive AT estimates in the no-offset conditions of the active intersection-crossing task should therefore have led our participants to increase their speed early on during the approach, when AT was largely underestimated, followed by a decrease in speed as actual AT decreased and estimates became more accurate. The results of the present study do not fit these predictions. While early and late offsets gave rise to early functional adjustments (characterized by, respectively, a decrease or increase in speed during the early phase of approach, compensating for the experimentally-induced current deviations), in the no-offset conditions speed was initially maintained approximately constant before increasing during the last seconds of approach to the intersection (Fig. 6a,). In the present contribution we furthermore tested how the size and type of incoming traffic vehicles influenced both AT judgments and active intersection-crossing behavior. Often confounded in the literature, both vehicle size and vehicle type were found to affect AT judgments albeit it with different effects at different actual ATs.

For longer actual ATs doubled-sized vehicles were judged to arrive earlier than normal-sized vehicles and this size effect diminished as actual AT decreased. The prevalence of the size effect on AT judgments when vehicles were still far from the intersection (i.e., 2-3 s before crossing, see Experiment 1) was expected to lead drivers to adopt a somewhat higher speed early on during approach to the intersection when the traffic train consisted of double-sized vehicles as compared to normal-sized vehicles. Our results, however, revealed no effect of vehicle size early on during approach. Rather, we observed a slight decrease in speed from 2.5 s before crossing onwards, persisting up to the moment of crossing itself. The observed speed regulations were therefore not compatible with the effects expected on the basis of AT judgments.

The effect of vehicle type revealed a similar finding: vehicle type did not affect the AT judgments of Experiment 1 at the longest actual AT (i.e., 3 s), but only came to the fore at the shorter actual ATs (i.e., 1 and 2 s), with cars being judged as arriving earlier than motorcycles. Thus, whether the train of incoming traffic contained cars or motorcycles was not expected to influence driving speed during the initial phase of approach to the intersection. A traffic train containing cars rather than motorcycles was however expected to lead drivers to slightly increase speed during the final phase. Contrary to these predictions, our results revealed that a traffic train containing cars rather than motorcycles provoked a slight decrease in speed very early during the approach (i.e., 5 s before crossing). This type effect subsequently washed out over the approach.

Overall, the results obtained thus indicate qualitative differences between, on the one hand, the behavior predicted from the AT judgment task results and, on the other hand, the behavior observed in the active intersection-crossing task, suggesting that the two tasks rely on different perceptual substrates. Not only was the temporality of both effects different in the two tasks, but the types of adjustments observed (i.e., either increase or decrease in speed) in the actual intersection-crossing task were also opposite to the predictions.

Taken together, the results from the two experiments indicate that the AT judgment task and the active intersection-crossing task rely on different perceptual substrates. As a consequence, the conclusions drawn from tasks in which participants are asked to judge AT cannot be directly transferred to predictions on behavior in active perceptual-motor tasks. If, as suggested by the results reported here, the general belief that AT estimates are necessarily involved in (safely) negotiating traffic situations is incorrect, one can wonder what type of perceptual information could then be used by active road users and more generally about the type of perceptual-motor mechanism that could be implemented. Identifying the type of perceptual information involved in the active control of approach to an intersection falls outside the scope of the present contribution work. For the time being, we must therefore limit ourselves to speculations only.

The first is related to the type of predictive information participants could use in our perceptual-motor task. Rather than calling upon AT estimates, the actual intersection-crossing task could require predictions about the speed of the approaching vehicle(s), so as to match ego speed accordingly. Recent work by Clark et al. (2013, 2016) on the perceived speed of moving objects indicates that a large object appears to move more slowly than a small object moving at the same speed. A lower speed estimation for double-sized vehicles (in comparison to normal-sized ones) could explain the decrease in driving speed produced by the participants in the active intersection-crossing task of Experiment 2. In this context the effect of vehicle type remains unclear however, in the sense that it is unlikely that the speed of a more threatening vehicle would be underestimated in comparison to a less threatening one. Additional experimental work will be necessary to clarify this point.

In seeking to identify the perceptual information involved in the active control of approach to an intersection one should keep in mind that the manipulations of both the size and the type of the incoming-traffic vehicles only marginally affected driving behavior (cf. Figs. 6b-7b and 6c-7c). On the other hand, the systematic observation of functional speed changes during the approach phase described in Experiment 2 (cf., Figs 6a-7a), conforming earlier findings from Chihak et al. (2010, 2014) and Louveton et al. (2012a, b), should not be minimized and could mirror the use of prospective information (i.e., information about the current future; Bootsma, 2009) in the regulation process. First indications of what such prospective information might entail may be gleaned from two earlier studies. The pattern of speed adjustments during approach to the intersection was found to be affected, on the one hand, by the geometry of the intersection (Louveton et al., 2012a) and, on the other hand, by the (global) characteristics of the inter-vehicular gap itself, as well as the characteristics of its (local) boundaries (Louveton et al., 2012b). Such effects appear to be compatible with the use of information contained in the change of bearing angle, as we already demonstrated in locomotor interception tasks (Bastin et al., 2006; Bootsma et al., 2016), driving the system toward a constant gap-related bearing angle and away from constant bearing angles of the lead and trail vehicles. Clearly the situation is more complex in crossing than in interception tasks, if only for the fact that the gap-related bearing angle can refer to a continuum of positions within the inter-vehicular gap. However this may be, identification of the perceptual information allowing for the occurrence of the gradual and functional regulations described in here and earlier work clearly requires further work. From the present study we have learned that in the new control architecture that will emerge arrival time estimations should not play more than a marginal role.

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