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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

1  
2 According to the European Road Safety Observatory ([www.erso.eu](http://www.erso.eu)), during the year 2013  
3 26,000 people were killed (and over a million injured) in road traffic accidents within the  
4 European Union. More than 5,300 fatalities (i.e., over 20%) were due to accidents at traffic  
5 junctions. The more accident-prone scenarios (representing nearly 30% of the traffic-junction  
6 fatalities) involved straight crossing paths, with other vehicles coming from either or both  
7 sides of the intersection. Factors associated with such accidents have been reported (e.g.,  
8 Caird & Hancock, 2002) to include not only characteristics of the driver (such as age and  
9 gender) and the environment (such as setting and layout of the intersection), but also the  
10 perceptual and motor mechanisms implicated in driving tasks. Our work aims to provide a  
11 better understanding of these latter mechanisms when drivers perform an intersection-crossing  
12 task in the presence of incoming traffic.

13 As already noted by Louveton et al. (2012a), the vast majority of work performed so  
14 far has focused on the capacity of drivers to judge when an approaching vehicle will reach a  
15 given location (e.g., Caird & Hancock, 1994; Berthelon & Mestre, 1993) or to decide when a  
16 safe manoeuvre can be initiated (e.g., Dewing et al., 1993; Hancock et al., 1991).  
17 Experimentally, such judgments or decisions are typically obtained in settings requiring  
18 participants to provide a discrete response after viewing part of an approach event involving  
19 one or more vehicles. Several authors (e.g., Caird & Hancock, 1994; Gray & Regan, 2005)  
20 have advocated the need for paradigms with higher ecological validity, allowing to preserve  
21 the natural links between perception and action that characterize the unfolding of the majority  
22 of driving maneuvers. There is in fact no guarantee that the results obtained using *discrete-*  
23 *response motion-extrapolation paradigms* can indeed be transferred to driving tasks in which  
24 the continuous perceptual-motor dialog underlying the unfolding of the action is preserved.  
25 More precisely, adoption of these paradigms rests on the hypothesis that predictive

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

42       Whereas the *discrete-response motion-extrapolation paradigm* has been used in many  
43 studies to better understand the underlying perceptual processes, to our knowledge only a few  
44 studies decided to preserve the perceptual-motor dialogue when studying intersection-  
45 crossing behavior. The work of Chihak et al. (2010, 2014) and that of Louveton et al. (2012a,  
46 2012b) constitute rather isolated attempts to study intersection-crossing behavior without  
47 separating the perceptual-motor mechanisms involved. While the former were interested in  
48 the perceptual-motor developmental changes accompanying the intersection-crossing  
49 behavior of cyclists, the latter focused on the mechanisms underlying the intersection-crossing  
50 behavior of adult drivers. Calling upon the same type of virtual environment technology, the

51 tasks studied required participants to regulate their speed of approach to an intersection so as  
52 to safely pass through an incoming traffic gap. Both groups shared the idea that, rather than  
53 trying to isolate particular components, intersection-crossing behavior should be studied as a  
54 whole in order to reveal the underlying mechanisms. A general finding of these studies was  
55 that functional (i.e., situation-appropriate) speed changes were observed over the entire  
56 approach phase, allowing participants to cross the inter-vehicular gap near its center, at a  
57 position slightly shifted towards the lead vehicle (e.g., Chihak et al., 2010; Louveton et al.,  
58 2012a). While consistent with an on-line, prospective control of the approach to the  
59 intersection, the observed gradual and functional speed adjustments seem to fit less well with  
60 expectations derived from arrival time (AT) judgments. Indeed, not only do AT judgments  
61 generally give rise to underestimations of actual AT, but the magnitude of the underestimation  
62 is known to be larger for longer actual ATs (e.g., Caird & Hancock, 1994; Schiff & Detwiler,  
63 1979). Thus, even during an approach to an intersection that does not require a change in  
64 speed to ensure safe crossing (that is, passing near the center of a gap between two incoming  
65 traffic vehicles), early estimates of time remaining until arrival of the traffic vehicles at the  
66 intersection would be considerably shorter than the actual ATs. Such underestimations of  
67 actual AT would be expected to give rise to an increase in speed. As actual AT decreases over  
68 the course of the approach, judgments would become more precise (less underestimated) and  
69 speed would therefore be expected to gradually decrease to more appropriate levels. The  
70 speed profiles described by Chihak et al. (2010, 2014) and Louveton et al. (2012a, 2012b) did  
71 not show such characteristics.

72         Moreover, several studies have demonstrated that perceptual processes operate more  
73 accurately within a perceptual-motor task than in a purely perceptual task (e.g., Bootsma,  
74 1989; Gray & Regan, 2005; Oudejans, Michaels & van Dort, 1996; Mann, Abernethy &  
75 Farrow, 2010). In the study by Bootsma (1989) participants experienced more difficulties (i.e.

76 larger variability) in judging arrival time of a moving ball than in initiating a movement to  
77 strike it. Comparably, Gray and Regan (2005) reported more appropriate decisions when  
78 drivers overtook a moving vehicle than when they had to judge the opportunity to initiate a  
79 safe overtaking maneuver. Thus, the magnitude of underestimation generally observed in AT  
80 judgment tasks may be attenuated during an active intersection-crossing task. Of course, such  
81 an attenuation effect may already have consequences for the generality of the conclusions  
82 drawn from the often-used judgment tasks.

83         The present contribution builds on the framework developed by Chihak et al. (2010,  
84 2014) and Louveton (2012a, 2012b), with the ambition to more directly test the hypothesis  
85 that the perceptual substrate underlying judgments of arrival time of a vehicle moving  
86 towards an intersection is (at least partly) distinct from the perceptual substrate underlying the  
87 active control of one's own approach to that same intersection. For that purpose, we compared  
88 the influence of a given set of experimental manipulations (specifically, the size and type of  
89 the vehicles encountered at the intersection) on both perceptual (i.e., AT judgment,  
90 Experiment 1) and perceptual-motor (i.e., active intersection crossing, Experiment 2) tasks.  
91 Vehicle size is known to affect AT judgments: larger vehicles are judged to arrive earlier than  
92 smaller vehicles (e.g., Eberts & MacMillan, 1985; De Lucia, 1991; Dewing et al., 1993; De  
93 Lucia & Warren, 1994; Caird & Hancock, 1994, 2002; see De Lucia, 2013 for a review). If  
94 active intersection crossing would (at least partly) share the perceptual substrate underlying  
95 AT judgments, the size of the vehicles encountered should affect behavior on both tasks in  
96 similar ways. However, before further examining the effects expected, a closer look at the  
97 way size has been experimentally manipulated is warranted.

98         Indeed, many of the studies attributing the observed increase in AT underestimation to  
99 increases in vehicle size in fact manipulated vehicle type at the same time. In the experiment  
100 by Horswill et al. (2005), for example, participants were asked to make AT judgments for



101 different vehicles approaching a junction. The different vehicles examined included a small  
102 motorbike, a large motorcycle, a car and a van. The larger AT underestimations recorded for  
103 both the car and the van, in comparison to the motorbikes, were said to result from the  
104 increase in size of the approaching vehicle. Unfortunately, the simultaneous variation of two  
105 dimensions (i.e., vehicle size and vehicle type) does not allow their respective effects to be  
106 disambiguated. This methodological confounding of size and type is all the more worrisome  
107 as recent experiments have indicated that the type *per se* of an approaching object influences  
108 AT judgments: Brendel et al. (2012) demonstrated that threatening pictures were judged as  
109 arriving earlier than neutral pictures, but also that ATs of angry faces were underestimated  
110 (see Brendel et al., 2014, for a discussion focusing on the underlying mechanisms). As a  
111 consequence, the type of vehicle approaching an intersection is likely to affect AT estimates  
112 as well as the vehicle's size. There is a need to control these factors experimentally to  
113 disambiguate their respective effects.

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

120 Based on the previous work described above, the following hypotheses can be  
121 formulated. In the judgment task of Experiment 1 arrival time of the vehicles encountered  
122 should generally be underestimated and the underestimation should be greater for longer  
123 actual ATs. More importantly for the present purposes, both the size and the type of the  
124 vehicles encountered should influence AT judgments. The underestimation in AT judgments  
125 should be greater for larger-sized vehicles (size effect) and for more threatening vehicles



a)



b)



151

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

157 *Apparatus and visual environment*

158 In both experiments participants sat in the driver seat of a fixed-base SIDROH driving  
159 simulator, based on a Renault Megane II (see Fig. 1, top panel). They could interact with the  
160 car using its standard equipment, including the steering wheel and a set of clutch, footbrake  
161 and accelerator pedals. The driving simulator implemented an automatic transmission so that  
162 participants did not have to shift gears while driving. The audio-visual environment was  
163 generated using the ARCHISIM traffic model (Espie & Auberlet, 2007). Using three Epson  
164 485W projectors operating at 60 Hz, the visual scene was presented on three planar (1.8-m  
165 high by 1.35-m wide) screens with the left and right screens oriented inward so as to sustain a  
166 total horizontal visual angle of 150° for a vertical visual angle of 40°. In order to improve  
167 immersion in the scene, the virtual environment was also presented in the side and rear-view  
168 mirrors. The participant's viewpoint was situated 1.2 m above the ground at a distance of 2.2  
169 m from the frontal projection screen. A quadriphonic sound system presented sounds from  
170 inside (e.g., engine, tires, start engine) and outside (e.g., engines of crossed vehicles) the car.

171 The simulated environment consisted of a straight textured road, with two lanes for  
172 opposing traffic separated by intermittent white lines, running through a flat rural  
173 environment (see Fig. 1, bottom panel). The road followed by the participant was  
174 orthogonally intersected by a similar second road over which a single vehicle (Experiment 1)  
175 or a train of vehicles (Experiment 2) could approach the intersection from the left. In  
176 Experiment 1 the participant was passively transported towards the intersection and had to  
177 judge when the other vehicle would reach the intersection. In Experiment 2 the participant  
178 actively drove the simulator car so as to cross the intersection by passing through a gap in the  
179 train of traffic. Each participant completed the two experiments within the same half day,  
180 with experimental sessions being separated by a 15 min rest period . Each experiment  
181 consisted of both a familiarization phase (3 min for Experiment 1, 8 min for Experiment 2)  
182 and an experimental phase (30 min for both experiments). The order of passage of the two

183 experiments was counterbalanced over participants, such that 7 participants performed  
184 Experiment 1 before Experiment 2 and 7 others performed Experiment 2 before Experiment  
185 1. In both Experiments each trial started with the participant moving at a speed 16 m/s, from  
186 initial distances of 72, 88, and 104 m from the intersection. Participants always moved in the  
187 right lane of the road. Data were collected at a 60 Hz sampling frequency.

## 188 **Experiment 1: Judging vehicle arrival time**

### 189 *Task and experimental design*

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

196 In order to study the effects of vehicle type and vehicle size independently, we created  
197 3D models of a car and a motorcycle-with-driver of identical physical outline dimensions.  
198 The normal-sized vehicles were 2.4 m long, 1.27 m wide and 1.7 m high. The double-sized  
199 vehicles were twice as large, 4.8 m long, 2.54 m wide and 3.4 m high. Both vehicles were  
200 colored red except for the wheels and tires that were respectively grey and black<sup>1</sup>.

201 Moving at 10 m/s the stimulus vehicle could start at distances of either 40 or 50 m  
202 from the intersection, corresponding to vehicle travel durations to the intersection of 4 or 5 s.

203 Moving at 16 m/s participants could start at distances of either 72, 88, or 104 m from the

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<sup>1</sup> 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.

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

### 212 *Procedure*

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

224 During the experimental phase participants performed five blocks of trials, for a total  
225 of 240 trials. In each block of trials all 48 experimental conditions, resulting from the  
226 combination of the factors vehicle type (2), vehicle size (2), initial vehicle distance (2),  
227 exposure duration (2) and initial participant distance (3), were presented once in a randomized

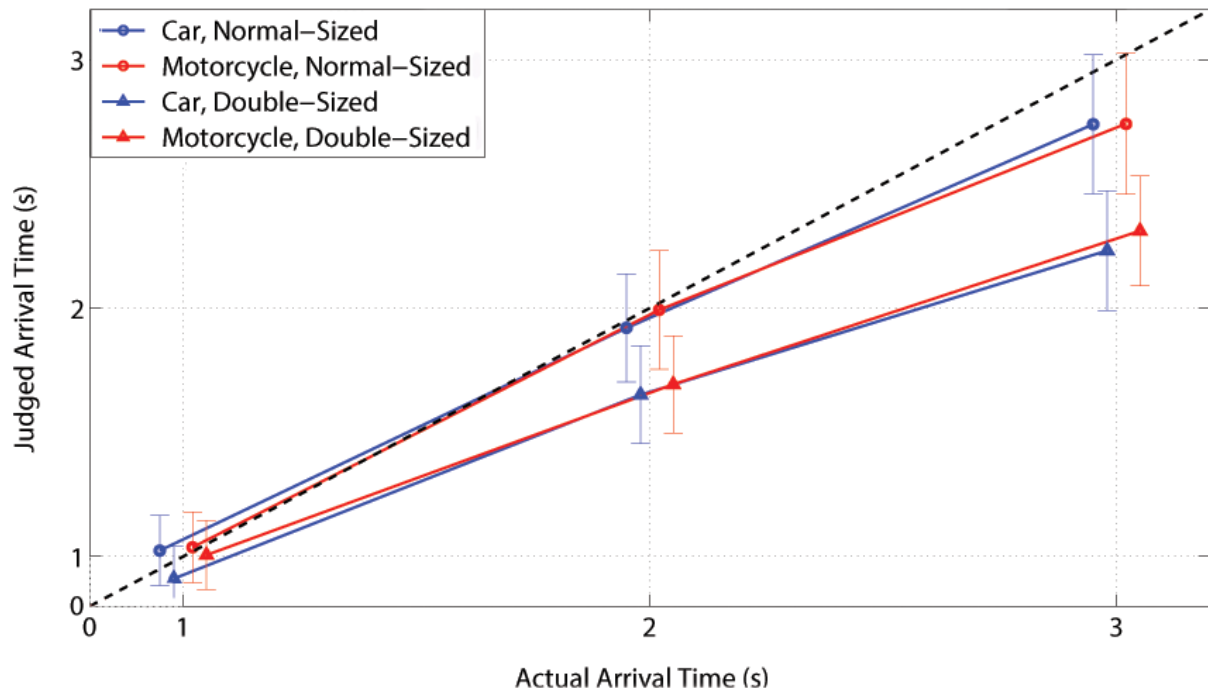
228 order. Only initial stimulus vehicle distance and exposure duration influenced the actual time  
229 remaining (1, 2, or 3 s) until the stimulus vehicle reached the intersection.

### 230 *Data analysis*

231 For each trial the difference between the actual moment of arrival of the stimulus vehicle at  
232 the intersection and the participant's estimation of this moment, indicated by activation of the  
233 lever command, was determined. For each modality of stimulus vehicle arrival time (1, 2, and  
234 3 s) we calculated, for each participant under each of the four vehicle type and size  
235 combinations separately, average estimated arrival time as well as the constant, absolute and  
236 variable estimation errors (Schmidt & Lee, 1988). The latter dependent variables were  
237 analyzed using repeated-measures ANOVAs with factors Vehicle Type (car or motorcycle),  
238 Vehicle Size (normal-sized or double-sized) and Arrival Time (1, 2, or 3 s). When Mauchly's  
239 test revealed violations of the sphericity assumption, Greenhouse-Geisser corrections were  
240 applied. Significance level was set at  $\alpha = .05$ . When appropriate, post-hoc analyses were  
241 performed using Scheffé tests.

## 242 **Results**

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



253

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

257 *Constant error*

258 The ANOVA on constant error (CE) in the participant's estimation of vehicle arrival time  
 259 revealed significant main effects of the factors Arrival Time ( $F(1.37, 17.87) = 53.07, p <$   
 260  $.001, \eta^2_p = .80$ ), Vehicle Type ( $F(1, 13) = 12.78, p < .01, \eta^2_p = .50$ ) and Vehicle Size ( $F(1, 13)$   
 261  $= 121.57, p < .001, \eta^2_p = .90$ ), a first-order interaction between Vehicle Size and Arrival Time  
 262 ( $F(1.44, 18.68) = 37.05, p < .001, \eta^2_p = .74$ ), as well as a second-order interaction between  
 263 Vehicle Type, Vehicle Size and Arrival Time ( $F(1.90, 24.65) = 3.45, p < .05, \eta^2_p = .21$ ). This  
 264 complex pattern of results indicated that both Vehicle Type and Vehicle Size affected CE but  
 265 not in the same way for each Arrival Time (Fig. 3A). We therefore ran separate ANOVAs  
 266 with factors Vehicle Type and Vehicle Size at each level of Arrival Time.

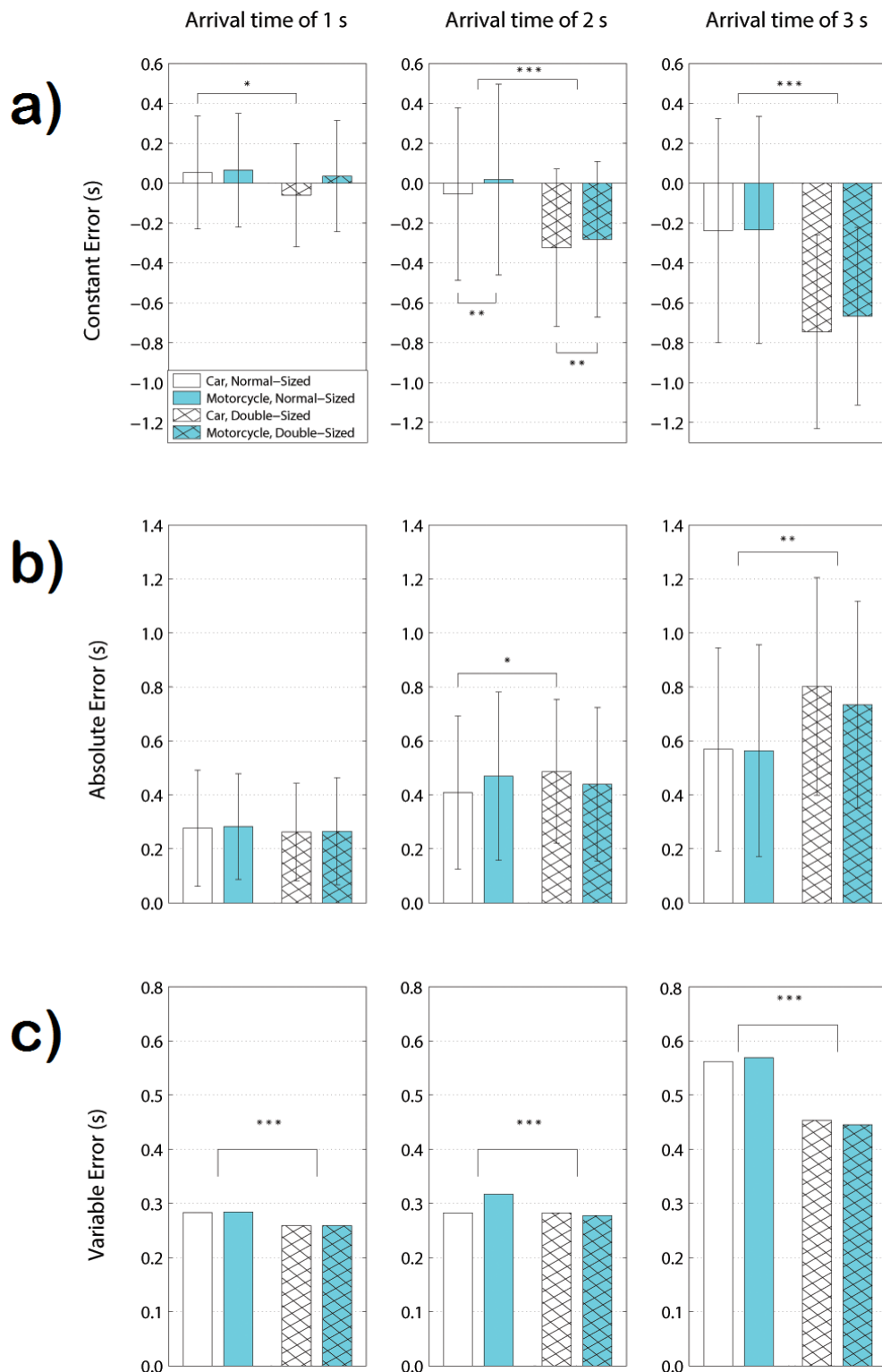


267 For an Arrival Time of 1 s, significant main effects were observed for Vehicle Type  
268 ( $F(1, 13) = 13.21, p < .01, \eta^2_p = .50$ ) and Vehicle Size ( $F(1, 13) = 17.92, p < .001, \eta^2_p = .58$ )  
269 together with a significant interaction between Vehicle Type and Vehicle Size ( $F(1, 13) =$   
270  $6.63, p < .05, \eta^2_p = .34$ ). Post-hoc analysis of the interaction indicated that the normal-sized  
271 car gave rise to a slight overestimation of arrival time while the double-sized car gave rise to a  
272 slight underestimation ( $p < .05$ ). No such an effect of Vehicle Size was observed for the  
273 motorcycle, with both sizes leading to CE's similar to that observed for the normal-sized car.  
274 For an Arrival Time of 2 s, significant main effects were observed for both Vehicle Type  
275 ( $F(1, 13) = 9.11, p < .01, \eta^2_p = .41$ ) and Vehicle Size ( $F(1, 13) = 79.33, p < .001, \eta^2_p = .86$ ).  
276 The interaction was not significant ( $p > .1, \eta^2_p = .07$ ). The normal-sized vehicles gave rise to,  
277 respectively, a small underestimation of arrival time for the car and a very slight  
278 overestimation for the motorcycle. A similar difference in CE's was observed for the double-  
279 sized vehicles, with larger underestimations for the car than for the motorcycle. For an Arrival  
280 Time of 3 s, arrival time was systematically underestimated (all CE's negative) and revealed a  
281 significant main effect of Vehicle Size only ( $F(1, 13) = 78.92, p < .001, \eta^2_p = .86$ ; other  
282 effects all  $p > .1$  and,  $\eta^2_p < .03$ ). For both the car and the motorcycle, double-sized vehicles  
283 gave rise to larger underestimations of arrival time than their normal-sized counterparts.

#### 284 *Absolute Error*

285 The ANOVA on absolute error (AE) in the participant's estimation of vehicle arrival time  
286 revealed significant main effects of the factors Arrival Time ( $F(1.14, 14.83) = 59.33, p <$   
287  $.001, \eta^2_p = .82$ ) and Vehicle Size ( $F(1, 13) = 6.17, p < .05, \eta^2_p = .32$ ), first-order interactions  
288 between Vehicle Size and Arrival Time ( $F(1.78, 23.15) = 15.75, p < .001, \eta^2_p = .55$ ) and  
289 Vehicle Type and Vehicle Size ( $F(1, 13) = 5.21, p < .05, \eta^2_p = .29$ ), as well as a second-order  
290 interaction between Vehicle Type, Vehicle Size and Arrival Time ( $F(1.89, 24.55) = 4.38, p <$   
291  $.05, \eta^2_p = .25$ ). As for CE, this complex pattern of results indicated that both Vehicle Type and

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



295

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

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

#### 309 *Variable error*

310 The ANOVA on variable error (VE) in the participant's estimation of vehicle arrival time  
311 revealed significant main effects of the factors Arrival Time ( $F(1.38, 17.93) = 55.97, p <$   
312  $.001, \eta^2_p = .81$ ) and Vehicle Size ( $F(2, 26) = 42.61, p < .001, \eta^2_p = .77$ ). No other effects  
313 reached significance (all  $p > .1$  and  $\eta^2_p < .18$ ). Post-hoc analysis of the Arrival Time effect  
314 revealed that VE was larger ( $p < .001$ ) for an Arrival Time of 3 s than for Arrival Times of 1 s  
315 and 2 s (Fig. 3C). Moreover, VE was larger for both the normal-sized car and motorcycle than  
316 for their double-sized counterparts.

### 317 **Discussion**

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

322 *Actual AT effects.* Longer ATs were judged with less precision, as evidenced by the increase  
323 in AE with increasing actual AT (on average, 0.27, 0.45, and 0.68 s for actual ATs of 1, 2,

324 and 3 s, respectively). In line with the literature (e.g., Schiff & Detwiler, 1979; McLeod &  
325 Ross, 1983; Cavallo & Laurent, 1988; Schiff & Oldak, 1991) this effect resulted from the  
326 combination of both an increasing underestimation (CE) and an increasing variability (VE) in  
327 the judgments of longer actual ATs. While the interpretation of these results in terms of  
328 interval timing falls outside the scope of the present contribution (see Gibbon, 1977, and  
329 Mattel and Meck, 2000), we note that the similarity of the results obtained in our study, in  
330 comparison with the results reported in the literature, is an important methodological step in  
331 validating our protocol. We can now address the influence of vehicle size and vehicle type on  
332 AT judgments.

333 *Size and Type effects.* The size of the approaching vehicle was found to systematically affect  
334 AT judgements. Double-sized vehicles gave rise to larger errors than normal-sized vehicles,  
335 in particular for the larger actual AT's (i.e., 2 and 3 s). In these conditions, compared to their  
336 normal-sized counterparts, double-sized vehicles led participants to underestimate AT by an  
337 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  
338 the approaching vehicle also affected variable error, with normal-sized vehicles giving rise to  
339 larger errors than double-sized vehicles. This pattern of results confirms the influence of the  
340 size of the approaching vehicle on perceptual judgments reported in the literature on  
341 numerous occasions (cf., De Lucia, 2013). While previous studies confounded the effects of  
342 vehicle size and type (e.g., Dewing et al., 1993; Caird & Hancock, 1994, 2002; Horswill et  
343 al., 2005), our experimental protocol, designed to disambiguate these effects, allowed us to  
344 ascertain that it was the size of the approaching vehicle *per se* that influenced the judgments  
345 of the participants. It also allowed us to highlight the influence of the type of approaching  
346 vehicle on the judgment of the participants. While not present in the 3-s AT condition, an  
347 effect of vehicle type appeared in the 2-s AT condition, characterized by a systematically  
348 larger AT underestimation for cars than for motorbikes. The observation that the average

349 difference was a modest 0.06 s indicates that the effect of the type of vehicle is not as strong  
350 as the effect of the size of the vehicle. Finally our results also demonstrated that in the shorter  
351 AT conditions size and type interacted, with size affecting judgments for cars but not for  
352 motorcycles (for AE in 2-s AT condition and for CE in 1-s AT condition).

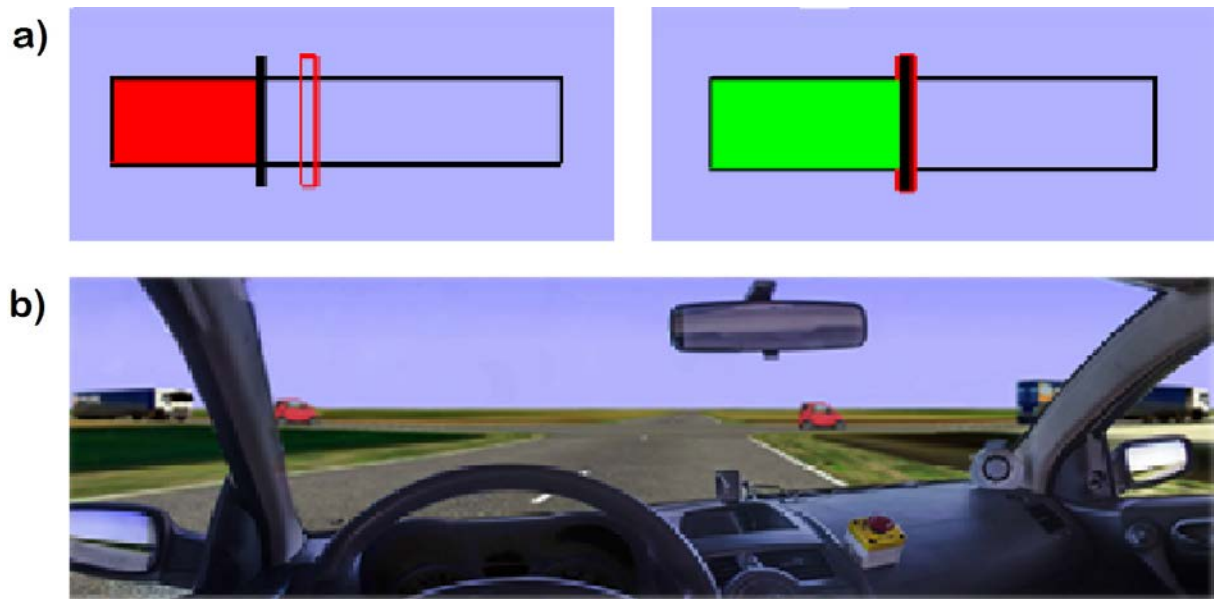
353 Overall, the present results therefore confirmed that the precision of AT judgments  
354 decreases (i.e., increasing underestimation and larger variability) when actual AT increases.  
355 Most interestingly for the present purposes, both the size and the type of an approaching  
356 vehicle were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

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

374 *Task and experimental design*

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

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



393

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

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

407 Three aspects of the situation were experimentally manipulated: the type of vehicle in  
 408 the traffic train, the size of the vehicles in the traffic train and the initial position of the  
 409 participant driving the simulator. Vehicle Type and Vehicle Size corresponded to those used



410 in Experiment 1: Vehicles could be cars or motorcycles and vehicles could be normal-sized or  
411 doubled-sized.

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

421 At the beginning of each trial, participants were parked in the middle of their lane,  
422 without any other vehicles in sight. They started the car's engine and operated the pedals in  
423 order to attain the required velocity of 16 m/s indicated by a horizontally-oriented  
424 speedometer placed directly in front of them. Their current speed was indicated by the  
425 position of a black vertical line on a speed gauge and the required speed by a vertically-  
426 elongated rectangular zone, without any numerical information being provided (Fig. 4, upper  
427 panel). When the car's speed was within the delimited zone the gauge was green; when it was  
428 outside the delimited zone the gauge was red. Speed had to be stabilized within the indicated  
429 zone. An 80-m long stretch of empty road was available for the initial acceleration and  
430 subsequent stabilization of speed. If the participant's car speed remained within the delimited  
431 zone (corresponding to  $16.0 \pm 0.55$  m/s =  $57.6 \pm 2.0$  km/h) over the last 20 m of the 80-m  
432 stretch, the speed gauge disappeared and the intersection scenario was started, with the four-  
433 vehicle traffic train appearing on the left. If not, the trial was restarted. Note that the presence  
434 of the gauge during the preparatory phase was in fact a methodological stratagem allowing us

435 to standardize the initial conditions from trial to trial (at the onset of the intersection scenario)  
436 while at the same time providing the participants with active control of their speed.. Because  
437 the gauge disappeared when the intersection scenario was started it cannot have interfered  
438 with the driver's behavior during the approach to the intersection.

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

#### 443 *Data analysis*

444 Intersection crossing was analyzed *via* the position of the participant within the traffic gap at  
445 the moment of crossing. Taking the center of the gap as the reference, a negative crossing  
446 position indicated crossing after the center of the gap (i.e., closer to the trail vehicle) while a  
447 positive crossing position indicated crossing before the center of the gap (i.e., closer to the  
448 lead vehicle). In order to examine the nature of the speed adjustments effected during  
449 approach to the intersection, we analyzed the time course of participant's speed and its  
450 instantaneous effect on future passing position within the traffic gap, allowing a functional  
451 interpretation of the observed speed adjustments. The latter was operationalized through the  
452 current deviation (CD) from the traffic gap center, calculated as the time (distance) from the  
453 center of the traffic gap at which the participant would pass the intersection if the current  
454 speed were to remain constant from thereon. In the No Offset condition, continuing at the  
455 initial (stabilized) speed would lead the participant to pass right in the center of the traffic  
456 gap. Thus, at the start of a No Offset trial, the temporal (spatial) CD was equal to 0 s (0 m). In  
457 the Late Offset condition, continuing at the initial speed would lead the participant to pass 1 s  
458 (10 m) behind the center of the traffic gap. Thus, at the start of a Late Offset condition CD  
459 was  $-1$  s ( $-10$  m). In the Early Offset condition, continuing at the initial speed would lead the

460 participant to pass 1 s (10 m) in front of the center of the traffic gap. Thus, at the start of an  
461 Early Offset trial CD was +1 s (+10 m).

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

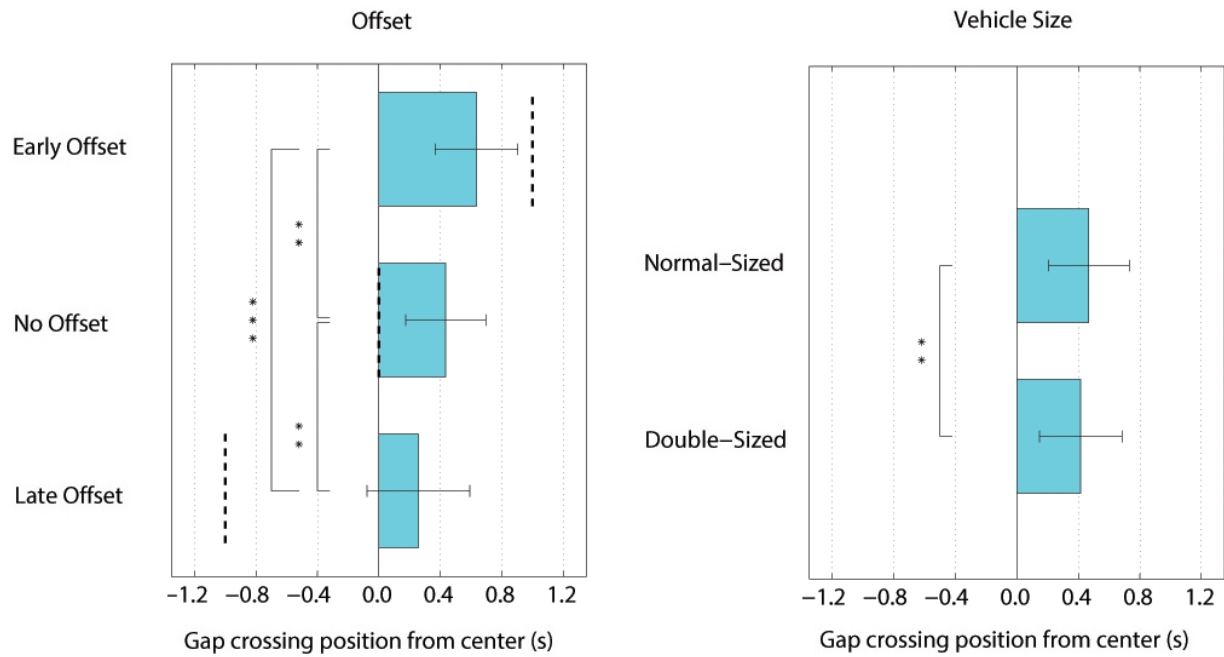
468 Statistical analyses were performed using repeated-measures ANOVAs. The  
469 temporally-defined position in the traffic gap at the moment the participant crossed the  
470 intersection was analyzed with the factors Vehicle Type (cars or motorcycles), Vehicle Size  
471 (normal-sized or double-sized) and Offset (early, no, late). For speed and temporally-defined  
472 current deviation similar 3-way ANOVAs were conducted at each Time Step (3.5, 2.5, 1.5 or  
473 0.5 s before crossing) in order to facilitate interpretation of the results. When Mauchly's test  
474 revealed violations of the sphericity assumption, Greenhouse-Geisser corrections were  
475 applied. Significance level was set at  $\alpha = .05$ . When appropriate post-hoc analyses were  
476 performed using Scheffé tests.

## 477 **Results**

### 478 *Gap crossing position*

479 The ANOVA on gap crossing position revealed significant main effects of the factors Offset  
480 ( $F(1.26, 16.42) = 55.19, p < .001, \eta^2_p = .81$ ) and Vehicle Size ( $F(1, 13) = 14.43, p < .01, \eta^2_p$   
481  $= .53$ ). The main effect of Vehicle Type was not significant ( $p > .1, \eta^2_p = .15$ ), nor were any  
482 of the interactions (all  $p > .1$  and  $\eta^2_p < .10$ ).

483 As can be seen from Fig. 5, participants crossed the intersection at a position ahead of  
484 the center of the traffic gap under all conditions. Gap crossing position was systematically a  
485 little (0.06 s on average) closer the center of the traffic gap when participants were confronted  
486 with the double-sized vehicles as compared to the normal-sized vehicles. Post-hoc analysis of  
487 the main effect of Offset demonstrated that, compared to the no-offset condition, an early  
488 offset gave rise to crossing the intersection further ahead of the center of the traffic gap ( $p <$   
489  $.01$ ) while a late offset gave rise to crossing the intersection closer to the center of the traffic  
490 gap ( $p < .01$ ). The persistence, up to the point of intersection crossing, of an effect of offset in  
491 the participant's initial distance to the intersection was also reported by Louveton et al.  
492 (2012a, 2012b). As in these earlier studies, however, this finding did not imply that  
493 participants continued to drive at the initial speed, without implementing functional speed  
494 regulations during approach to the intersection: At the time of crossing the initial (+1 s)  
495 difference between early and no offset conditions had been reduced to +0.19 s and the initial  
496 (-1 s) difference between late and no offset conditions had been reduced to -0.18 s, on  
497 average. These changes correspond to average final crossing positions of +0.65, +0.46, and  
498 +0.28 s for the early (+1 s), no (0 s), and late (-1 s) offset conditions, respectively.



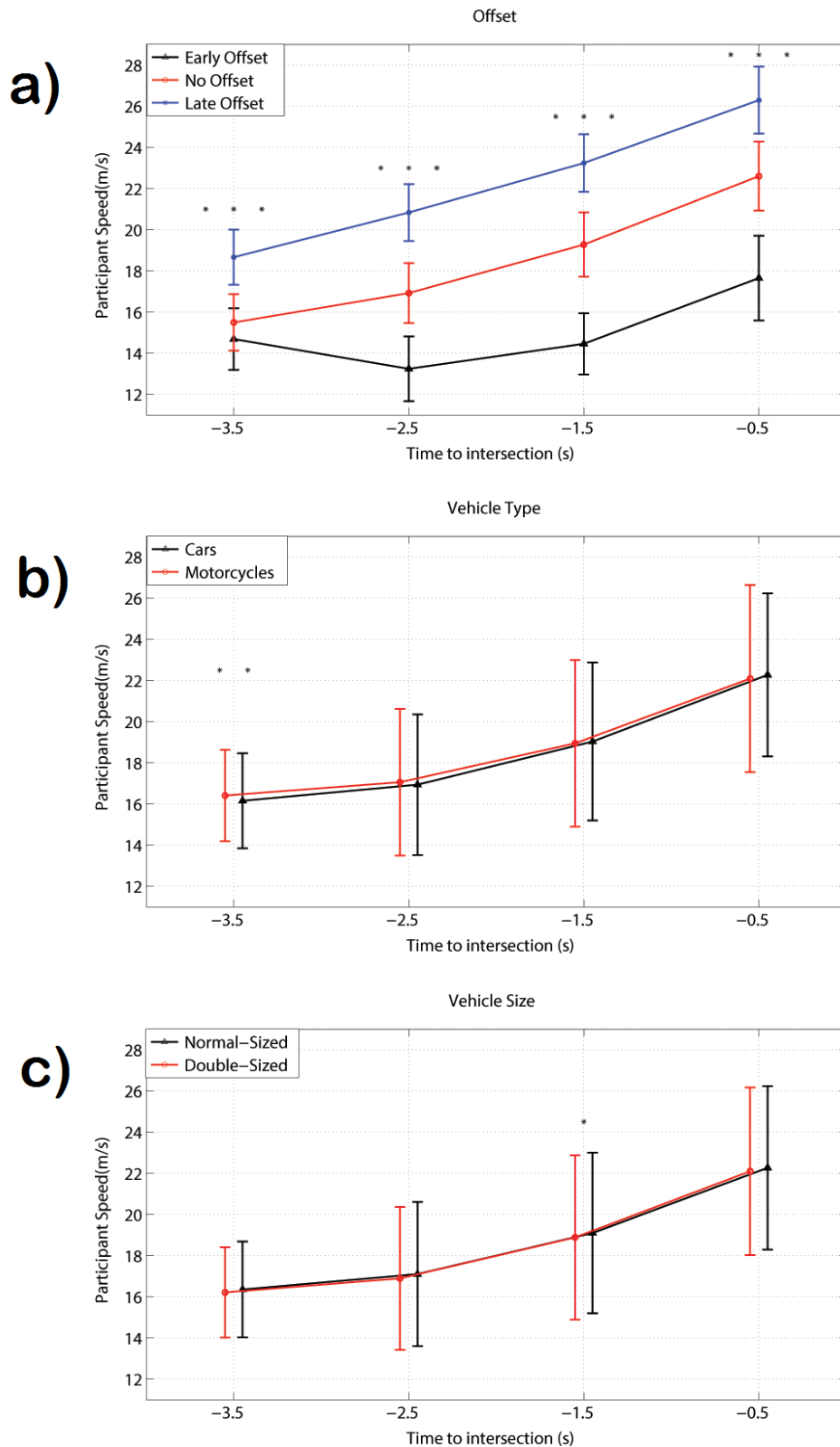
499

500 **Figure 5:** Average gap crossing position as a function of initial offset (left panel) and traffic  
 501 vehicle size (right panel). Vertical dotted black line segments indicate the position where  
 502 participants would have crossed the intersection if they had maintained the initial speed over  
 503 the full duration of the trial. The gap's trail and lead vehicles were respectively located at -  
 504 1.35 s and +1.35 s from the gap center. \*\*\* $p < .001$  and \*\* $p < .01$  significant differences.  
 505 Error bars indicate average within-participant standard deviations.

506 *Speed profiles*

507 As already indicated by the results on gap crossing position, participants did not simply  
 508 maintain their initial speed notwithstanding the fact that this would have allowed them to  
 509 cross the intersection without colliding with the traffic vehicles. The speed profiles presented  
 510 in Fig. 6A indicated that in the early offset conditions participants appeared to have  
 511 decelerated early on during the approach, as speed was already well below its initial value at  
 512 3.5 s before reaching the intersection. They continued to decelerate up to 2.5 s before reaching  
 513 the intersection before reaccelerating during the final phase of approach. In the no offset  
 514 conditions, participants appeared to have almost fully maintained their initial speed during the

515 initial phase of approach: at 3.5 s before reaching the intersection participant speed was only  
516 slightly below 16 m/s. From there on they began to accelerate and continued to do so up to the  
517 moment of intersection crossing. In the late offset conditions participants appeared to have  
518 accelerated early on during the approach, as speed was already well above its initial value at  
519 3.5 s before reaching the intersection. They continued to accelerate up to the moment of  
520 intersection crossing. This general pattern of speed regulation as a function of offset condition  
521 was observed whether the traffic vehicles were cars or motorcycles and whether they were  
522 normal-sized or large-sized. As demonstrated by the statistical analyses, the size and type  
523 characteristics of the vehicles in the traffic train did however bring about subtle but systematic  
524 variations in this general pattern.



525

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

529           Since we already observed differences in participant speed at the earliest Time Step  
530 analyzed (i.e., at 3.5 s before reaching the intersection), we first assessed the participants'  
531 initial reaction to the different experimental conditions by analyzing the speed after having  
532 been exposed to the intersection-crossing scenario for 1 s (i.e., around 4 s before arrival at the  
533 intersection). An ANOVA on participant speed at 1 s after the beginning of the approach to  
534 the intersection revealed significant main effects of factors Offset ( $F(1.98, 25.77) = 21.90, p <$   
535  $.001, \eta^2_p = .63$ ) and Vehicle Type ( $F(1, 13) = 10.92, p < .01, \eta^2_p = .45$ ). While none of the  
536 interactions approached significance (all  $p > .1$  and  $\eta^2_p < .13$ ), the factor Vehicle Size tended  
537 towards significance ( $F(1, 13) = 3.44, p = .09, \eta^2_p = .21$ ). Nevertheless, because the speed  
538 difference between the normal-sized and double-sized vehicles was less than 0.1 m/s, the  
539 possible early effect of Vehicle Size could be considered negligible. On average speed after 1  
540 s of exposure was lower under the early offset conditions than under the no offset conditions  
541 (15.5 m/s vs. 15.8 m/s,  $p < .01$ ) and higher under the late offset conditions than under the no  
542 offset conditions (16.0 m/s vs. 15.8 m/s,  $p < .05$ ). Thus, the different offset conditions evoked  
543 quite rapid, offset-specific reactions. Of particular interest for the present purposes was that  
544 different vehicle types also evoked such rapid reactions: On average participant speed after 1  
545 s of approach to the intersection was lower when the traffic train contained cars as compared  
546 to motorcycles (15.7 m/s vs. 15.9 m/s).

547           As was to be expected from the observation of an influence of offset conditions on the  
548 final gap crossing position, Offset effects on participant speed persisted throughout the  
549 approach to the intersection (at each Time Step:  $F > 300, p < .001, \eta^2_p > .98$ ). More  
550 interesting for the present purposes was the finding that the effect of Vehicle Type (already  
551 observed at 1 s into the scenario) was still present at 3.5 s before reaching the intersection  
552 before washing out over the course of the approach to the intersection (see Table 1 and Fig.  
553 6B). At 3.5 s before reaching the intersection the effect of Vehicle Size, characterized by  $\eta^2_p =$



554 .17, was not significant ( $p > .1$ ), nor were any of the interactions (all  $p > .1$  and  $\eta^2_p < .10$ ).  
 555 While Vehicle size did not affect participant speed in the early stages of the approach (i.e., at  
 556 1 s after the start and at 3.5 s before reaching the intersection), traffic trains containing  
 557 double-sized vehicles were found to give rise to slightly but systematically lower participant  
 558 speeds at 2.5 s ( $p = .084$ ,  $\eta^2_p = .21$ ) and 1.5 s ( $p < .05$ ,  $\eta^2_p = .13$ ) as compared to traffic trains  
 559 containing normal-sized vehicles (see Table 1 and Fig. 6C). This effect of Vehicle Size on  
 560 participant speed was no longer significant shortly before the intersection was crossed.

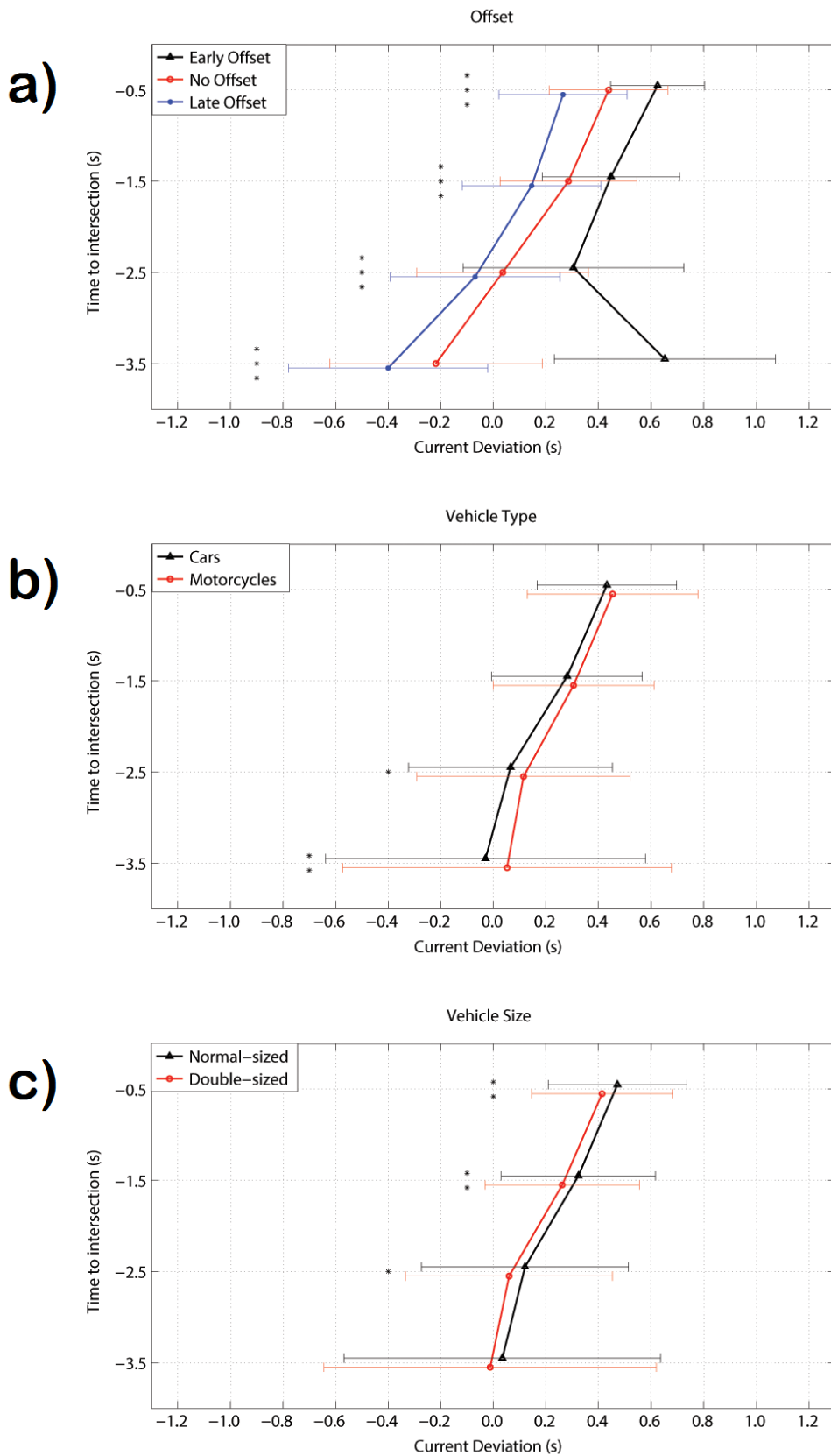
561 **Table 1:** Effects of Vehicle Type and Vehicle Size on participant speed at different times  
 562 before arrival at the intersection.

TTI (s)	Diff. Mot-Car (m/s)	Vehicle Type			Vehicle Size			
		$F$ (1, 13)	$p$	$\eta^2_p$	Diff. Nor-Dble (m/s)	$F$ (1, 13)	$p$	$\eta^2_p$
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

563  
 564 TTI: Time to intersection. Diff. Mot-Car: Average difference in participant speed between  
 565 traffic trains containing motorcycles and traffic trains containing cars. Diff. Nor-Dble:  
 566 Average difference in participant speed between traffic trains containing normal-sized  
 567 vehicles and traffic trains containing double-sized vehicles.

568 *Current deviation*

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



573

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

576 respectively located at -1.35 s and +1.35 s from the gap center. \*\*\* $p < .001$ , \*\* $p < .01$  and \* $p$   
577  $< .05$  significant differences. Error bars indicate average within-participant standard  
578 deviations.

579 As can be seen from Fig. 7A, at 3.5 s before reaching the intersection the initial early  
580 (+1 s) and late (-1 s) offsets had already been reduced, as a result of the early change in speed  
581 discussed in the previous section. For the no-offset conditions, CD was only slightly below 0  
582 s, as a result of participants largely maintaining their initial speed. Speed regulations  
583 continued to reduce CD under all conditions up to 2.5 s before reaching the intersection. From  
584 there on the acceleration observed under all conditions (see Fig. 6A) gave rise to a systematic  
585 increase in CD, leading participants to cross the intersection at positions ahead of the center of  
586 the traffic gap (see Fig. 5).

587 As was to be expected from the observation of an influence of offset conditions on the  
588 final gap crossing position, Offset effects persisted throughout the approach to the intersection  
589 (at each Time Step:  $F > 30$ ,  $p < .001$ ,  $\eta^2_p > .70$ ). More interestingly for the present purposes  
590 was the observation of an early effect of Vehicle Type on current deviation. Participants'  
591 current deviation at 3.5 s before reaching the intersection was slightly (0.08 s) but  
592 systematically larger when the traffic train contained motorcycles rather than cars. This initial  
593 effect of Vehicle Type gradually disappeared over the approach to the intersection (see Table  
594 2 and Fig. 7B). The washing out of the Vehicle Type effect over the course of the approach to  
595 the intersection ( $\eta^2_p$  decreasing from .53, to .17, see Table 2) is consistent with the absence of  
596 such an effect at the moment the participants crossed the intersection. The effect of Vehicle  
597 Size, on the other hand, did not reach significance in the earliest stage of approach ( $p = .065$ ,  
598  $\eta^2_p = .24$ ), but became significant thereafter ( $\eta^2_p$  increasing from .24 to .55, see Table 2),  
599 consistent with the finding that participants crossed the intersection closer to the lead vehicle  
600 for normal-sized cars than for double-sized cars (see Fig. 7C).

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

TTI (s)	Diff. Mot-Car (s)	Vehicle Type			Diff. Nor-Dble (s)	Vehicle Size		
		$F$ (1, 13)	$p$	$\eta^2_p$		$F$ (1, 13)	$p$	$\eta^2_p$
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

603  
 604 TTI: Time to intersection. Diff. Mot-Car: Average difference in temporal current deviation  
 605 between traffic trains containing motorcycles and traffic trains containing cars. Diff. Nor-  
 606 Dble: Average difference in temporal current deviation between traffic trains containing  
 607 normal-sized vehicles and traffic trains containing double-sized vehicles. TTI = 0 s  
 608 corresponds to the moment the participants crossed the intersection.

609 **Discussion**

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

615 *Patterns of speed change at each offset.* Offset manipulations were introduced to encourage  
 616 participants to actively control their speed during approach to the intersection so as to ensure  
 617 a safe crossing. The results obtained in the  $\pm 1$ -s offset conditions revealed functional speed  
 618 changes spread over the course of approach to the intersection allowing the participants to  
 619 cross the inter-vehicular gap near its center, with a small bias towards early arrival in all

620 conditions. Two additional adjustment characteristics are worth noting. First of all, the  
621 participants were shown to detect the need for producing speed changes early on during the  
622 approach, with offset-related functional speed changes already being present 1 s after the  
623 appearance of the train of vehicles. This strategy allowed the participants to distribute speed  
624 adjustments over the entire approach, rather than producing large, and probably not optimal,  
625 last second adjustments. The second characteristic is related to the fact that participants did  
626 not fully compensate for the initial offsets; the final crossing positions were still different  
627 among the three offsets (see Louveton et al., 2012a, 2012b, and Chihak et al., 2010, 2014, for  
628 similar results). Taken together, these results speak to the operation of an information-driven  
629 type of control allowing functional adjustments to take place all along the approach.

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

643 Overall, the results of the second experiment indicated a systematic thought limited  
644 influence of both the size and the type of the approaching vehicles on participants'

645 intersection crossing behavior. The type effect coincided with the appearance of the train of  
646 vehicles and vanished during the second part of the approach. Conversely, the size effect  
647 appeared later and was maintained until the end of the approach, giving rise to distinct  
648 intersection crossing positions.

## 649 **General Discussion**

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

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

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

683 For longer actual ATs doubled-sized vehicles were judged to arrive earlier than  
684 normal-sized vehicles and this size effect diminished as actual AT decreased. The prevalence  
685 of the size effect on AT judgments when vehicles were still far from the intersection (i.e., 2-3  
686 s before crossing, see Experiment 1) was expected to lead drivers to adopt a somewhat higher  
687 speed early on during approach to the intersection when the traffic train consisted of double-  
688 sized vehicles as compared to normal-sized vehicles. Our results, however, revealed no effect  
689 of vehicle size early on during approach. Rather, we observed a slight decrease in speed from  
690 2.5 s before crossing onwards, persisting up to the moment of crossing itself. The observed  
691 speed regulations were therefore not compatible with the effects expected on the basis of AT  
692 judgments.

693 The effect of vehicle type revealed a similar finding: vehicle type did not affect the AT  
694 judgments of Experiment 1 at the longest actual AT (i.e., 3 s), but only came to the fore at the

695 shorter actual ATs (i.e., 1 and 2 s), with cars being judged as arriving earlier than  
696 motorcycles. Thus, whether the train of incoming traffic contained cars or motorcycles was  
697 not expected to influence driving speed during the initial phase of approach to the  
698 intersection. A traffic train containing cars rather than motorcycles was however expected to  
699 lead drivers to slightly increase speed during the final phase. Contrary to these predictions,  
700 our results revealed that a traffic train containing cars rather than motorcycles provoked a  
701 slight decrease in speed very early during the approach (i.e., 5 s before crossing). This type  
702 effect subsequently washed out over the approach.

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

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



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

731           In seeking to identify the perceptual information involved in the active control of  
732 approach to an intersection one should keep in mind that the manipulations of both the size  
733 and the type of the incoming-traffic vehicles only marginally affected driving behavior (cf.  
734 Figs. 6b-7b and 6c-7c). On the other hand, the systematic observation of functional speed  
735 changes during the approach phase described in Experiment 2 (cf., Figs 6a-7a), conforming  
736 earlier findings from Chihak et al. (2010, 2014) and Louveton et al. (2012a, b), should not be  
737 minimized and could mirror the use of prospective information (i.e., information about the  
738 current future; Bootsma, 2009) in the regulation process. First indications of what such  
739 prospective information might entail may be gleaned from two earlier studies. The pattern of  
740 speed adjustments during approach to the intersection was found to be affected, on the one  
741 hand, by the geometry of the intersection (Louveton et al., 2012a) and, on the other hand, by  
742 the (global) characteristics of the inter-vehicular gap itself, as well as the characteristics of its  
743 (local) boundaries (Louveton et al., 2012b). Such effects appear to be compatible with the use  
744 of information contained in the change of bearing angle, as we already demonstrated in

745 locomotor interception tasks (Bastin et al., 2006; Bootsma et al., 2016), driving the system  
746 toward a constant gap-related bearing angle and away from constant bearing angles of the  
747 lead and trail vehicles. Clearly the situation is more complex in crossing than in interception  
748 tasks, if only for the fact that the gap-related bearing angle can refer to a continuum of  
749 positions within the inter-vehicular gap. However this may be, identification of the perceptual  
750 information allowing for the occurrence of the gradual and functional regulations described in  
751 here and earlier work clearly requires further work. From the present study we have learned  
752 that in the new control architecture that will emerge arrival time estimations should not play  
753 more than a marginal role.

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- 756 Bastin, J., Craig, C., & Montagne, G. (2006). Prospective strategies underlie the control of  
757 interceptive action. *Human Movement Science*, 25, 718-732.
- 758 Berthelon, C., & Mestre, D. (1993). Curvilinear approach to an intersection and visual  
759 detection of a collision. *Human Factors*, 35, 521-534.
- 760 Bootsma, R.J. (1989). Accuracy of perceptual processes subserving different perception-  
761 action systems. *The Quarterly Journal of Experimental Psychology Section A*, 41, 489-  
762 500.
- 763 Bootsma, R. J. (2009). The (current) future is here! *Perception*, 38, 851.
- 764 Bootsma, R. J., Ledouit, S., Casanova, R., & Zaal, F. T. J. M. (2016). Fractional-order  
765 information in the visual control of lateral locomotor interception. *Journal of*  
766 *Experimental Psychology: Human Perception and Performance*, 42, 517–529.
- 767 Brendel, E., De Lucia, P.R., Hecht, H., Stacy, R.L., & Larsen, J.T. (2010). Threatening  
768 pictures induce shortened time-to-contact estimates. *Attention Perception and*  
769 *Psychophysics*, 74, 979-987.
- 770 Brendel, E., Hecht, H., De Lucia, P.R., & Gamer, M. (2014). Emotional effects on time-to-  
771 contact judgments : arousal, threat, and fear of spiders modulate the effect of pictorial  
772 content. *Experimental Brain Research*, 232, 2337-2347.
- 773 Caird, J.K., & Hancock, P.A. (1994). The perception of arrival time for different oncoming  
774 vehicles at an intersection. *Ecological Psychology*, 6, 83-109.
- 775 Caird, J.K. & Hancock, P.A. (2002). Left turn and gap acceptance crashes. In Olson, P. et  
776 Dewer, E., (Eds.): *Human Factors in Traffic Safety* (pp. 613-652). Lawyers & Judges  
777 Publishing Company, Tucson, AZ.
- 778 Cavallo, V., & Laurent, M. (1988). Visual information and skill level in time-to-collision  
779 estimation. *Perception*, 17, 623-632.
- 780 Chihak, B.J., Plumert, J.M., Ziemer, C.J., Babu, S., Grechkin, T., Cremer, J.F., & Kearney,  
781 J.K. (2010). Synchronizing self and object movement : How child and adult cyclists  
782 intercept moving gaps in a virtual environment. *Journal of Experimental Psychology:*  
783 *Human Perception and Performance*, 36, 1535-1552.
- 784 Chihak, B.J., Grechkin, T.Y., Kearney, J.K., Cremer, J.F., & Plumert, J.M. (2014). How  
785 children and adults learn to intercept moving gaps. *Journal of Experimental Child*  
786 *Psychology*, 122, 134-152.
- 787 Clark, H.E., Perrone, J.A., & Isler, R.B. (2013). An illusory size-speed bias and railway  
788 crossing collisions. *Accident Analysis and Prevention*, 55, 226-231.
- 789 Clark, H.E., Perrone, J.A., Isler, R.B., & Charlton, S.G. (2016). The role of eye movements in  
790 the size-speed illusion of approaching trains. *Accident Analysis and Prevention*, 55,  
791 226-231.
- 792 De Lucia, P.R. (1991). Pictorial and motion-based information for depth perception. *Journal*  
793 *of Experimental Psychology: Human Perception and Performance*, 17, 738-748.
- 794 De Lucia, P.R., & Warren, R. (1994). Pictorial and motion-based depth information during  
795 active control of self-motion : size-arrival effects on collision avoidance. *Journal of*  
796 *Experimental Psychology: Human Perception and Performance*, 20, 783-798.

- 797 De Lucia, P.R. (2013). Effects of size on collision perception and implications for perceptual  
798 theory and transportation safety. *Current Directions in Psychological Science*, 22, 199-  
799 204.
- 800 Dewing, W., Duley, J., & Hancock, P. (1993). The role of vehicle type, velocity and gap size  
801 on driver left-turn decisions. In 37th Annual Meeting of the Human Factor Society,  
802 Seattle, WA.
- 803 Eberts, R. E., & MacMillan, A. G. (1985). Missperception of small cars. In R. E. Eberts & C.  
804 G. Eberts (Eds.), *Trends in Ergonomics/Human Factors II* (pp. 33–39). Amsterdam:  
805 North-Holland.
- 806 Espie, S., & Auberlet, J.M. (2007). ARCHISIM : a behavioral multi-actors traffic simulation  
807 model for the study of a traffic system including ITS aspects. *International Journal of*  
808 *ITS Research*, 5, 7-16.
- 809 Gibbon, J. (1977). Scalar expectancy theory and Weber's law in animal timing. *Psychological*  
810 *Review*, 84, 279-325.
- 811 Gray, R., & Regan, D. (2005). Perceptual processes used by drivers during overtaking in a  
812 driving simulator. *Human Factors*, 47, 394-417.
- 813 Hancock, P.A., Caird, J.K., Shekhar, S., & Vercruyssen, M. (1991). Factors influencing  
814 drivers left turn decisions. *Proceedings of the Human Factors and Ergonomics Society*  
815 *Annual Meeting*, 35, 1139-1143.
- 816 Horswill, M.S., Helman, S., Ardiles, P., & Wann, J.P. (2005). Motorcycle accident risk could  
817 be inflated by a time to arrival illusion. *Optometry and Vision Science*, 82, 740-746.
- 818 Lenoir, M., Savelsbergh, G.J., Musch, E., Thiery, E., Uyttenhove, J., & Janssens, M.  
819 (1999). Intercepting moving objects during self-motion : effects of environmental  
820 changes. *Research Quarterly for Exercise and Sport*, 70, 349-60.
- 821 Louveton, N., Bootsma, R.J., Guerrin, P., Berhelon, C., & Montagne, G. (2012a). Intersection  
822 crossing considered as intercepting a moving traffic gap : effects of task and  
823 environmental constraints. *Acta Psychologica*, 141, 287-294.
- 824 Louveton, N., Montagne, G., Berthelon, C., & Bootsma, R.J. (2012b). Intercepting a moving  
825 traffic gap while avoiding collision with lead and trail vehicles: Gap-related and  
826 boundary-related influences on drivers' speed regulations during approach to an  
827 intersection. *Human Movement Science*, 31, 1500-1516.
- 828 Mann, D.L., Abernethy, B., & Farrow, D. (2010). Action specificity increases anticipatory  
829 performance and the expert advantage in natural interceptive tasks. *Acta Psychologica*,  
830 135, 17–23.
- 831 Mattel, M.S., & Meck, W.H. (2000). Neuropsychological mechanisms of interval timing  
832 behavior. *BioEssays*, 22, 94-103.
- 833 McLeod, R.W., & Ross, H.E. (1983). Optic flow and cognitive factors in time-to-collision  
834 estimates. *Perception*, 12, 417-423.
- 835 McLeod, P., & Dienes, Z. (1993). Running to catch the ball. *Nature*, 362, 23-23.
- 836 Montagne, G. (2005). Prospective control in sport. *International Journal of Sport Psychology*,  
837 36, 127-150.
- 838 Oudejans, R.R.D., Michaels, C.F., & van Dort, B. (1996). To cross or not to cross: The effect  
839 of locomotion on street-crossing behavior. *Ecological Psychology*, 8, 259–267.

- 840 Schiff, W., & Detwiler, M. (1979). Information used in judging impending collisions.  
841 *Perception*, 8, 647-658.
- 842 Schiff, W., & Oldak, R. (1990). Accuracy in judging time to arrival : Effect of modularity,  
843 trajectory and gender. *Journal of Experimental Psychology: Human Perception and*  
844 *Performance*, 16, 303-316.