Synchronising self-displacement with a cross-traffic gap: How does the size of traffic vehicles impact continuous speed regulations?

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Abstract

In this article, we investigated what visual information is used by drivers at a road crossing when they want to synchronize their displacement with that of an incoming traffic train. We made the hypothesis that synchronizing self-displacement with that of a traffic gap shares the same perceptual-motor basis as interception tasks. While a large body of literature demonstrates that bearing angle is used to control interception, another range of studies points to optical size and expansion as playing a critical role in collision avoidance. In order to test the hypothesis of the exclusive use of bearing angle in road crossing task, we manipulated the optical size and expansion of oncoming traffic elements independently of bearing angle variations. We designed a driving simulator study in which participants were to adjust their approach speed in order to cross a road junction within a moving traffic gap.

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We manipulated the initial offset of participants with the traffic gap, the geometry of the road junction and the way optical size of oncoming traffic elements evolves over the course of a trial. Our results showed an effect of optical size and optical expansion manipulations eventhough, we also found similar displacement profiles as in interception studies. This demonstrates that bearing angle could not explain alone the control of such a complex perceptual-motor task. We discuss these results with regard to similar results in other fields of literature.

1. Introduction

In everyday life, we observe drivers' capacity to cope with highly constrained situations, requiring synchronization of self-displacements with the flow of traffic. In turns, this ability implies perceptual-motor processes which allow for rapid and precise adjustments to situation constraints. This is particularly critical at road junctions where drivers are confronted to potential collision scenarios.

In this respect, road crossing literature showed that the size of oncoming traffic vehicles is critical in drivers' estimation of time constraints. For instance, an early study (Hancock et al., 1991) evidenced that participants were less likely to initiate a left-turn maneuver when the oncoming vehicle was large (for example a truck) than when it was small (a motorcycle). Another study (Caird and Hancock, 1994) also showed that drivers parked near a road junction underestimate arrival time of big vehicles in comparison with small ones. In those early studies, authors assumed that participants' behavior was determined by the optical size of vehicles. Eventhough it is difficult to dissociate the impact of the type of vehicles *per se* from that of their optical size, this assumption was based on the seminal work of Lee (1976).

In that study, the author showed that drivers can estimate Time-To-Contact (TTC) when braking in front a traffic vehicle, based on a combination of its optical size and rate of expansion. A range of empirical results is supporting this hypothesis in various research contexts (see for example Yilmaz and Warren, 1995; Regan and Hamstra, 1993; Gould et al., 2012).

However, recent road crossing studies on bicycle riders (Chihak et al., 2010) and drivers (Louveton et al., 2012a) pointed out that managing a road crossing through oncoming traffic could not be assimilated completely to a collision avoidance or to an object reaching task. In these two studies, participants were to cross an oncoming traffic gap while they were starting their displacement with either an early or a late offset with regard to this moving gap. Both studies showed that participants performed gradual and continuous speed adjustments and eventually intercepted the traffic gap in a narrow zone, close the center of the gap. Those results suggest that drivers behavior at road crossing could not be explained solely by a predictive TTC estimation (as assumed by the disappearance paradigm used in Hancock et al., 1991; Caird and Hancock, 1994) but would rather involve a continuous adaptation to oncoming traffic.

As pointed out by Chihak et al. (2010); Louveton et al. (2012a), the observed behavioral pattern is close to the one evidenced in tasks involving the interception of an horizontally moving object (Chardenon et al., 2004; Lenoir et al., 1999, 2002). Indeed, crossing a moving traffic gap shares very similar constraints with intercepting a horizontally moving object. For this reason, the similarities between the two tasks is a compelling argument to interpret road crossing behavior using models already tested in the context of interception tasks.

For instance, the Constant Bearing Angle (CBA) strategy has been successful in explaining interception behaviors. This strategy consists in keeping the angle between subject's heading and target's position (i.e., the bearing angle) constant to ensure a successful interception. The explanatory power of this hypothesis has been showed in many studies both in humans (Bastin et al., 2006a, 2008; Chardenon et al., 2004, 2005, 2002; François et al., 2011; Lenoir et al., 2002) and in animals (Lanchester and Mark, 1975; Rossel, Corlija and Schuster, 2002; Olberg, Worthington and Venator, 2000; Olberg, 2011; Ghose, Horiuchi, Krishnaprasad and Moss, 2006).

However, the road crossing task proposed by Chihak *et al.* (Chihak et al., 2010) and Louveton *et al.* (Louveton et al., 2012a) is more complex than the usual single-object interception scenario. While the moving traffic gap has to be intercepted, the boundaries (i.e., the traffic vehicles) have strictly to be avoided. Furthermore, the two boundaries have their own motion characteristics leading to various dynamic concerning the size of the gap and the velocity of the overall traffic train. For this reason, Louveton et al. (2012b) manipulated in another study the speed of the two boundary-vehicles and subsequently the speed and the size of the resulting traffic gap. Authors evidenced that participants synchronized their displacement with regard to the speed of the two boundaries perceived independently and to the speed and size of the traffic gap itself.

According to the authors, those findings point to a regulation based both on intercepting the traffic gap and on avoiding the boundary-vehicles. A possible hypothesis is that participants used bearing angle for both purposes, namely a CBA strategy to synchronize (i.e., to intercept the gap) their displacement with the traffic and an inverse-CBA strategy to de-synchronize it (i.e., to avoid a collision; e.g., strategy used by sailors Le Brun et al., 2007).

An alternative hypothesis is that the bearing angle could be used along with optical size and its rate of expansion in order to manage both interception and collision avoidance. This hypothesis would be consistent with interception studies showing a marginal yet demonstrated effect of target's optical size and rate of expansion. For instance, Chardenon et al. (2004); de Rugy et al. (2001) showed that target's optical expansion influences participants' speed adjustments, particularly at the end of the trials where participants decreased their approach speed for high target's optical expansion rate.

Hence, in this paper we aim at testing the hypothesis of an exclusive use of the (inverse-)CBA strategy in a road crossing task involving synchronization between self- and traffic vehicles displacements. To achieve this goal we designed an experiment in which manipulations of optical size and its expansion rate was independent from the evolution of bearing angle.

In a driving simulator study, we used a similar protocol as in former studies (Chihak et al., 2010; Louveton, Montagne, Berthelon and Bootsma, 2012b; Louveton, Bootsma, Guerrin, Berthelon and Montagne, 2012a). We manipulated the initial Offset of participants relative to the traffic train displacement (three initial offset conditions) and the intersection geometry (three approach angles). Additionally, we manipulated the size of oncoming traffic vehicles both between- (constant half-, normal- or double-sized) and within-trials (expanding or contracting sizes).

While Offset and Geometry impact how bearing angle evolves over the course of a trial, optical size and expansion rate manipulations do not. For this reason, an effect of optical size manipulations will contradict the hypothesis of an exclusive use of the CBA strategy to control this kind of task. Furthermore optical size manipulations within the trial are inducing a pattern of over- or under-expansion with regard to constant size conditions (see

Figures 3 and 4). This latter manipulation is intended to weight the relative importance of optical size relative to its expansion rate in our task.

2. Methodology

2.0.1. Participants

Twelve participants (24.7 $\pm$ 2.9 years old; $m \pm sd$) with normal or corrected to normal vision volunteered for participation in the experiment. They all held a driver's license for at least three years, with an average of 6.8 $\pm$ 2.7 years.

2.0.2. Apparatus and visual environment

Participants drove a fixed-base driving simulator (cf., Figure 1, left panel) equipped with a car seat, a steering wheel, and a set of accelerator and brake pedals. The drivers' visual environment was generated using the ARCHISIM (2011 release) software package Espie and Auberlet (2007). Using three PLUS projectors operating at 60 Hz, the visual scene was presented on three planar 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°. Participants drove on a conventional two-lane 7-m wide road through a flat textured rural environment (see Figure 1, right panel). The driving simulator implemented an automatic transmission. The participant's car was 3.45 m long and 1.55 m wide, with the viewpoint located 1.15 m from the ground.

2.0.3. Task and procedure

In order to familiarize the participants with the simulator, they first performed a car following task, consisting in keeping a constant distance (of two central line segments) behind a car moving in front. The latter changed speed regularly, moving at 50, 60 or 70 km/h during 4, 6, or 8 second periods.

Figure 1: Simulator and simulated environment: controllers and screens (left panel); road crossing task with the two light vehicles defining the inter-vehicular gap (right panel).

Speed and duration parameters were randomly combined into a sequence of eight minutes. Accelerating, decelerating, and maintaining velocity during this following task allowed the participant to discover the action capabilities of the simulated vehicle being driven.

Following this familiarization phase and a short break, the experimental phase was started. During the experimental phase the participants' task was to safely cross an intersection formed by two straight roads. During the approach to the intersection the participant was confronted with a four-vehicle traffic train coming from the left. This traffic train consisted of a truck, two vehicles and another truck (see Figure 1, right panel). Participants were to cross the intersection using the gap between the two vehicles (i.e., the traffic gap). In the absence of any horizontal or vertical traffic signs, no information with respect to priority was provided.

The four-vehicle traffic train travels at a speed of 10 m/s and the center of the traffic gap (middle point of the space between the lead vehicle's rear bumper and the trail vehicle's front bumper) always arrived at the middle of driver's lane 5.5 s after the beginning of the intersection scenario. The spatial window available for passing the intersection was 26.55 m from bumper-to-bumper (30 m between the geometric center of both vehicle), corresponding to a temporal window of 2.66 s as the traffic train's travel speed is 10 m/s.

2.1. Experimental factors

Three aspects of the situation were experimentally manipulated: the geometry of the intersection, the initial position of the driver and the size of the two oncoming vehicles. Varying the intersection angle between the two roads (60°, 90°, or 120°) affected intersection geometry. From the participant's point of view (Figure 2), the three different intersection geometries gave rise to opened-angle, perpendicular-angle, or closed-angle intersections. This experimental factor has an impact on the rate of change in bearing angle as well as on optical size Chardenon et al. (2005) and expansion of cross-traffic vehicles (see Figures 3 and 4).

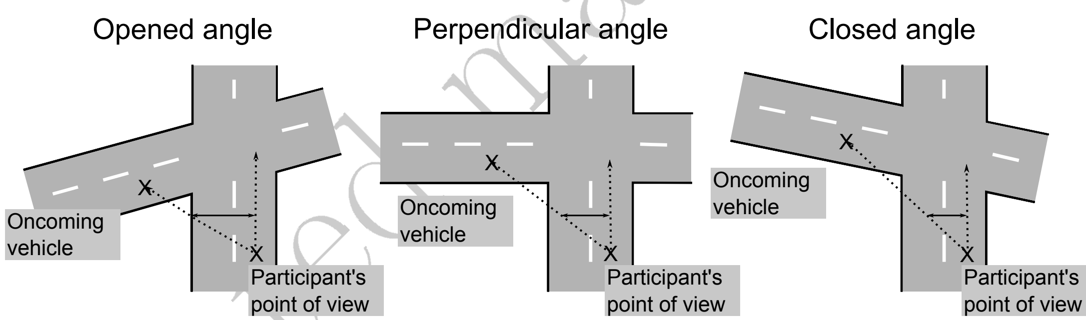

Figure 2: The three different intersection geometries used give rise to three different angle of approach conditions. The traffic vehicles move from left to right and participants from bottom to top. The arrows indicate the angular distance between the participant's trajectory and an oncoming object. For equivalent distances to the intersection this angle is large in the opened-angle condition, small in the closed angle condition and intermediate in the perpendicular-angle condition.

The second factor manipulated was the participant's initial distance from the intersection, so as to create an offset between the anticipated moment of arrival of the participant and the moment of arrival of the center of the traffic gap at the intersection . To this end, the participant's distance from the intersection was set to 104, 88, or 72 m at the onset of the intersection-crossing scenario. This occurred once the participant had stabilized the car's velocity (see below). If the participant would continue at the stabilized velocity (16 m/s = 57.6 km/h), s/he would arrive at the intersection with a temporal offset of -1 s (Late Offset), 0 s (No Offset), or +1 s (Early Offset) with respect to the center of the traffic gap (corresponding to a spatial offset of -10 m, 0 m, or +10 m, respectively). Thus, in the No Offset condition participants did not need to change their velocity to cross the intersection safely. In contrast, in Late or Early Offset conditions they had to increase or decrease their velocity during the approach to the intersection in order to avoid (near) collision with the trail or lead vehicle, respectively located at distances of -13.275 m and +13.275 m from the traffic gap's center (5.5 seconds after the beginning of the trial).

The last factor manipulated was the two oncoming vehicles' size (the same for both of the two vehicles) which could be normal-sized (factor 1 or 3.45 m long), half-sized (factor 0.5 or 1.725 m long) or double-sized (factor 2 or 6.9 m long). Additionally, vehicles' size could either not to change during the trial unfolding or change gradually from half- or double-sized at the beginning of the trial to normal-sized when the gap's center cross the intersection. In the normalizing size condition, half-sized (respectively double-sized) vehicles increase (decrease) in size linearly over the trial unfolding. To illustrate how optical size and expansion vary over the course of a trial we provide simulations for both constant size and normalizing size conditions in Figure 3 in Figure 4, respectively. Method for computations is given by equations A.3 and A.4 in Appendix. If we consider that the bearing angle of an object could be assimilated to that of its geometric center, performing size manipulation with vehicles' geometric center as origin means that the bearing angle was not affected by those manipulations.

Manipulating vehicles' size would impact the inter-vehicular distance from front- to rear-bumpers (i.e., vehicle's size manipulation are performed relative to their geometric center). This by-product of size manipulations is handled differently in constant and normalizing size conditions. In constant size condition, half-sized (respectively double-sized) vehicles might have implied a larger (smaller) inter-vehicular gap if oncoming vehicles' position would have been the same as in normal-sized condition. In order to neutralize this by-product of size manipulations, position of half-sized or double-sized vehicles were respectively set closer (28.275 m center-to-center) or farther (33.45 m center-to-center) to each other so as to maintain the same inter-vehicular gap's distance in each trial (26.55 m distance from bumper to bumper).

In normalizing size condition, gradual changes in vehicles' size induces gradual changes in inter-vehicular gap's distance (from bumper to bumper). In the half-to-normal sized condition (respectively double-to-normal condition), the inter-vehicular gap's distance begins larger (smaller) than in normal sized vehicles condition and linearly decreases (increases) in size over the trial unfolding until it reaches the normal-sized dimension, when the gap's center crosses the middle of driver's lane (i.e., after 5.5s). In doing so, the final gap crossing constraints remain constant with an inter-vehicular gap distance of 26.55 m (see also (Louveton, Montagne, Berthelon and Bootsma, 2012b) for a similar experimental control of traffic vehicles' acceleration). In both cases (half-/double-to-normal sized vehicles) inter-vehicular gap's distance continue to vary (i.e., to decrease/increase, respectively) after having crossed the intersection.

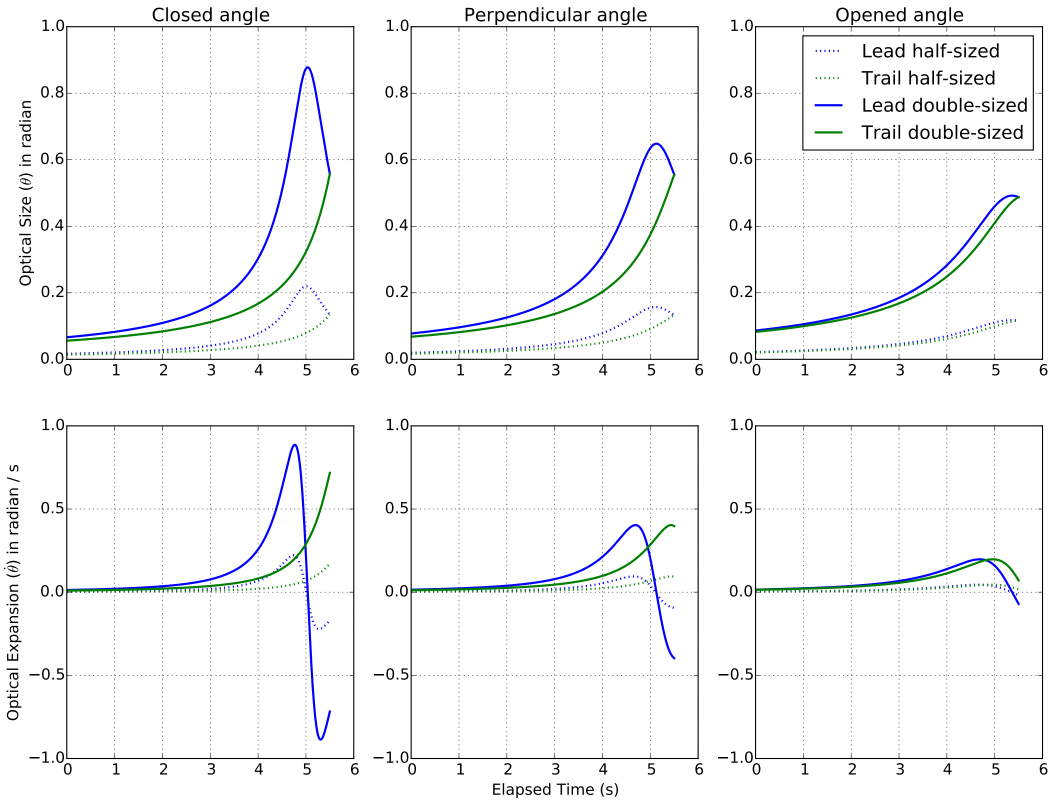

Figure 3: Simulations of optical size (top) and its expansion rate (bottom) of traffic vehicles (spherical estimation) in constant size condition and assuming the participant aimed at the center of the gap. Simulations show that the optical size and expansion rate are the highest in double-sized condition (as opposed to half-sized one) and in the closed-angle condition (as opposed to opened-angle one).

2.2. Procedure

At the beginning of each trial, participants found themselves parked (i.e., with zero velocity) in the middle of their lane, without any other vehicles in sight. They started the car's engine and operated the accelerator pedal in order to attain a required velocity indicated by a speed dial placed directly in front of them. Their current speed was indicated by the needle's position and the required speed by a red zone on the dial, without any numerical

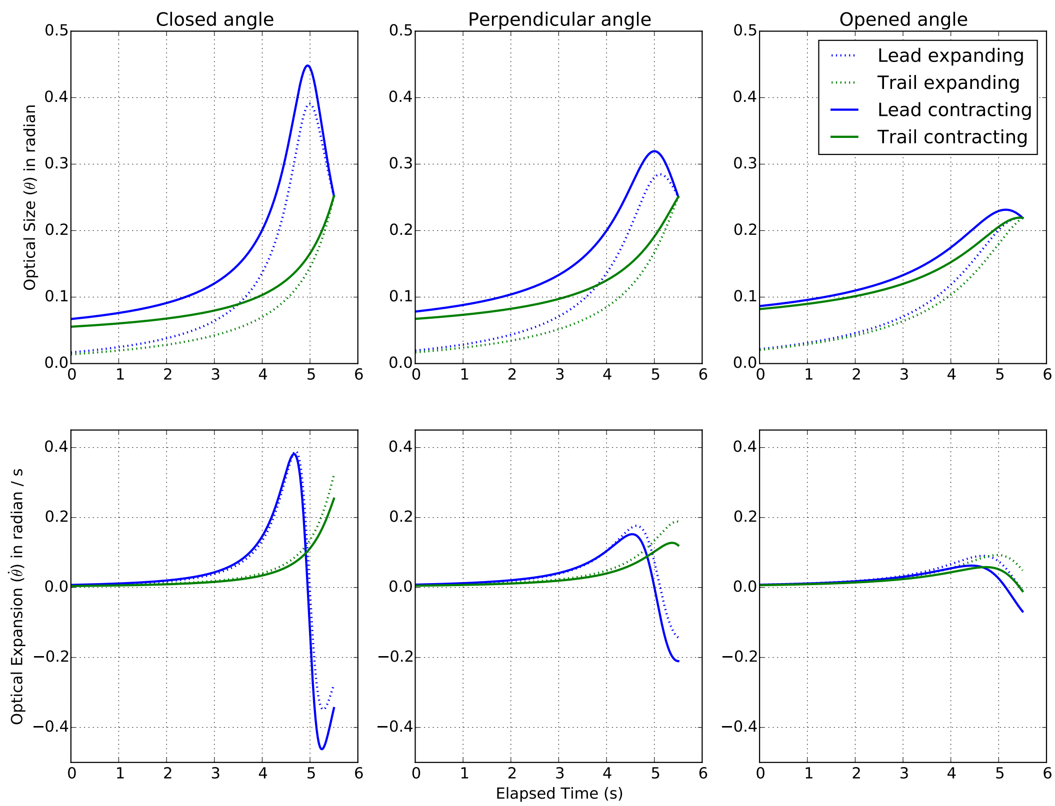

Figure 4: *Idem* as for Fig. 3, in normalizing size condition. Shows that the optical size and expansion are the highest in closed-angle geometry condition. It also shows that optical expansion is fairly similar between half- and double-to-normal conditions, while optical size itself is much different between those.

information being provided. 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 ± 0.69 m/s = 57.6 ± 2.5 km/h) over the last 20 m of the 80-m stretch, the speed dial disappeared and the intersection scenario was started, with the four-vehicle traffic train appearing on the left. If not, the trial was restarted. In the (rare) case that the driver did not pass between the traffic vehicles (colliding with one of them or braking so as to let the full four-vehicle traffic train pass) a large red triangle was presented.

The three constant vehicle size conditions were combined with the three intersection geometries, and the three driver's position offsets. The two normalizing vehicles size conditions were combined only with the three intersection geometries (always in null Offset condition). This resulted in an experimental block of $3 \times 3 \times 3 + 2 \times 3 = 33$ trials. Each participant performed five blocks of 33 trials for a total of 165 trials. The order of presentation of the 33 different conditions was randomized within each block. Normal-sized vehicles trials from constant sizes conditions were used as control trials in the formalizing size analysis.

2.3. Data Analysis

Intersection crossing was analyzed via the position of the participant within the traffic gap at the moment of crossing. Taking the (geometrical) center of the gap as the reference, a negative crossing position indicated crossing the intersection later than the center of the gap (i.e., closer to the trail vehicle) while a positive crossing position indicated crossing earlier than the center of the gap (i.e., closer to the lead vehicles). In order to examine the nature of the velocity adjustments effected during the approach to the intersection, we analyzed the time course of participant's velocity and its instantaneous effect on future passing position within the traffic gap, allowing a functional interpretation of the observed velocity adjustments. As in (Louveton, Montagne, Berthelon and Bootsma, 2012b; Louveton, Bootsma, Guerrin, Berthelon and Montagne, 2012a) the latter was implemented through the current deviation (CD) from the traffic gap cent re, calculated as the spatial or temporal distance from the center of the traffic gap at which the participant would pass the intersection if the current velocity were to remain constant. In the No Offset condition, continuing at the initial (stabilized) velocity 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) current deviation (CD) was equal to 0 s (0 m). In the Late Offset condition, continuing at the initial velocity 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 velocity 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 velocity and temporal current deviation were analyzed in five time steps, by averaging each of these variables over five 1-s intervals synchronized with the final moment of passing the intersection (i.e., 5 to 4 s, 4 to 3 s, 3 to 2 s, 2 to 1 s, 1 to 0 s before the participant arrived at the intersection). Our criteria for statistical significance was $p < .05$. We proceeded to *post-hoc* analyses only when an interaction effect reached this threshold. For clarity and coherence with earlier studies, we decided not to report results which did not meet this criteria.

3. Results

3.1. General behavior

All participants attempted to cross the intersection inside the traffic gap on all trials. On seven out of a total of 1980 trials, a participant collided with the lead or the trail vehicles. These rare (0.35%) collision trials were excluded from the analyses.

In the Method section we stated that in the No Offset condition participants could have kept their initial speed constant and yet could have crossed the traffic gap successfully. As already observed in Louveton et al. (2012a,b), participants did adjust their speed ($M = 60.5$ km/h , $SD = 4.3$, compared to the initial speed of 57.6 km/h) in order to cross slightly farther ahead from the center of the traffic gap ($M = 2.4$ m, $SD = 2$). This behavior has been interpreted in former work (Louveton et al., 2012a,b) as a preference for safety as the trail vehicle actually closes the temporal window and represents a higher risk of collision. This has been linked to a repeated pattern of acceleration in the last seconds suggesting that participants regulated their speed with regards to the trail vehicle at the end of the trial.

3.2. Constant size condition

3.2.1. Gap crossing position

Participants crossed the gap at a position that was overall slightly biased towards the lead vehicle, for a grand mean of 1.85 m (SD = 1.49 m) corresponding to 185 ms. This general trend was impacted by the different experimental conditions. A three-way repeated measures ANOVA ($Offset_3 \times Size_3 \times Geometry_3$) showed a main effect of $Offset$: $F(2, 22) = 266.34$, $p < .05$, $\eta^2_{partial} = .96$; $Geometry$: $F(2, 22) = 105.68$, $p < .05$, $\eta^2_{partial} = .91$ and also an effect of interaction $Offset \times Geometry$: $F(4, 44) = 4.99$, $p < .05$, $\eta^2_{partial} = .31$ and $Geometry \times Size$: $F(4, 44) = 9.19$, $p < .05$, $\eta^2_{partial} = .46$.

A post-hoc analysis (Scheffé test) performed on the $Offset \times Geometry$ effect revealed (see Figure 5, left panel) that participants did not compensate completely the initial offset. When comparing to the no-oiffset condition, they crossed closer to the lead vehicle in the early-offset condition and closer to the trail vehicle in the late-offset condition ($ps < .05$).

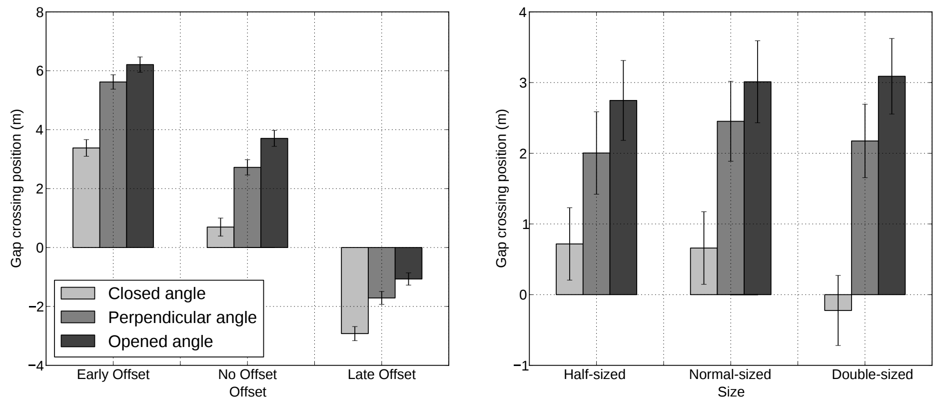

Figure 5: Left panel: the gap crossing position for Offset × Geometry interaction shows that participants crossed farther from the lead in closed-angle geometry and did not compensated totally the initial offset (either early or late one). Right panel: Geometry × Size interaction reveals that in combined conditions of closed-angle geometry and double-sized vehicles is qualitatively (and significantly, see text) different from all other combination of factors.

A post-hoc analysis performed on the $Geometry \times Size$ effect we found (see Figure 5, right panel) that participants crossed the gap closer to the lead vehicle in all condition but one: they crossed slightly behind the gap's center in the joint double-sized vehicles and closed-angle conditions. We found this combination of factor to be significantly different from all others (Scheffé test, $ps < .05$), while no other statistical differences were found in this interaction.

3.2.2. *Velocity profiles*

A four-way repeated measures ANOVA ($Offset_3 \times Geometry_3 \times Size_3 \times Time_5$) showed how our experimental factors affected this general pattern. Indeed, results showed a main effect of $Offset$: $F(2, 22) = 823.87$, $p < .05$, $\eta^2_{partial} = .99$; $Geometry$: $F(2, 22) = 68.482$, $p < .05$, $\eta^2_{partial} = .86$; $Time$: $F(4, 44) = 39.449$, $p < .05$, $\eta^2_{partial} = .78$; an effect of second order interaction $Offset \times Geometry$: $F(4, 44) = 5.016$, $p < .05$, $\eta^2_{partial} = .31$; $Size \times Geometry$: $F(4, 44) = 8.53$, $p < .05$, $\eta^2_{partial} = .44$; $Offset \times Time$: $F(8, 88) = 505.63$, $p < .05$, $\eta^2_{partial} = .98$; $Geometry \times Time$: $F(8, 88) = 41.839$, $p < .05$, $\eta^2_{partial} = .79$ and effect of third order interaction $Offset \times Geometry \times Time$: $F(16, 176) = 10.185$, $p < .05$, $\eta^2_{partial} = .48$; $Offset \times Size \times Time$: $F(16, 176) = 2.566$, $p < .05$, $\eta^2_{partial} = .19$; $Size \times Geometry \times Time$: $F(16, 176) = 4.04$, $p < .05$, $\eta^2_{partial} = .27$.

In the previous section we have seen that the combination of double-size vehicles and closed-angle Geometry conditions resulted in a gap crossing position that was significantly farther from the lead vehicles compared to the other conditions. This behavior is also visible on velocity profiles (see also figure 6) and confirmed by the Scheffé post-hoc analysis performed on the $Size \times Geometry \times Time$ effect ($ps < .05$). We choose to explore this interaction effect specifically because we need to consider Size and Geometry altogether in order to test our hypothesis.

Consistently with gap crossing results, we found that in the closed-angle condition participants drove at a significantly lower speed during the four last seconds of the trial in the double-sized condition than in the normal-sized one. Additionally, we found no Size effects in relation to perpendicular and opened-angle conditions.

3.2.3. Current deviation profiles

Continuously extrapolating the current state of affairs to the future moment of passing the intersection, the variations of the current deviation (CD) from the center of the traffic gap at the moment of its arrival at the intersection allow a functional interpretation of the velocity adjustments discussed in the method section. The four-way repeated measures ANOVA

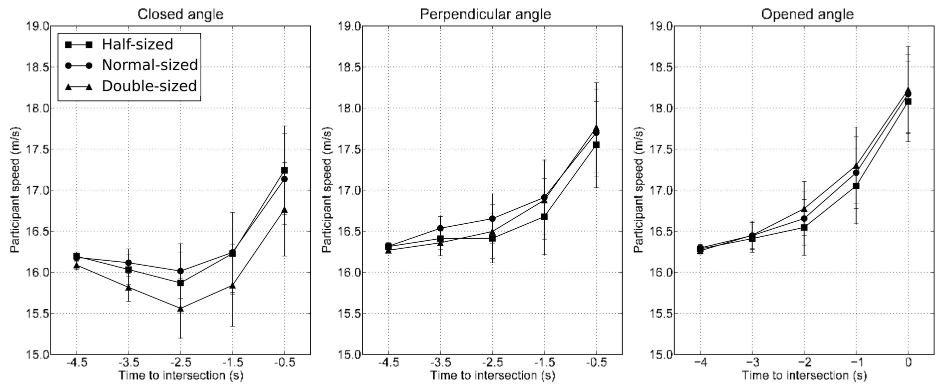

Figure 6: Participants drove at a slower speed in joint conditions of double-sized vehicles and closed-angle geometry conditions when compared to other conditions.

$(Offset_3 \times Geometry_3 \times Size_3 \times Time_5)$ showed a main effect of $Offset$: $F(2,22) = 958.24$, $p < .05$, $\eta^2_{partial} = .99$; $Geometry$: $F(2,22) = 42.665$, $p < .05$, $\eta^2_{partial} = .80$; $Time$: $F(4,44) = 9.089$, $p < .05$, $\eta^2_{partial} = .45$; an effect of second order interaction $Offset \times Geometry$: $F(4,44) = 3.245$, $p < .05$, $\eta^2_{partial} = .23$; $Size \times Geometry$: $F(4,44) = 5.889$, $p < .05$, $\eta^2_{partial} = .35$; $Offset \times Time$: $F(8,88) = 362.06$, $p < .05$, $\eta^2_{partial} = .97$; $Geometry \times Time$: $F(8,88) = 39.011$, $p < .05$, $\eta^2_{partial} = .78$ and effect of third order interaction $Offset \times Geometry \times Time$: $F(16,176) = 14.159$, $p < .05$, $\eta^2_{partial} = .56$; $Offset \times Size \times Time$: $F(16,176) = 2.199$, $p < .05$, $\eta^2_{partial} = .17$; $Size \times Geometry \times Time$: $F(16,176) = 6.621$, $p < .05$, $\eta^2_{partial} = .38$.

The $Size \times Geometry \times Time$ interaction shows (see Figure 7) a qualitatively different behavioral pattern in combined closed-angle and double-sized conditions, in which participants aimed much farther from the lead vehicle than in other conditions. We are particularly interested in this interaction effect because the two factor of our hypothesis altogether. In joint closed-angle and double-sized conditions, participants' current deviation was significantly different (i.e., they aimed farther from the lead vehicle) from which of the normal-sized ones during the four last seconds of the trial (Scheffé post-hoc, $ps < .05$). Such a difference appeared only in the closed-angle Geometry and was not found in the perpendicular and the opened-angle Geometries: We found no effect of Size in the opened-angle Geometry and only transient differences in the perpendicular-angle one (i.e., at the third and fourth second between the half- and normal-sized vehicles conditions).

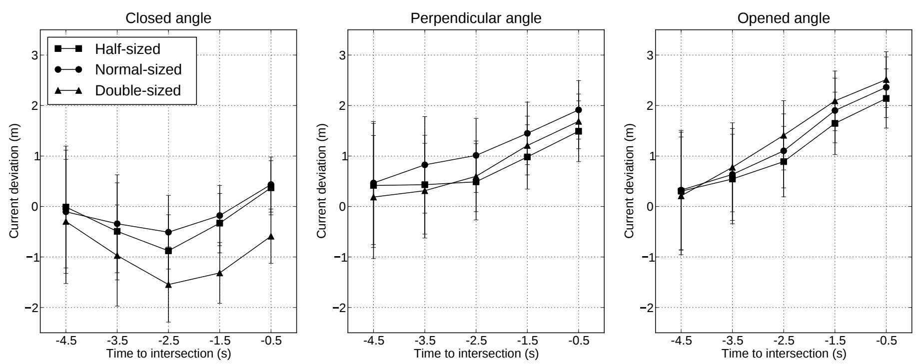

Figure 7: Current deviation profiles show a clear tendency to cross the moving gap farther from the lead vehicle in the joint conditions of double-sized vehicles and closed-angle geometry.

3.3. Normalizing size condition

3.3.1. Gap crossing position

Similarly to constant size conditions, participants crossed the gap with a slight bias towards the lead vehicle, for a grand mean of 2.29 m (SD = 1.69 m). A two-way repeated measures ANOVA ($Size_3 \times Geometry_3$) showed a main effect of *Geometry*: $F(2,22) = 46.741$, $p < .05$, $\eta^2_{partial} = .81$; *Size*: $F(2,22) = 13.274$, $p < .05$, $\eta^2_{partial} = .55$.

Looking at the main effect of Geometry factor, results revealed (Scheffé test, $ps < .05$) that participants crossed the intersection farther from the lead vehicle in the closed-angle Geometry than in the other ones (see Figure 8, left panel). In contrast, there was no significant difference between the perpendicular- and opened-angle conditions. Regarding the main effect of Size, results also showed (see Figure 8, right panel) that participants crossed the intersection farther from the lead vehicle in the half-to-normal-sized vehicles condition (i.e., over-expansion of vehicles' optical size) than in the other Size conditions. Finally, no differences were found to be significant when comparing the normal-sized vehicles to the double-to-normal-sized vehicles conditions.

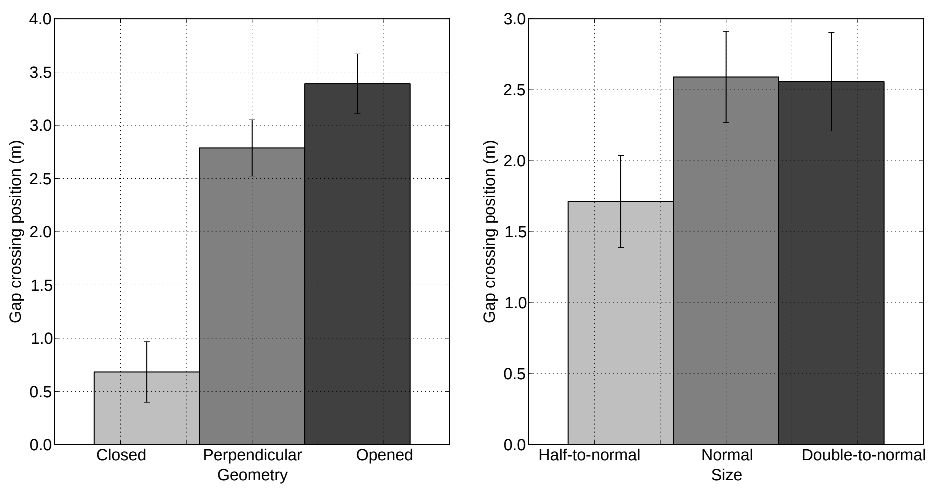

Figure 8: Left: while no difference in gap crossing position were found between the perpendicular- and opened-angle Geometries, participants crossed significantly farther from the lead vehicle in the closed-angle one. Right: in the half-to-normal condition, participant aimed at a gap crossing location significantly farther from the lead vehicle than the other conditions. No differences were found between the other size conditions.

3.3.2. Velocity profiles

A three-way repeated measures ANOVA ($Geometryy_3 \times Size \times Time_5$) showed a main effect of $Size$: $F(2, 22) = 13.157$, $p < .05$, $\eta^2_{partial} = .54$; $Geometry$: $F(2, 22) = 32.87$, $p < .05$, $\eta^2_{partial} = .75$; $Time$: $F(4, 44) = 60.523$, $p < .05$, $\eta^2_{partial} = .85$ and an effect of second order interaction $Geometry \times Time$: $F(8, 88) = 15.897$, $p < .05$, $\eta^2_{partial} = .59$; $Size \times Time$: $F(8, 88) = 22.038$, $p < .05$, $\eta^2_{partial} = .67$.

Consistently with gap crossing position, the velocity profiles revealed that participants drove slower in the closed-angle geometry than in any other conditions (see Figure 9, left panel). A post-hoc Scheffé performed on the $Geometry \times Time$ effect evidenced ($ps < .05$) that participants drove at a lower speed during the last three seconds in the closed-angle Geometry than in the perpendicular one, whereas there were no differences in travailing speed between the perpendicular- and the opened-angle Geometries.

Participants' velocity profiles have been specifically affected by half-to-normal condition (i.e., over-expansion). Indeed, participants drove slower in half-to-normal condition than in other Size conditions (see Figure 9, right panel). A Scheffé test performed on the $Size \times Time$ effect evidenced ($ps < .05$) that participants drove at a lower speed during the last three seconds in the half-to-normal sized vehicle condition than in the normal-sized one. In contrast, no differences were found to be significant in travel speed when comparing the normal-sized vehicle condition to the double-to-normal one.

3.3.3. Current deviation profiles

A three-way repeated measures ANOVA ($Geometry_3 \times Size_3 \times Time_5$) showed a main effect of $Size$: $F(2, 22) = 4.717$, $p < .05$, $\eta^2_{partial} = .30$; $Geometry$: $F(2, 22) = 20.965$, $p < .05$, $\eta^2_{partial} = .66$; $Time$: $F(4, 44) =$

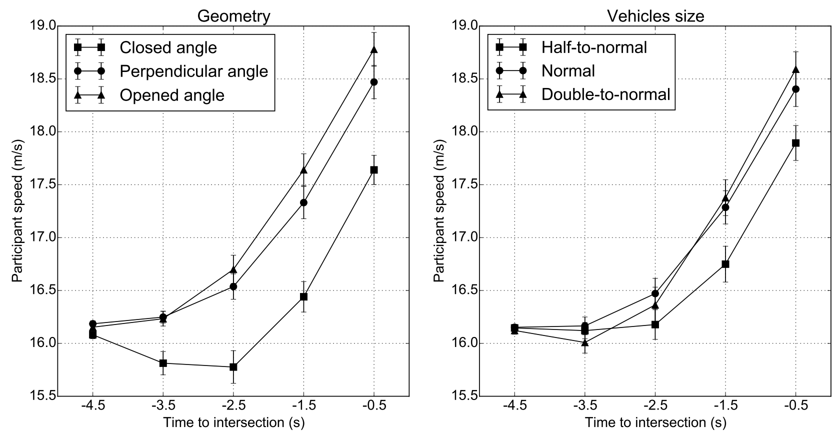

Figure 9: Left: traveling speed was found significantly lower in closed-angle condition than in other size conditions. The two other geometry conditions were not found to be statistically different. Right: in the half-to-normal condition, participant drove at a significantly slower speed than the other conditions. No differences were found between the other size conditions.

13.755, $p < .05$, $\eta^2_{partial} = .56$, an effect of second order interaction $Geometry \times Time$: $F(8, 88) = 23.713$, $p < .05$, $\eta^2_{partial} = .68$; $Size \times Time$: $F(8, 88) = 20.097$, $p < .05$, $\eta^2_{partial} = .65$ and an effect of third order interaction $Size \times Geometry \times Time$: $F(16, 176) = 1.819$, $p < .05$, $\eta^2_{partial} = .14$.

A post-hoc analysis on the $Size \times Geometry \times Time$ interaction (see Figure 10) revealed a significant difference of current deviation pattern between closed- and perpendicular-angle geometries (Scheffé test, $ps < .05$). When comparing closed- to perpendicular-angle conditions, we found that participants were likely-to-cross farther from the lead vehicle during the last three seconds in the half-to-normal condition, and during the last four seconds in the double-to-normal one.

This analysis also revealed the specific effect of half-to-normal sized vehicles on current deviation: we found (Scheffé test, $ps < .05$) that participants were likely-to-cross farther from the lead vehicle during the last four seconds in the half-to-normal condition than in the normal one for both in the perpendicular and opened angle conditions.

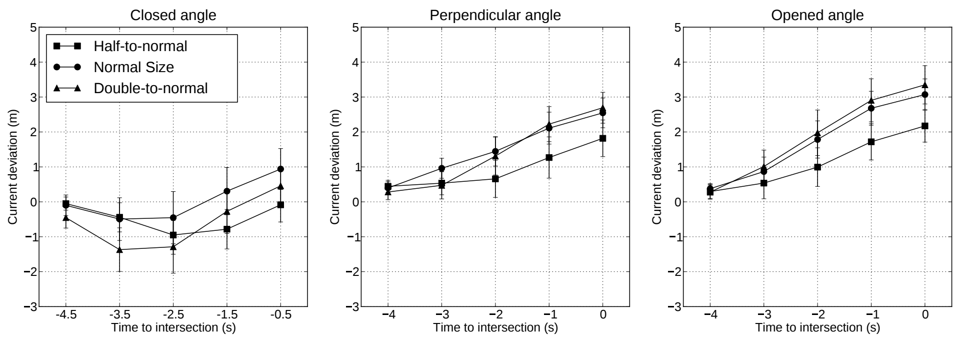

Figure 10: Participants aimed at a gap crossing location farther from the lead vehicle in closed-angle condition compared to perpendicular one. Overall participants drove at a slower speed in half-to-normal (expanding) size condition, while in closed-angle condition double-to-normal (contracting) size condition also induced slower traveling speed.

4. Discussion

The first goal of this study was aimed at testing the hypothesis of an exclusive use of bearing angle to control self-displacement synchronization with a moving traffic gap. In the case this hypothesis would be refuted, the second goal was to better understand the role of optical size and its expansion rate in road crossing tasks. Results showed an effect of intersection geometry and size manipulations altogether (both constant and normalizing size conditions). Hence, the hypothesis of an exclusive use of bearing angle is refuted by our results. Furthermore, they also demonstrate the role of cross-traffic vehicles' size in a perceptual-motor task.

4.1. The role of bearing angle

As stated in the introduction section, an effect of optical size and expansion rate has been observed in tasks where CBA strategy is known to provide a good account for participants behavior (Chardenon et al., 2004; de Rugy et al., 2001). In those studies it has been shown that optical expansion did impact participants' behavior although the effect was of a moderated importance and was taking place at the end of the trial. In our study, optical size and expansion manipulations had an important impact (particularly in interaction with closed angle geometry) and appeared early in the course of the trial (i.e., effect visible over the four last seconds of a trial in some conditions).

While these results seem to refute the hypothesis of the exclusive use of CBA strategy, they do not totally dismiss it either. In interceptive tasks, online control strategies such as the CBA strategy have been shown as accounting better for participants behavior than predictive ones based on TTC estimation (Bastin et al., 2006b). However our findings are not necessarily contradictory. Indeed, a study from Diaz et al. (2009) demonstrated that in interceptive actions a predictive control strategy based on TTC estimation could be used along with the CBA strategy. The authors showed that the best model for accounting behavioral data was the one combining a predictive estimation of time using optical size and expansion along with a CBA strategy applied with a little foresight rather than to the current instant.

Another alternative hypothesis could be formulated. For instance, in this work, the object in motion is a car, which is a larger and visually more sophisticated object than those usually under study (most of the time a sphere). In that regard, one may argue that if the bearing angle may have been perceived from another point than the geometric center of the vehicle (for example a point near the bumper), it could have had an impact on behavior as size manipulations were performed around the geometric center of the object. Although this alternative hypothesis could argue in favor of the exclusive bearing angle hypothesis, it also suffers an important flaw: the underlying mechanisms behind the selection of a partial object (i.e., the bumper instead of the whole car) as reference for the bearing angle is largely to be determined and justified. This calls for specific research on how bearing angle could support interception of complex objects.

4.2. Effect of size manipulations

Particularly, in the constant size condition we showed that participants drove at a slower speed and crossed the intersection later in the traffic gap in the combined condition of double-sized vehicles and closed-angle geometry. This makes a compelling replication of former study on road crossing Caird and Hancock (1994); Hancock and Manster (1997); Horswill, Helman, Ardiles and Wann (2005), generalizing to active control task and eliminating the bias induced by manipulating vehicles' type.

In normalizing size condition, results showed that in the half-to-normal sized condition, participants drove at slower speed and aimed at a gap crossing position farther from the lead vehicle, particularly in the last seconds of the trial unfolding. The same pattern of results is found in the closed-angle geometry condition, although we found an interaction between the two factors only for current deviation profiles. These profiles suggest two phases in the control of approach, particularly in the closed-angle condition: at the beginning of the trial, participants are aiming at a delayed position in the traffic gap when confronted to double-to-normal size condition compared to the half-to-normal one; at the end of the trial, the situation flips and the delayed approach to the traffic gap is observed in the half-to-normal condition.

With regard to optical size and expansion simulations (see Fig. 3 and 4), careful interpretations should be drawn from this work. Indeed, findings in constant size conditions seemed to indicate that participants exhibit a more "conservative" behavior in size conditions with the highest optical size and expansion (i.e., in joint conditions of closed-angle geometry and double-sized vehicles, see also Fig. 3). While in normalizing condition, participants exhibited a "conservative" behavior in over-expanding (half-to-normal size) condition may suggest the importance of optical expansion over optical size itself. However, simulations indicate that optical expansion is pretty similar in both conditions of size while an actual differentiation is observed in optical size itself. Also, current deviation profiles showed that double-to-normal size condition seems to induce a similar "conservative" behavior particularly at the beginning of the trial. Also, those results point to an higher importance of optical size itself in online regulations compared to optical expansion.

4.3. Underlying mechanisms

Those results seem compatible with former observations in the literature Caird and Hancock (1994); Hancock and Manster (1997); Horswill, Helman, Ardiles and Wann (2005) which demonstrated retarded action or an underestimated time for large vehicles. Indeed, we can interpret a slower traveling speed and a delayed crossing within the gap as a "conservative" behavior, possibly guided by a "safety" principle. However, in the former studies we mentioned, the task was based on perceptual judgment, did not require an active control of intersection crossing, and the risk of collision was specified by only one vehicle. In our situation, a delayed crossing time might be induced by a "safe" behavior toward the lead vehicle which in turn correspond to a less "safe" behavior toward the trail one. However, the final acceleration observed in all condition suggests that participants may regulate in priority with regard to the lead vehicle and then "finalize" the gap crossing taking into account the trail one.

However, the notion of "safety" is a functional concept as it describes how an agent is handling the constraints of the situation in order to achieve a particular goal or a set of sub-goals. Our task is sufficiently complex to let the agent controlling his/her behavior toward different goals (intercepting the gap, avoiding the first and second vehicles).

Also, recent studies on speed perception of an oncoming train showed that speed of trains was under-estimated compared to that of a light vehicle Clark et al. (2013). This result has been reproduced independently of the possible cognitive bias induced by the type of vehicle and seems to be due to a larger visual scanning pattern Clark et al. (2016). Those results are contradictory with former literature on road crossing as participants are less "conservative" when confronted to large vehicles.

We may explain this contradiction by two hypotheses. First, Clark and colleagues Clark et al. (2013, 2016) investigated only two sizes of vehicle, either a car or a train, thus we cannot exclude that the under-estimated speed effect might be due to an outstandingly large object, while road crossing literature was studying only road vehicles. The second hypothesis is more focused on the nature of the task itself: As said above, our task includes two sub-tasks, namely to intercept the gap and to avoid boundaries, which open new ways to interpret those results. Indeed, in our study participants decelerated when they were confronted to larger vehicles which could mean either that they adopted a "conservative" behavior with regard to estimated arrival time (i.e., the lead vehicle appears to approach faster, participants are decelerating to avoid collision); or that they adopted an adjusted behavior with regard to gap interception (i.e., the lead vehicle opening the gap appears to move slower, participants are decelerating to intercept it). Another study including an additional vehicle type and discussing possible explanations such as the nature of the task itself could be found in Petzoldt (2016).

5. Conclusion

In this work we tested the hypothesis of an exclusive use of bearing angle for synchronizing self-displacement with a moving cross-traffic gap. We also manipulated optical size of cross-traffic vehicles and the way it evolves over trial unfolding. Our results refute the hypothesis of an exclusive use of bearing angle. It also generalize to an active driving task results obtained in former literature concerning the effect of optical size of oncoming vehicle on road crossing behavior. Indeed, participants seemed to demonstrate a more "conservative" behavior in conditions were the optical size of oncoming vehicle was the highest. We discussed the relativity of concepts such those of "safe" or "conservative" behaviors usually put forward to explain participants behavior.

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Appendix A. Calculations

Bearing angle

The bearing angle is defined as the angular distance between an observer's motion heading and the position of a target. We calculated the bearing angle (ϕ) using the following formula:

$$\phi = \arctan \frac{|X_{target} - X_{observer}|}{|Y_{target} - Y_{observer}|} \tag{A.1}$$

Where $(X_{target}; Y_{target})$ and $(X_{observer}; Y_{observer})$ are the successive $(x; y)$ coordinates of the target and the observer respectively. Hence, the first order temporal derivative was calculated as below:

$$\dot{\phi} = \frac{\mathrm{d}\phi}{\mathrm{d}t} \tag{A.2}$$

Optical size and expansion

Optical size and expansion rate simulations were performed under the assumption of an observer aiming at the center of the traffic gap, which means he or she would keep vehicle's travelling speed constant all over the trial unfolding. We used a spherical approximation to compute the optical size of oncoming objects (i.e., oncoming vehicles):

$$\theta = 2 \cdot \arctan \frac{\mathrm{r}}{2 \cdot \mathrm{D}} \tag{A.3}$$

Where r is the radius of the target object (the longest diagonal in rectangular shaped objects such as a car) and D the successive euclidean distances between the target object and the observer. Hence, the optical expansion rate is defined as the first order temporal derivative of optical size:

$$\dot{\theta} = \frac{\mathrm{d}\theta}{\mathrm{d}t} \tag{A.4}$$