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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. 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, Caird, Shekhar, & Vercruyssen, 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

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was small (a motorcycle). Another study (Caird & 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 Gould, Poulter, Helman, & Wann, 2012; Regan & Hamstra, 1993; Yilmaz & Warren, 1995).

However, recent road crossing studies on bicycle riders (Chihak et al., 2010) and drivers (Louveton, Bootsma, Guerrin, Berthelon, & Montagne, 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 Caird & Hancock, 1994; Hancock et al., 1991) but would rather involve a continuous adaptation to oncoming traffic.

As pointed out by Chihak et al. (2010) and 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, Montagne, Laurent, & Bootsma, 2004; Lenoir, Musch, Thiery, & Savelsbergh, 2002; Lenoir et al., 1999). 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, Calvin, & Montagne, 2006; Bastin, Jacobs, Morice, Craig, & Montagne, 2008; Chardenon, Montagne, Buekers, & Laurent, 2002; Chardenon et al., 2004; Chardenon, Montagne, Laurent, & Bootsma, 2005; François, Morice, Blouin, & Montagne, 2011; Lenoir et al., 2002) and in animals (Ghose, Horiuchi, Krishnaprasad, & Moss, 2006; Lanchester & Mark, 1975; Olberg, Worthington, & Venator, 2000; Olberg, 2011; Rossel, Corlija, & Schuster, 2002).

However, the road crossing task proposed by Chihak et al. (2010) and 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, Montagne, Berthelon, and Bootsma (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, Bordier, & Le Guern (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) and de Rugy, Montagne, Buekers, and Laurent (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 et al., 2012b; Louveton et al., 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 Figs. 3 and 4). This latter manipulation is intended to weight the relative importance of optical size relative to its expansion rate in our task.