Accident Analysis and Prevention 65 (2014) 72–84

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

# Arrival-time judgments on multiple-lane streets: The failure to ignore irrelevant traffic☆

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ARTICLE INFO

*Article history:*
Received 27 June 2013
Received in revised form 2 October 2013
Accepted 23 December 2013

*Keywords:*
Intersection-crossing
Time-to-arrival
Multiple gaps
Perceptual averaging

ABSTRACT

How do road users decide whether or not they have enough time to cross a multiple-lane street with multiple approaching vehicles? Temporal judgments have been investigated for single cars approaching an intersection; however, close to nothing is known about how street crossing decisions are being made when several vehicles are simultaneously approaching in two adjacent lanes. This task is relatively common in urban environments. We report two simulator experiments in which drivers had to judge whether it would be safe to initiate street crossing in such cases. Matching traffic gaps (i.e., the temporal separation between two consecutive vehicles) were presented either with cars approaching on a single lane or with cars approaching on two adjacent lanes, either from the same side (Experiment 1) or from the opposite sides (Experiment 2). The stimuli were designed such that only the shortest gap was decision-relevant. The results showed that when the two gaps were in sight simultaneously (Experiment 1), street-crossing decisions were also influenced by the decision-irrelevant longer gap. Observers were more willing to cross the street when they had access to information about the irrelevant gap. However, when the two gaps could not be seen simultaneously but only sequentially (Experiment 2), only the shorter and relevant gap influenced the street-crossing decisions. The results are discussed within the framework of perceptual averaging processes, and practical implications for road safety are presented.


## 1. Introduction

In France, a total number of 40,357 accidents occurred at intersections in the years 2010 and 2011 (ONISR, 2011, 2012). Most of these accidents occurred in city surroundings, where the velocity is highly limited, so that only a minor part (approximately 2.2%), led to one or more fatalities. However, these losses at intersections represent an important part of the road causalities, approximately 12% of the death toll. Independently of the responsibilities of the different road users (pedestrians, drivers and cyclists) involved and the multiple and cumulative causes of the accidents, it appears likely that at least one of the actors may have misjudged the time-to-arrival (TA, that is the time remaining before the approaching car reaches the intended crossing path) of the other approaching vehicle. Indeed, before crossing a road or an intersection, road users need to consider the traffic situation and decide whether or not they have enough time to safely complete their crossing maneuver. In such a task, the temporal size of the available gap (i.e., the temporal separation between two consecutive vehicles) has to be anticipated, which requires an accurate estimation of the TA. In this respect, a gap is crossable if its corresponding TA is greater than the crossing time needed by the observer, plus a safety margin. The temporal window available for the observer may or may not be sufficient to accomplish the street crossing maneuver.

Within the last years, it has been proposed that interceptive or avoidance actions, like street crossing actions are, are controlled based on optical expansion cues such as tau [$\tau(\theta)$, the instantaneous visual angle subtended by the object divided by the instantaneous rate of expansion, Lee, 1976] on other tau-like variables (Bootsma and Oudejans, 1993), or simpler optical parameters, such as the bearing angle of the approaching car (the angle subtended by the current position of the car and the direction of the subjects' motion; e.g., Chardenon et al., 2005; Bastin et al., 2006). In addition, previous research suggests that several factors influence street-crossing decisions in pedestrian or driver situations, or more generally the capacity to detect and avoid a collision with an approaching object, mainly the observer's age (e.g., Oxley et al., 2005; Yan et al., 2007; Lobjois and Cavallo, 2009), the approaching vehicle's speed

☆ Part of Experiment 1 has been presented at the Skills conference, 15–16 December 2011, Montpellier, France, under the form of a poster.

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http://dx.doi.org/10.1016/j.aap.2013.12.013

or distance (Cavallo and Laurent, 1988; Alexander et al., 2002; te Velde et al., 2005; Lobjois and Cavallo, 2007), and the relative size of the object (the size-arrival effect, DeLucia and Warren, 1994).

However, little attention has been paid to the situation where several objects have to be avoided in the same time, for example in a street crossing situation when multiple lanes have to be crossed (see e.g., Grechkin et al., 2013). One can conceive of this situation as the task to concurrently judge a number of moving gaps. In the case of two cars approaching in two adjacent lanes, the gaps are defined as the temporal intervals between each car and its respective intersection point with the observers' path (note that this is not equal to the temporal separation between the two cars). This situation is more complex than the typical temporal-range estimation scenarios. We provide what to our knowledge is the first temporal-range estimation data for this rather common situation. City centers abound with streets in which road users may have to cross multiple lanes, and hence are put in a position to deal with more than one gap at the time. It cannot be assumed that the reasonably good performance in the face of one gap necessarily generalizes to situations where several gaps need to be judged simultaneously. The TA perception in multiple-lane streets and the crossing decision based upon it may significantly differ from those obtained in a one-lane street.

Evidence suggesting that such a difference is to be expected in multiple-gap scenarios comes from previous laboratory-based experiments based on the simpler case of multiple concurrent TA estimations of moving objects. They showed that relative and absolute TA judgments were affected by the number of objects that had to be considered (set size). Relative TA judgments assess which of several objects will arrive first, whereas absolute TA judgments assess the exact time at which a given object is taken to arrive. Relative TA judgments were affected by set-size, with a decrease in accuracy as set-size increased (DeLucia and Novak, 1997). Moreover, dual absolute TA estimations have been shown to interfere with one another in an asymmetric fashion (Baurès et al., 2010, 2011), which indicates a perceptual bottleneck at the visual level. When comparing the TA estimates with a one-object condition in which the moving object had the same motion parameters (velocity and TA), the results showed that for two simultaneously moving objects, the TA estimates for the first-arriving object did not differ from the estimates in the one-object situation. However, participants significantly overestimated the TA of the later-arriving object, relative to the one-object condition. The human visual system thus appears to be unable to accurately process two TAs at the same time.

When confronted with multiple gaps, the visual system might resort to perceptual averaging, or statistical summary representations (Albrecht and Scholl, 2010). It has been shown that when observers are confronted with a set of objects, the visual system represents the overall statistical properties of the set rather than individual properties (Ariely, 2001). Based on this hypothesis, when being confronted with multiple gaps, observers might perceive the mean value of the gaps rather than the individual value of each gap, and behave according to this mean value.

To determine if observers' ability to estimate several TAs is indeed distorted in such a manner, we carried out two street-crossing experiments in which observers had to pass through a single gap or through two simultaneous gaps (dual-gap condition). For the sake of simplicity, we illustrate this scenario by taking the situation where the gap is already opened and the critical decision is to judge whether or not the street can be safely crossed before the oncoming traffic reaches the observer. Three potential outcomes can be predicted.

1) *Ideal observer*: For an ideal observer, the decision to cross the street should depend only on the shortest TA, and be independent of the longer ones. If the shortest TA is shorter than the crossing time, then the gap(s) should be refused as unsafe for crossing. If the shortest TA is longer than the crossing time, then the gap should be accepted. Hence, if observers are able to make independent and precise TA estimations for all approaching vehicles, so that they can positively identify the vehicle with the shortest TA, then the number of approaching cars should be irrelevant, and street-crossing decisions should depend only on the value of the shortest TA. Accordingly, for a given shortest gap value, street-crossing decisions should not differ between the single-gap and the dual-gap conditions. The perceptual bottleneck highlighted by Baurès et al. (2010, 2011) predicts this outcome. Note however that as the crossing time may be significantly different when crossing the first lane only vs. the whole intersection (lanes 1 and 2), then the shortest gap value may afford the observer to cross the street if placed in the first lane but not if placed in the farther second lane.
2) *Increased safety margin*: If the two TA estimations are not independent but interfere with each other, then the irrelevant gap may emphasize the perceived danger and decrease the probability that the observers decide to cross the street in the dual-gap condition compared to the single-gap condition. One possibility to explain such a pattern of results would be that the interference between the two TA estimations causes the shortest TA to be underestimated. This would lead observers to think they have less time to cross the street than is actually available, and based on this wrong perception, to refuse the gaps. Alternatively, TA estimations could be less precise in the dual-gap condition, preventing the observers to identify which object has the shortest TA, and therefore inducing the use of a safety strategy that votes for not crossing the street.
3) *Averaging*: Finally, the interference in the TA estimations might increase the probability that the observers decide to cross the street in the dual-gap condition compared to the single-gap condition. Indeed, within the framework of the perceptual averaging hypothesis, the presence of a second gap would lead the observer to base her decision on a mean TA of the two individual TAs. The obvious consequence of such an averaging process leads the shortest TA to be overestimated, and the largest to be underestimated. That is, observers may think they have more time to cross the street than is actually available, and based on this (mis)perception, decide more readily to accept the gaps.

Note that compared to the situation with only a single approaching vehicle, the two first cases (1 and 2) would not affect the observer's safety when a second approaching vehicle is added. The third alternative (3), however, implies an increase of hazardous behavior, and may be an important risk factor when crossing a multiple-lane street.

To decide between the three potential outcomes, we carried out two gap-acceptance experiments in which participants faced one (single-gap condition) or two (dual-gap condition) cars that were approaching in adjacent lanes. In the dual-gap condition, the cars were either approaching from the same direction toward the observer (Experiment 1), or from the opposite directions (Experiment 2). At different TAs, the car(s) disappeared from view, and participants were asked to judge whether or not they would have had enough time to safely drive their car through the intersection.

## 2. Experiment 1

### 2.1. Materials and methods

#### 2.1.1. Subjects

Fourteen observers (5 women, 9 men, age 31.64 years ± 5.56 (mean ± SD), min. age 25, max. age 43) participated voluntarily after giving informed consent. All participants had normal or