Accident Analysis and Prevention 72 (2014) 127–133

Contents lists available at ScienceDirect

Accident Analysis and Prevention

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

On the relationship between pedestrian gap acceptance and time to arrival estimates

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ARTICLE INFO

Article history:
Received 4 April 2014
Received in revised form 17 June 2014
Accepted 28 June 2014
Available online 16 July 2014

Keywords:
Pedestrian
Street crossing
Time to arrival
Ageing

ABSTRACT

The identification of safe gaps between passing cars when crossing a street is a task most of us accomplish successfully on a daily basis. Objectively, how safe a specific gap is, is mainly dependent on how long it would take the approaching vehicle to arrive (time to arrival; TTA). Common sense might suggest that TTA is the basis for pedestrians' gap selection. However, it has been shown repeatedly that vehicle approach speed has a substantial influence on the size of chosen gaps. At higher speeds, pedestrians tend to accept smaller time gaps, i.e. they initiate riskier crossings. Some researchers have gone so far as to suggest that pedestrians rely more on physical distance of a vehicle in their crossing decisions than TTA. Yet, at the same time, there is evidence that TTA estimates themselves are influenced by object approach speed. It is suspected that pedestrians are more apt to base their decisions on systematically distorted TTA estimates, rather than physical distance. The goal of the two experiments described in this article was to explore the relationship between gap acceptance and TTA estimation. Participants were presented with video clips of approaching vehicles, and were either required to indicate a crossing decision, or to estimate TTA. Results show the typical effects of speed (smaller gaps at higher speed, lower TTA estimate at lower speed) and age (larger gaps for older participants). However, when using subjective time gap size (the TTA estimate) instead of objective time gap size to predict gap acceptance, the effect of speed either disappeared (Experiment I) or decreased substantially (Experiment II). The results indicate that systematic differences in TTA estimates can be a reasonable explanation for the effect of speed on gap acceptance.

1. Introduction

Accident statistics show that pedestrians are at considerable risk of being involved in injury or fatal crashes. According to German data, 520 (14.4%) of the 3600 road users killed in 2012 were pedestrians (Statistisches Bundesamt, 2013). Worldwide, more than 270,000 pedestrians die in traffic accidents annually, a share of 22% of all traffic casualties. In some countries (especially middle and low income), this share is as high as 75% (World Health Organisation, 2013). Interestingly, it is not uncommon that it is the pedestrian who is at fault. German statistics suggest that in about 30,000 injury accidents with pedestrian involvement in 2012, the pedestrian bore main responsibility for the crash in more than 8500 cases (Statistisches Bundesamt, 2013). From a recent review of 6434 pedestrian crashes in Florida (Alluri et al., 2013), the pedestrian is reported to have been at fault in 53% of all crashes.

Already in the 1950s, the high numbers of killed and injured pedestrians prompted investigations of pedestrian crossing decisions. Moore (1953) observed pedestrians' choices at a pedestrian crossing with a central reservation. He found that around 75% of the pedestrians crossed in front of a vehicle 60 ft away if it was travelling at about 5–10 mph, whereas only 25% crossed if the vehicle was approaching at 20–25 mph (and again was approximately 60 ft away). Based on that finding, the author concluded that "this suggests that pedestrians are concerned primarily with a time-gap and not a distance gap in the traffic" (p. 5), although he fails to provide actual data on the chosen time gaps to substantiate that claim. Cohen et al. (1955) already realised that the time gap was likely the most relevant measure. They observed on a road crossing that a time gap of 4–5 s was acceptable to about half of the pedestrians, whereas there were virtually no crossings at time gaps of 2.5 s or shorter. Unfortunately, the authors did not differentiate between different vehicle speeds; thus, the influence of approach speed on the acceptance of gaps remained unclear.

In the last two decades, interest in pedestrian behaviour increased substantially. Several observational studies were conducted (e.g. Yannis et al., 2013), often from an engineering

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http://dx.doi.org/10.1016/j.aap.2014.06.019
0001-4575/

perspective, with the aim of informing simulations and models of pedestrian behaviour with real life data (e.g. Chandra et al., 2014; Kadali and Vedagiri, 2013). As older pedestrians and children have been found to be at greater risk in general (e.g. Jonah and Engel, 1983), and in particular tend to accept more unsafe gaps than other age groups (Connelly et al., 1998; Oxley et al., 1997), subsequent experimental research has overwhelmingly focused on age effects on pedestrian crossing decisions. From such studies, it has been reported that older participants are especially likely to select smaller time gaps with higher speeds (Lobjois and Cavallo, 2007, 2009). Others have found the effect of speed on the selection of gaps regardless of age (Oxley et al., 2005), especially when response time was constrained (Lobjois and Cavallo, 2007). Conclusions from those experiments state that crossing decisions "were based primarily on the distance of oncoming vehicles and to a lesser extent on time of arrival" (Oxley et al., 2005, p. 969), or that under time constraints, "all participants took more risks as speed increased" (Lobjois and Cavallo, 2007, p. 942).

While those descriptions are accurate, they fail to answer the question of whether this seemingly irrational and obviously unsafe behaviour is the result of the use of an inappropriate evaluative strategy (using distance gap instead of time gap for crossing decisions), or the faulty use of an appropriate strategy (attempting to use time gap for crossing decisions, but somehow failing to assess time correctly). Interestingly, Oxley et al. (2005) speculated about the ability to estimate time-to-arrival (TTA) as one critical factor that might explain age differences. Indeed, there is evidence for age effects in speed or time-to-arrival estimation tasks (Schiff et al., 1992; Scialfa et al., 1991). However, the potential explanatory power of TTA estimates goes far beyond age effects. Although overall TTA estimates are in general less than actual TTA, Schiff et al. (1992) report that the accuracy of TTA estimates increased with increased speed, i.e. TTA estimates were higher for higher speeds than for lower speeds (although still below actual TTA). Similar results have been found by Hancock and Manser (1997), Manser and Hancock (1996) and Sidaway et al. (1996). Thus, the same time gaps might be perceived as larger or smaller depending on vehicle approach speed, which might explain variations in accepted time gap size.

Dommes and Cavallo (2011) are, so far, the only ones who assessed their participants' skill to judge TTA as part of a battery of cognitive tests in their investigation of pedestrians' gap acceptance. Unfortunately, although TTA estimates were investigated in the same simulator environment as gap acceptance, the authors did not directly link the size of the presented time gaps to the respective TTA estimates. Instead, they used the accuracy of participants' TTA estimation as an indicator of their general ability to assess TTA, and found a substantial correlation between the percentage of unsafe street crossing decisions and what they call TTA-estimate distortion. The goal of this paper is to build upon this approach by directly linking participants' individual estimates of TTA to the actual time gaps. This will allow for a direct measure of how the presented time gaps are perceived subjectively. Two experiments were conducted to investigate this relationship. Although both experiments were video based, in Experiment I, scenes from a virtual environment were used, whereas in Experiment II, real world video material was presented. In addition, Experiment II investigated two different age groups to account for the previously reported age effects.

2. Experiment I

In the first experiment, the goal was to establish the basic relationship between pedestrians' individual crossing decisions and their estimate of the length of the presented gaps. More specifically, the influence that vehicle approach speed has on the length of accepted time gaps and the gap size estimate was assessed.

Fig. 1. Example screenshot out of the video sequence.

2.1. Method

2.1.1. Participants

Fifty-three students from Technische Universität Chemnitz took part in this experiment. Thirty-six participants were female and 17 were male, with a mean age of 24.2 years (SD = 4.8). All participants had normal or corrected-to-normal vision. Students received course credits or monetary compensation for their participation.

2.1.2. Material

Using a driving simulation-like tool, short video sequences of a vehicle approaching (see Fig. 1 for an example) at either 30 or 50 km/h (both common speed limits in urban areas in Germany) were created. Instead of designing a scenario lacking any environmental cues (e.g. Seward et al., 2007), participants were provided with environmental stimuli that would be comparable to a real world situation. The sequences were filmed from a pedestrian's point of view. A white line was drawn across the street surface as a reference for participants. Sequences were 3 s long, followed by a blank screen. TTA at the moment the screen was blanked ranged from 1 s to 5 s (in increments of 0.5 s), resulting in nine different time gap sizes. Videos were presented using a projector (projection size roughly $155 \times 110\,cm^2$) to achieve a somewhat higher degree of realism than is possible with a normal computer screen. Participants were seated at a distance of 250 cm from the projection. They viewed exactly the same sequences in both the crossing decision task and the TTA estimation task.

In the crossing decision task, participants were required to indicate whether they would have crossed the street in front of the car or not (at the position of the white line) at the moment the screen was blanked. They were instructed to imagine a normal crossing situation, for example, on their way to work or university—without being in a hurry, but with a clear destination. They indicated their response by pressing one of two designated keys. For the TTA estimation task, participants were instead required to indicate when they thought the car might have crossed the white line. After viewing a video sequence (while the screen was blank), they were instructed to press the spacebar the moment they felt the car would have arrived. The whole experiment was implemented using the E-Prime environment.

2.1.3. Procedure

First, participants became acquainted with the nature of the video sequences. They were presented with some example screenshots and one sequence in order to familiarise them with the overall setting. Then, one of the two different tasks (crossing decision task or TTA estimation task) was explained, followed by three practice trials, before actual performance was measured on the first task. The same procedure (explanation, practice trials and