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

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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.

Keywords: *Pedestrian, street crossing, time to arrival, aging*

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 3,600 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 8,500 cases (Statistisches Bundesamt, 2013). From a recent review of 6,434 pedestrian crashes in Florida (Alluri, Haleem, Gan, Lavasani, & Saha, 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 feet 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 feet 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, Dearnaley and Hansel (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, Papadimitriou, & Theofilatos, 2013), often from

an engineering perspective, with the aim of informing simulations and models of pedestrian behaviour with real life data (e.g. Chandra, Rastogi, & Das, 2014; Kadali & Vedagiri, 2013). As older pedestrians and children have been found to be at greater risk in general (e.g. Jonah & Engel, 1983), and in particular tend to accept more unsafe gaps than other age groups (Connelly, Conaglen, Parsonson, & Isler, 1998; Oxley, Fildes, Ihsen, Charlton, & Day, 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 & Cavallo, 2007, 2009). Others have found the effect of speed on the selection of gaps regardless of age (Oxley, Ihsen, Fildes, Charlton, & Day, 2005), especially when response time was constrained (Lobjois & 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 & 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, Oldak, & Shah, 1992; Scialfa, Guzy, Leibowitz, Garvey, & Tyrrell, 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, Fairweather, Sekiya and Mcnitt-Gray (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.

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 seventeen 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 Figure 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, Ashmead, & Bodenheimer, 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 x 110 cm) 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.

Figure 1. Example screenshot out of the video sequence.

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, measurement) was followed for the second of the two tasks. After measurement, participants provided demographic information via a short questionnaire. The whole experiment was completed in about 15 to 20 min, with the order of tasks counter-balanced for participants.

2.1.4. Analysis. As indices of participants' individual crossing decision behaviour, the mean time gap and the mean distance gap accepted for each participant for both speeds were calculated. As road users are not fully consistent in their behaviour (i.e., they do not always accept gaps larger than a certain critical gap and do not always reject smaller gaps), there is a stochastic element in the decision making process that has to be accounted for (Alexander, Barham, & Black, 2002). Following the example of Lobjois and colleagues (Lobjois, Benguigui, & Cavallo, 2013; Lobjois & Cavallo, 2007, 2009), who used the same experimental approach, this was done with logistic regression. Logistic regression is used to model binary outcome variables, such as the yes/no decision to cross a road,

based on one or more predictors. Each participant's crossing decision pattern at each speed was used to create an individual regression model to predict the probability that a certain gap is accepted for crossing based on either TTA or distance. The TTA / distance at which, according to the individual model, the probability of acceptance was 50% (the transition point of the logistic regression line), was defined as the participant's mean time gap / mean distance gap accepted. The formula used was

$F(x) = 1/1 + e^{-((x-\alpha)/\beta)}$, with *F* interpreted as the probability of a gap being accepted, x being the time/distance gap, and β the slope of the logistic function at point α, the transition point.

The same procedure was used to calculate a "mean subjective time gap accepted". Here, instead of objective time gap size, participants' TTA estimates were used to predict the probability of accepting a certain time gap for crossing. With that approach, it was possible to assess participants' perception of the size of the presented time gaps, as well as the average subjective time gap they would be willing to accept.

For each analysis, the mean value of Nagelkerke's R^2 (Nagelkerke, 1991) - averaged across the values of R^2 for each individual regression model - is reported as an indicator of model fit. The statistic is analogous to the conventional R^2-statistic used in linear regression.

2.2. Results

The data from five participants had to be excluded from the analysis. Two participants produced data that strongly suggested a misunderstanding of instructions (one appeared to accept all the smaller and decline all the larger time gaps for crossing; another one indicated TTA estimates even before the screen was blanked, resulting in negative values). Three other participants did not accept any of the presented gaps; therefore, a calculation of the mean time or distance gap accepted was not possible.

In Figure 2, the individual regression models for all participants for 30 and 50 km/h are displayed (mean Nagelkerke's R^2 = .88). As can be seen, the models for 50 km/h are distributed somewhat

closer to the y-axis, i.e. around smaller time gaps, than those for 30 km/h. Indeed, the calculated mean time gap accepted was smaller when the displayed vehicle was approaching at 50 km/h (M = 2.98 s, SD = 0.78 s) than at 30 km/h (M = 3.57 s, SD = 0.90 s). A paired t-test revealed that this difference was significant, $t(47)$ = 6.12, $p < 0.001$, d = 0.89. The same procedure was followed to assess the mean distance gap accepted (mean Nagelkerke's R^2 = .88). On average, the mean distance gap accepted was 29.71 m (SD = 7.46 m) for the car approaching at 30 km/h, which was significantly shorter than the 41.33m (SD = 10.90 m) at 50 km/h, $t(47)$ = 10.22, $p < 0.001$, d = 1.49.
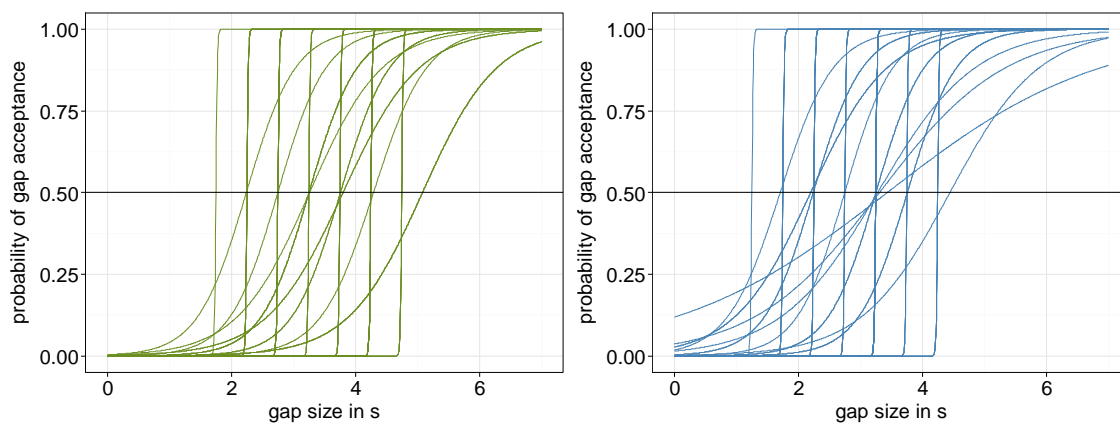

Figure 2. Individual regression models for participants' time gap acceptance at approach speeds of 30km/h (left) and 50km/h (right). Due to the fact that multiple participants showed identical decision patterns, several models are identical as well, and hence overlap in the graph.

As a next step, participants' TTA estimates for the same video sequences were analysed (Figure 3). Participants were in general quite accurate in assessing TTA. However, it appeared that for the 50 km/h condition, there was a slight overestimation of TTA, especially for longer distances. Statistical analysis confirmed this impression. A two-factorial ANOVA revealed a significant main effect of speed, $F(1, 47)$ = 27.54, $p < 0.001$, η^2_p = 0.37, as well as a significant interaction between speed and time gap size, $F(8, 376)$ = 2.04, p = 0.041, η^2_p = 0.04. Of course, the effect of time gap size on the estimated TTA was highly significant, $F(8, 376)$ = 134.86, $p < 0.001$, η^2_p = 0.74.
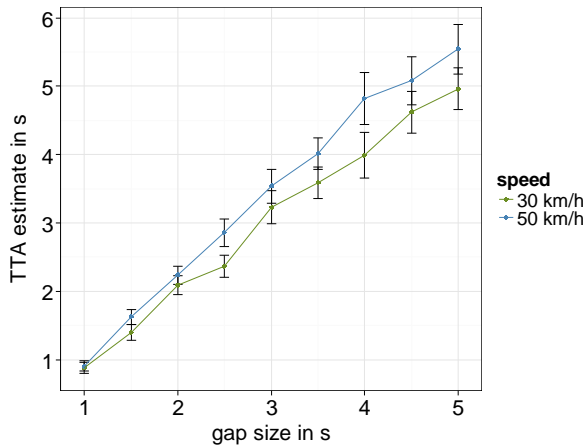
Figure 3. Participants' TTA estimates for the different time gaps at 30 km/h and 50 km/h approach speed.

In a third step, participants' TTA estimates were used to identify the mean subjective time gap accepted. Based on the TTA estimates, individual logistic regression models were calculated to predict time gap acceptance from subjective TTA (mean Nagelkerke's R^2 = .74). In Figure 4, again, all individual regression models for 30 and 50 km/h are displayed. As can be clearly seen, the distribution is now much wider for both speed conditions. However, the difference between the two speed levels all but disappeared. With a mean subjective time gap accepted of 3.80 s (*SD* = 2.37) for 30 km/h, and 3.70 s (*SD* = 2.47) for 50 km/h, they are practically identical, which was confirmed through statistical analysis, $t(47)$ = 0.37, p = 0.711, d = 0.05.
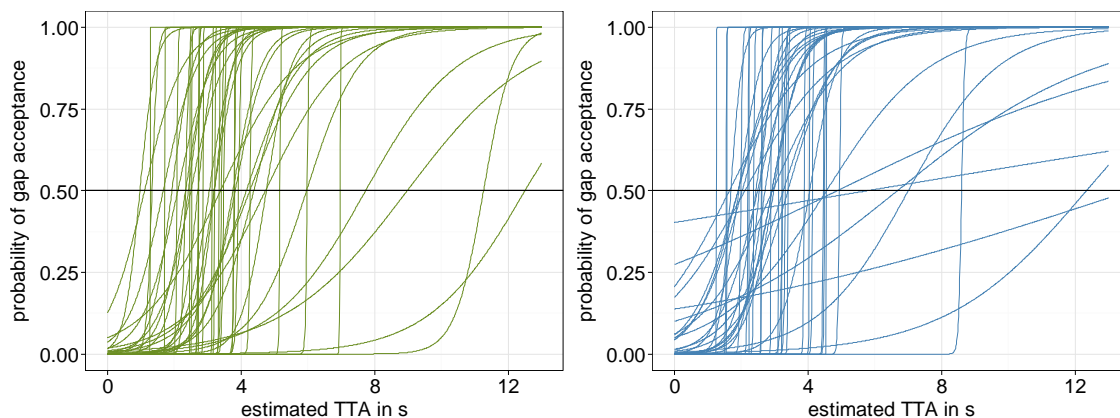

Figure 4. Individual regression models for participants' time gap acceptance at 30 km/h (left) and 50 km/h (right) approach speed based on individual TTA estimate.

2.3. Discussion

From the results in the crossing decision task, it is clear that there is an effect of vehicle approach speed on participants' gap acceptance. At a higher speed, participants chose, on average, smaller time gaps than at a lower speed, a finding that is consistent with the results of e.g. Oxley et al. (2005). At the same time, the results from the TTA estimation task clearly show that TTA at a higher speed was estimated as being longer than the same TTA at lower speed, a finding, again, consistent with previous research (Hancock & Manser, 1997; Sidaway et al., 1996). Taken together, the results from these two tasks provide evidence that subjectively, the size of the mean time gap accepted is about the same for both the higher and lower speed condition. When looking at physical distance, however, the results provide no support for the assumption that gap acceptance was based on vehicle distance. Although the size of the selected time gaps was influenced by approach speed, this effect was even stronger on the size of the selected distance gaps. Although, given the available data, it cannot be ruled out that distance plays a certain role in the size of the accepted gaps, it certainly appears that it is not the primary basis for gap selection.

3. Experiment II

One major shortcoming of Experiment I is the fact that crossing behaviour was only assessed in a group of younger participants. While the results are highly interesting, older pedestrians are a much larger road safety concern. To find out whether the effects found in Experiment I would be similar in a sample of older participants, Experiment II was conducted with two different age groups. In order to investigate whether the effects from Experiment I would be stable across different settings, instead of the virtual environment, participants were presented with real world video scenes.

3.1. Method

3.1.1. Participants. Fourty-four participants divided into two age groups (22 participants each) took part in the study. The younger group was aged 20 to 45 (*M* = 32.4, *SD* = 8.6), the older group 65 to 80

(M = 71.3, SD = 3.7). Twenty-two of the participants were male, 22 female. All participants had normal or corrected-to-normal vision. They received monetary compensation or course credits (student participants only) for their participation.

3.1.2. Material. In contrast to Experiment I, real life video sequences showing a vehicle approaching at either 30 or 50 km/h were created. The video material was recorded on the taxiway (overall width 7.5m, straight, no grade) of a small general aviation airport. The sequences were filmed from a pedestrian's point of view. Sequences were 4 s long, followed by a blank screen. TTA at the moment the screen was blanked ranged from 3 s to 10 s (in increments of 0.5 s), resulting in 15 different TTA values. The change to a higher minimum TTA and a wider range of TTAs compared to Experiment I was introduced as a result of pre-tests with the material (which indicated that most time gaps presented in Experiment I would not be accepted with the new material), and taking into account research indicating that older participants on average prefer larger time gaps than younger individuals (e.g. Lobjois & Cavallo, 2007). Videos were presented using a projector (widescreen projection, size roughly 220 x 125 cm), with participants seated at a distance of 250 cm from the projection.

The experiment was implemented in E-Prime. Again, participants viewed exactly the same sequences in both the crossing decision task, in which they were supposed to indicate whether they would accept a certain gap for crossing, and the TTA estimation task, in which they were required to press the spacebar the moment they felt the car would have arrived at their position.

3.1.3. Procedure. The procedure remained unchanged from Experiment I. Participants received detailed instructions, completed sample trials and experimental trials for both the crossing decision task and the TTA estimation task (counterbalanced), and finally completed the demographics questionnaire. The experiment was completed in about 25 to 30 min.

3.1.4. Analysis. Participants' crossing decisions were analysed the same way as in Experiment I. Objective TTA and distance, as well as estimated TTA were used (separately) in individual logistic regressions as predictors of crossing probability, to again identify the mean time gap, mean distance gap and mean subjective time gap accepted.

3.2. Results

Data from three participants were excluded from the analysis, as the data indicated that the participants did not follow instructions (e.g. providing TTA estimates before the screen was blanked, resulting in negative TTA values).

In Figure 5, the mean time gap accepted for the two speeds and age groups is displayed (based on the individual regression models, mean Nagelkerke's R^2 = .74). As can be clearly seen, participants tended to accept smaller time gaps when the displayed vehicle was approaching at 50 km/h than 30 km/h. Interestingly, at 30 km/h, older participants were much more conservative than the younger group (with a difference of ca. 1.6s), whereas at 50 km/h, the size of the mean time gaps accepted was practically identical. A 2x2 mixed design ANOVA found significant main effects of speed, $F(1, 39)$ = 52.62, $p < 0.001$, η^2_p = 0.57, and age group, $F(1, 39)$ = 6.02, p = 0.019, η^2_p = 0.13, as well as a significant interaction between presented speed and participants age, $F(1, 39)$ = 12.44, p = 0.001, η^2_p = 0.24.
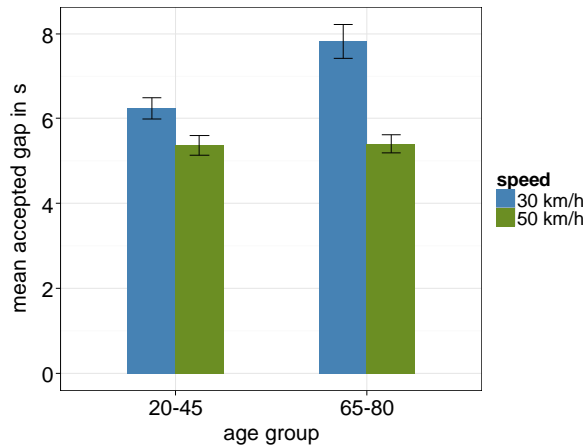
Figure 5. Mean time gap accepted derived from individual regression models for participants' gap acceptance at approach speeds of 30 km/h and 50 km/h

The same procedure was used to assess the mean distance gap accepted (see Figure 6; mean Nagelkerke's R^2 = .74 for the regression models). Approach speed had an obvious influence on the mean distance gap accepted, which was confirmed through statistical analysis, $F(1, 39)$ = 53.94, $p <$ 0.001, η^2_p = 0.58. There was no significant effect of age group, $F(1, 39)$ = 3.82, p = 0.058, η^2_p = 0.09. However, there was a significant interaction between age group and speed, $F(1, 39)$ = 7.89, p = 0.008, η^2_p = 0.17. As can be seen in the figure, although there is clearly an effect of speed on the mean distance gap for the younger age group, this effect is much less pronounced for older participants.
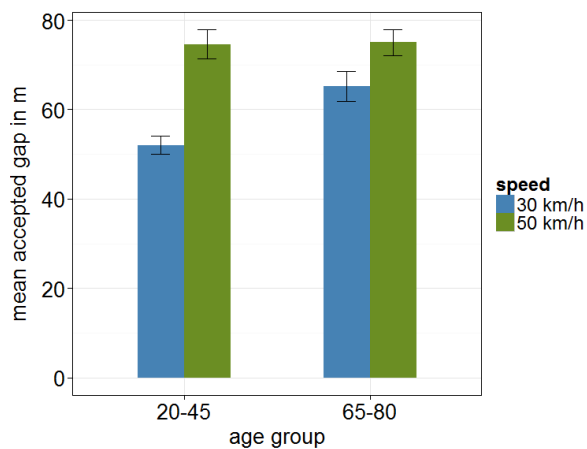

Figure 6. Mean distance gap accepted derived from individual regression models for participants' gap acceptance at approach speeds of 30 km/h and 50 km/h for the two age groups

Participants' TTA estimates were analysed as well (Figure 7). Again, there seemed to be a clear effect of speed on TTA estimates, with TTA estimates at an approach speed of 50 km/h being consistently higher than at 30 km/h. Older participants also appeared to estimate TTA as being shorter than the younger group across approach speed conditions. A three-factorial mixed design ANOVA revealed significant main effects of speed, $F(1, 39) = 78.11$, $p < 0.001$, $\eta^2_p = 0.66$, and age group, $F(1, 39) = 18.73$, $p < 0.001$, $\eta^2_p = 0.32$. Also, the effect of time gap size on estimated TTA was highly significant, $F(14, 546) = 67.46$, $p < 0.001$, $\eta^2_p = 0.63$. In addition, there were significant interactions between age group and time gap size, $F(14, 546) = 5.87$, $p < 0.001$, $\eta^2_p = 0.13$, and speed and time gap size, $F(14, 546) = 1.83$, $p = 0.032$, $\eta^2_p = 0.04$. It appears that with increased time gap size, the effects of age and speed strengthened.
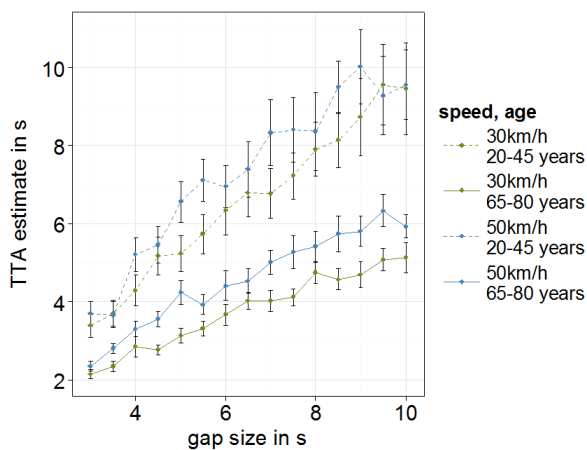

Figure 7. Participants' TTA estimates for the different time gaps at approach speeds of 30 km/h and 50 km/h for the two age groups.

Finally, participants' subjective TTA assessments were used to again calculate the mean subjective time gap accepted (mean Nagelkerke's $R^2 = .53$). As can be seen in Figure 8, the age effect was reversed relative to the effect of age on mean time gap accepted (see Figure 7). While older participants were more conservative in accepting time gaps from an objective point of view, the subjective time gaps they accepted were shorter than those that the younger participants accepted. The effect of speed on gap acceptance was still present; however the effect was much smaller here.

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Statistical analysis confirmed this impression, with significant main effects for age group, $F(1, 39) = 8.42$, $p = 0.006$, $\eta^2_p = 0.18$, and speed, $F(1, 39) = 4.14$, $p = 0.049$, $\eta^2_p = 0.09$. Notably, the effect size of speed decreased to less than a sixth of the original effect size when objective gap size was used as the reference. There was no interaction between age group and speed, $F(1, 39) = 0.40$, $p = 0.530$, $\eta^2_p = 0.01$.
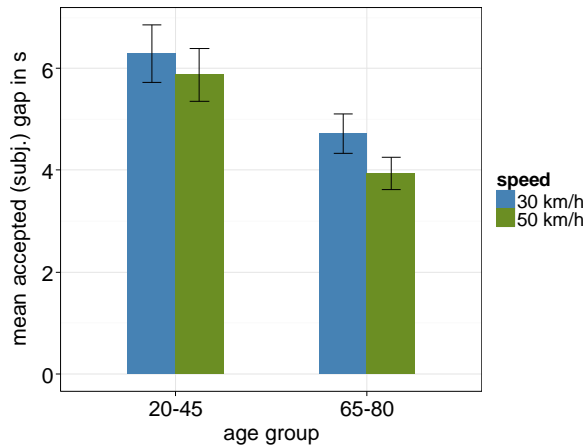

Figure 8. Mean subjective time gap accepted derived from individual regression models for participants' gap acceptance at approach speeds of 30 km/h and 50 km/h for the two age groups, based on the individual TTA estimate.

3.3. Discussion

The results from Experiment II largely confirm the findings from Experiment I. Again, the effect of speed on the size of the mean time gap accepted was found, regardless of age group. This effect was stronger for the older participants, confirming previous findings that older pedestrians appear to rely more on distance for their crossing decisions than younger pedestrians (Lobjois & Cavallo, 2007). On average, younger participants accepted smaller time gaps than the older group. The effect of speed on TTA estimates was also identical to Experiment I. A higher approach speed resulted in consistently higher TTA estimates. Here, the older participants tended to estimate TTA lower than the younger age group across approach speed conditions. When combining these results to assess the subjective size of the accepted time gaps, the effect of speed again was substantially diminished; however, it

did not completely disappear. Interestingly, although there was an interaction between speed and age for both mean time and distance gap accepted, there was no such interaction for subjective time gap accepted. This can be interpreted as a strong indicator that the frequently observed stronger effect of speed on gap acceptance in older pedestrians is the result of specific problems for this group with TTA estimation.

4. General discussion and conclusions

Two experiments were presented that assessed the relationship between pedestrians' gap acceptance and their estimation of time to arrival (TTA) of approaching vehicles. Both experiments were able to replicate common findings in this field. Participants tended to accept smaller time gaps when the vehicle was approaching at higher speed, with younger participants accepting smaller time gaps than older participants. At the same time, participants provided lower TTA estimates when the vehicle was approaching at a lower speed. When linking TTA estimates to crossing decisions, it became clear that the effect of speed on accepted gap size might be primarily attributable to variations in TTA estimates.

It is still unclear whether the effect of physical distance on gap acceptance is merely a by-product of the effect of TTA estimates, or if perhaps the TTA estimates are based upon physical distance. In TTA literature, the effect of speed is usually not framed in terms of "lower vs. higher estimates", but rather as "lower vs. higher estimate accuracy" (e.g. Manser & Hancock, 1996). A potential explanation is that at higher speed, there is a higher rate of optic flow, which could allow for more accurate TTA estimates (Sidaway et al., 1996). The existence of this phenomenon provides strong evidence against the argument that the determining factor is physical distance. However, an empirical assessment of the question is extremely difficult, because of the direct links between TTA, speed and distance.

Regardless of the actual causal relationship, this pattern of effects clearly indicates that potentially risky crossing behaviour cannot easily be modified. The repeatedly reported finding that pedestrians appear to rely on physical distance in order to make crossing decisions cannot simply be attributed to the use of an unreliable heuristic or inappropriate strategy. Rather, the distortion in TTA estimates allows for the possibility that pedestrians simply lack the correct information that they need to make a better decision. Even if participants used the appropriate strategy (rely on TTA), the systematic errors in TTA estimation would result in more unsafe decisions at higher vehicle approach speeds.

It has to be noted that the gap acceptance task used in the two experiments was somewhat artificial. Participants did not actually cross a road, real or virtual. They were seated comfortably in front of a projection and indicated their decisions by pressing a button. Lobjois and Cavallo (2009) as well as Te Velde, van der Kamp, Barela and Savelsbergh (2005) have shown previously that in a more realistic task setting (actual crossing), crossing decisions are usually more conservative compared to a setting in which intent to cross is assessed. A more "natural" experimental environment would certainly be a valuable extension of the research presented here. However, it also must be emphasised that for the research questions addressed in this paper, the absolute size of the accepted gaps is only of secondary relevance. The main interest does not lie in the assessment of how safe the selected gaps would be, but rather how this selection occurs. The fact that results from previous research were reliably replicated supports the overall validity of the approach. It can therefore be assumed that although the absolute size of the chosen gaps must be viewed with caution, the general findings on the relationship between gap acceptance and TTA estimation are valid.

Additional experiments are required to further explore the relationship between pedestrian gap acceptance and TTA estimation. A reasonable manipulation appears to be the variation of presentation time. Based on the assumption that TTA estimation becomes more difficult with shorter presentation times (which might be analogous to shorter glances towards the roadway to take a crossing decision), the question is whether an eventual decrease in TTA estimation accuracy is

accompanied by comparable effects on gap acceptance. Furthermore, the relationship between vehicle type/size, gap acceptance and TTA estimation seems worthwhile to investigate. Previous research has found an effect of object size on estimated TTA and on the size of accepted gaps (see DeLucia, 2013 for an overview). Again, however, it is unclear if the effect on TTA is directly related to the effect on gap acceptance, or if additional factors (e.g. perceived threat, ease of collision avoidance manoeuvre if required) come into play.

Another aspect that merits further investigation is the role that speed plays in crossing decisions. The experiments reported in this paper, as well as most previous studies (Lobjois et al., 2013; Lobjois & Cavallo, 2007, 2009), have used approach speeds that are typical in urban environments, i.e. between 30 and 60 km/h. Dommes and Cavallo (2011) included a 70 km/h condition as the maximum speed. However, especially in developing countries, walking is often the primary mode of transportation and is not limited to urban areas (e.g. Gough, 2008). Pedestrians cross freeways on a regular basis (Cable, 2013), where they must contend with vehicles travelling at speeds well beyond 100 km/h. Whether crossing decisions and TTA judgments under such conditions follow the same patterns observed here is at the very least questionable. Answers to these questions might help to shed some more light onto the relation between pedestrians' perception of traffic situations and their subsequent behaviour, and can provide vital information for the development of road safety measures.

5. Acknowledgments

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