Pedestrians' overt attention affects time-to-arrival estimates of oncoming traffic

Jennifer Sudkamp, David Souto

Department of Neuroscience, Psychology and Behaviour, University of Leicester, UK

Corresponding author:

Jennifer Sudkamp

College of Medicine, Biological Sciences & Psychology

University of Leicester

University Road, Leicester, LE1 7RH, UK

+44 (0)116 229 7184

Email address: js993@leicester.ac.uk

Abstract

To navigate safely, pedestrians need to accurately perceive and predict other road users' motion trajectories. Previous research has shown that the way visual information is sampled affects motion perception. Here we asked how overt attention affects time-to-arrival prediction of oncoming vehicles when viewed from a pedestrian's point of view in a virtual road-crossing scenario. In three online experiments, we tested time-to-arrival prediction accuracies when observers pursued an approaching vehicle, fixated towards the road-crossing area, fixated towards the road close to the vehicle's trajectory or were free to view the scene. When the observer-vehicle distance was high, participants displayed a central tendency in their predicted arrival times, indicating that vehicle speed was insufficiently taken into account when estimating its time-to-arrival. This was especially the case when participants fixated towards the road-crossing area, resulting in time-to-arrival overestimation of slow-moving vehicles and underestimation of fast-moving vehicles. The central tendency bias decreased when participants pursued the vehicle or when the eccentricity between the fixation location and the vehicle trajectory was reduced. Our results identify an unfavorable visual sampling strategy as a potential risk factor for pedestrians and suggest that overt attention is best directed towards the direction of the approaching traffic to derive accurate time-to-arrival estimates. To support pedestrian safety, we conclude that the promotion of adequate visual sampling strategies should be considered in both traffic planning and safety training measures.

Introduction

Misjudgments about the motion of other road users can severely compromise pedestrian safety when road-crossing decisions are based on biased motion estimates (Nie, Li, Gan, Xing, Huang & Li, 2021). On the other hand, even the minute eye movements performed spontaneously influence the perception of relevant motion parameters such as the time-to-arrival of an approaching vehicle (Sudkamp, Bocian & Souto, in press). Eye tracking studies investigating gaze behavior in road-crossing demonstrate that visual exploration varies with individual factors of a pedestrian (e.g., age) and the visual composition of the road environment (e.g., type of intersection; see Lvque, Ranchet, Deniel, Bornard & Bellet, 2020 for a review). Yet, little focus has so far been given to the question of how visual exploration affects pedestrians' motion perception in road-crossing. Here, we investigate how overt attention, i.e., visual attention indicated by gaze allocation, affects pedestrians' time-to-arrival estimates by contrasting prediction accuracies of a vehicle's arrival time when observers either pursue the approaching vehicle or fixate along the road.

Generally, the retinal periphery has been found to be less sensitive towards time-to-arrival information than the fovea (Manser & Hancock, 1996; Regan & Vincent, 1995). Consistent with this, observers appear to rely more on heuristics and less on invariant time-to-arrival cues, e.g., the ratio between a target's angular size and rate of expansion called tau, when judging the time-to-arrival of peripherally viewed targets, which may increase their susceptibility to perceptual biases (see DeLucia, 2014 for a review). Conversely, tracking a moving target, naturally achieved via smooth pursuit eye movements, keeps the target foveated, stabilizes its image on the retina and increases the visual acuity with which an observer can sample its visual features. Through the efference copy of the oculomotor signal, pursuit eye movements moreover provide an extra-retinal motion signal supposedly aiding the

extrapolation of its motion trajectory (see Spering & Montagnini, 2011 for a review). Previous studies using abstract motion stimuli show that time-to-arrival estimates are more accurate when observers pursue a moving target instead of directing gaze towards its arrival location: When motion is presented on the frontoparallel plane, observers underestimate the time-to-arrival of slow-moving targets more when fixating the arrival location compared to pursuing the target (Bennett, Baures, Hecht, & Benguigui, 2010). For motion in depth, a similar tendency has been observed, resulting in a generally higher prediction accuracy during pursuit (Matsumiya & Kaneko, 2008).

Although overt attention towards a moving target seems to be favored for accurate time-to-arrival prediction, in a more complex and dynamic traffic environment, different visual elements compete for visual attention. Pedestrians may thus not continuously pursue the approaching traffic, but instead direct overt attention towards other areas of the visual scene. Using a mobile eye-tracking methodology in a real road environment, only around 65% of all fixations have been found to land on approaching vehicles while pedestrians stand at the curb of an unsignalized crossing, i.e., a crosswalk at which pedestrians are not guided by traffic light signals (Geruschat, Hassan & Turano, 2003). Other areas of visual exploration include the roadway, road-crossing elements and the general road environment. At a signalized crossing, the average number of fixations registered onto vehicles has been found to be even lower at 39% (although this proportion increased to about 50% for pedestrians crossing the road while disregarding the traffic light signal). Comparing visual exploration across different age groups, an increased tendency to direct attention away from the approaching traffic has been observed for children and older adults especially. Children show higher levels of gaze dispersion compared to adults in visually complex road environments (Tapiro, Oron-Gilad & Parmet, 2020), direct gaze more often towards visual elements considered irrelevant for road-

crossing (Biassoni, Bina, Confalonieri & Ciceri, 2018) and spend more time looking at the central region in front of them instead of the direction from which the vehicles approach (Tapiro, Meir, Parmet, & Oron-Gilad, 2014). Similarly, older pedestrians have been found to allocate less overt attention towards the location of approaching vehicles than younger pedestrians, but spend more time sampling central regions, such as the road-crossing area in front of them, which was specifically the case during the last 5 seconds before they initiated crossing (Tapiro, Borowsky, Oron-Gilad & Parmet, 2016).

As discussed earlier, directing visual attention away from the approaching traffic may come at the cost of decreased sensitivity towards relevant motion parameters, and thus may result in biased estimates of the time oncoming vehicles take to reach the crossing point. The present study evaluates this assumption by testing how overt attention influences time-to-arrival prediction of vehicles when viewed from the typical perspective of a pedestrian during road-crossing. To do so, we compare the time-to-arrival prediction accuracy in a simple road-crossing scenario between locations that have been previously identified to be frequently sampled by asking observers to either pursue an approaching vehicle or to fixate along the road. In three online experiments, we presented participants with video sequences of a simulated road scene displaying an approaching vehicle as viewed from a pedestrian's point of view at a zebra crossing. After a fixed display interval (3 seconds), the vehicle disappeared, requiring participants to extrapolate the trajectory of the vehicle. Participants pressed a button to indicate the extrapolated arrival of the vehicle at the crossing area had it continued to drive with a constant speed. To ensure that participants followed the gaze instructions, a secondary discrimination task prompting participants to identify either the location of a flashing headlight (in pursuit trials) or the displacement of a fixation cross overlaying the road (in fixation trials) was added to the task. Based on what has been reported for abstract motion

stimuli, we predicted that observers would be more accurate at predicting the arrival of the vehicle when they pursued its motion trajectory compared to when they fixated towards other areas of the road scene.

In Experiment 1, we assessed time-to-arrival prediction when participants either pursued the vehicle or fixated towards the road-crossing area. As the cognitive load, i.e., the amount of information processing required by the task, has been suggested to affect time-to-arrival perception (e.g., DeLucia & Novak, 1997), a free viewing condition was added in Experiment 2 and compared against the fixation and pursuit conditions to account for the potentially higher cognitive load introduced by the secondary discrimination task. In Experiment 3, we tested the effect of retinal eccentricity between the fixation location and vehicle trajectory by asking participants to fixate on the road-crossing area or on varying locations along the road. Previewing our results, we found that prediction accuracies differed little between gaze conditions when the virtual vehicle-observer distance was short. At higher distances, observers insufficiently adjusted their response times to the speed of the vehicle. This was especially the case when observers directed overt attention away from the vehicles' approach direction resulting in biased time-to-arrival estimates. This effect decreased when the eccentricity between the fixation location and the vehicle's trajectory was reduced.

Experiment 1

Methodology

Participants

Overall, 12 participants (9 female, 3 male) aged 18 – 44 years ($M = 24.42$ years, $SD = 9.23$ years) representing students and staff from the University of Leicester and including the authors DS and JS took part in the experiment. All participants had self-reported normal or corrected-to-normal vision. All experiments herein reported were conducted in accordance

with the principles of the Declaration of Helsinki and were approved by the University of Leicester's ethics committee. Participants had to confirm their informed consent before being able to proceed to the main task of the online experiments.

Stimuli & Procedure

For all experiments, we used the Gorilla online experiment platform (<https://gorilla.sc/>; Anwyl-Irvine, Massonnié, Flitton, Kirkham & Evershed, 2020) to present our stimuli and to collect participants' response data. Video sequences of a vehicle approaching from the right on a single-lane, rural road were created in Unity3D 2018.3.1f1. Figure 1 shows two sample images from the video sequences used in the experiments. Each video was preceded by a black fixation cross displayed on a uniform grey screen for 500 ms signaling either the starting position of the vehicle (pursuit trials) or the fixation position along the road (fixation trials). In each trial, the vehicle then approached the road-crossing area for 3000 ms. After that period, the vehicle disappeared and the static road scene remained visible until participants responded. Participants were instructed to press the space bar on their keyboard when they believed that the car would have arrived at the stopping line had it continued driving with a constant speed. The driving speeds of the vehicle were drawn from a range of 20 to 80 km/h (10 km/h steps). Vehicles were either 15 m (short distance trials) or 65 m (long distance trials) away from the stopping line when they disappeared. This was achieved by varying the starting positions of the vehicles accordingly. The resulting times-to-arrival ranged from 0.68 to 2.70 s in short distance trials and from 2.93 to 11.70 s in long distance trials. The combination of vehicle speeds, distances and gaze conditions resulted in 28 unique trials. Overall, participants performed four repetitions of unique trials resulting in a total number of 112 trials. Vehicle speeds and distances were randomized between trials. Gaze condition order was counterbalanced between participants.

To ensure that participants followed the gaze instruction, they were asked to perform a secondary discrimination task: In pursuit trials, either the left or right headlight of the vehicle briefly lit up. In fixation trials, a fixation cross was displayed on top of the stopping line and the vertical bar of the cross moved to the left or right from its center position. The displacement always appeared after 2400 ms after the vehicle onset and lasted for 500 ms before it was masked by a similar sized rectangle. Pursuit trials employed equal timings for the flashing of the headlight. After estimating the time-to-arrival of the vehicle, participants were prompted to indicate the position of the flashing headlight or cross displacement by pressing the left or right arrow key on their keyboard. For each participant and gaze condition we calculated the percentage of correct discriminations to evaluate compliance with the gaze instructions.

Figure 1. Sample images from the video sequences used in the experiment. The fixation cross and vehicle headlights are highlighted here for visualization. (A) Fixation condition: Participants were instructed to keep their gaze on the fixation cross overlaying the stopping line to monitor the displacement of the vertical bar while the vehicle approached. (B) Pursuit condition: Participants were instructed to keep their gaze on the vehicle and monitor the flashing of the headlight.

Data preparation & analysis

The response error was calculated for each trial as the difference between the response time of the participant and the remaining time-to-arrival of the vehicle at the time

of disappearance. We further derived the inferred vehicle speed for each trial, which we calculated as the distance of the vehicle at the time of disappearance divided by the response time of the participant.

All trials in which participants responded before the vehicle disappeared were removed (0.22% of all trials). After inspecting the distribution of response errors and inferred speeds, we used two fixed criteria to detect and remove outliers: Trials were excluded when the absolute error, i.e., the unsigned response error, exceeded 15 s (0.89% of all trials) and/or when the inferred vehicle speed exceeded 200 km/h (0.15% of all trials, see supplementary material for data distributions).

Evaluating performance on the secondary discrimination task, we found that the average percentage correct discrimination was between 0.88 - 1 ($M = 0.96$, $SD = 0.04$) in the fixation trials and between 0.86 - 1 ($M = 0.96$, $SD = 0.05$) in the pursuit trials, indicating sufficient compliance with the gaze instructions.

Response data were pre-processed in Matlab R2018b (Matlab, 2018) and statistical analyses were performed in the R software environment (R Core Team, 2017) using the *lme4* (Bates, Mächler, Bolker & Walker, 2015) and *lmerTest* package (Kuznetsova, Brockhoff & Christensen, 2017) for linear mixed model analyses.

Results

Figure 2A shows participants' averaged response times plotted against the actual time-to-arrival of the vehicle. For better visualization, we also plotted the inferred vehicle speeds as a function of the actual speed of the vehicle (Figure 2B). These data suggest that there was little difference in participants' response times between the fixation and pursuit condition when the actual times-to-arrival were low, i.e., in short vehicle distance trials. In long distance trials, response times increased with increasing times-to-arrival of the vehicle when

participants pursued the approaching vehicle but remained relatively constant during fixation. In long distance trials and when participants fixated towards the crossing area, the distribution of inferred speeds across actual vehicle speeds indicated that participants adjusted their response times only little to the actual speed of the vehicle.

Figure 2. Response times and inferred vehicle speeds (Experiment 1). (A) shows response times averaged across participants and plotted against the actual times-to-arrival (TTA) of the vehicle. (B) shows inferred vehicle speeds

averaged across participants and plotted against the actual vehicle speeds. For clarity, positions of data points in the inferred speed plots were slightly jittered horizontally. Whiskers depict the 95% confidence interval.

To test how overt attention affected the time-to-arrival prediction accuracy, we fitted a linear mixed-effect model including gaze condition, vehicle speed and vehicle distance as well as their interaction terms as fixed effect predictors to the response errors of each trial. Participants were included as random effects. Contrasts for categorical predictors, i.e., gaze condition and distance, were sum coded so that parameter estimates reflect the deviations from the mean of all data points and comparisons (with pursuit and short distance serving as reference levels) can be interpreted as “main effects”. The speed predictor was centered on its minimum, i.e., 20 km/h, so that the intercept represents the average response error at the lowest presented speed level.

Table 1 reports the parameter estimates of the fixed effect predictors. Both gaze condition as well as speed had a significant effect on the response error. On average, the response error was lower in fixation compared to pursuit trials, indicating that participants responded overall earlier while fixating towards the crossing area. However, in short distance trials, gaze condition had little influence on the response error. Instead, performance differed mainly in long distance trials as indicated by a significant interaction between gaze condition and distance (see also Figure 3). Moreover, the response error increased with increasing vehicle speeds. This was again mainly the case for long distance trials. While the response error remained constant across different speed levels in short distance trials, it increased in long distance trials as reflected in a significant interaction between vehicle distance and speed. The significant three-way interaction between gaze condition, vehicle and vehicle distance suggested that this increase was more pronounced during fixation compared to pursuit trials.

Figure 3. Predicted response errors (Experiment 1). Panels depict the predicted response error by gaze condition, vehicle speed and distance. Shaded areas represent the 95% confidence interval.

Table 1. Effects of gaze, vehicle speed and distance on the response error (LMM analysis, Experiment 1). Contrasts for gaze condition and distance were sum coded. Speed was centered on its minimum (20 km/h).

Fixed Effects	Estimate	SE	<i>t</i>	<i>p</i>
(Intercept)	0.53	0.59	0.90	.387
Gaze (Fixation)	-1.43	0.34	-4.23	.001**
Speed	0.03	0.01	3.42	.006**
Distance (long)	-0.58	0.38	-1.53	.153
Gaze (Fixation) x Distance (long)	-1.16	0.21	-5.63	<.001***
Gaze (Fixation) x Speed	0.03	0.01	4.16	.002**
Speed x Distance (long)	0.04	0.01	7.32	<.001***
Gaze (Fixation) x Speed x Distance (long)	0.02	0.01	4.56	<.001***

Note. * significant at $p < .05$, ** significant at $p < .01$, *** significant at $p < .001$.

Discussion

The results of Experiment 1 suggest that the prediction accuracy was similar across vehicle speeds and independent of whether overt attention was directed towards the vehicle or crossing area as long as the vehicles were close to the zebra crossing i.e., 15m away from the stopping line when they disappeared. In long distance trials, i.e., vehicles disappeared when they were 65m away from the stopping line, the response error increased with increasing vehicle speed. This tendency was more pronounced when observers fixated

towards the road-crossing area compared to when they tracked the vehicle. An evaluation of the inferred vehicle speeds suggests that the increasing response error in the fixation condition could be explained by an insufficient discrimination of the actual vehicle speeds. A central tendency towards the average speed level of our presented stimuli range, i.e., 50 km/h, would result in a similar distribution of time-to-arrival estimates, i.e., underestimation of time-to-arrival for slow vehicle speeds (< 50 km/h) and overestimation of time-to-arrival for faster vehicle speeds (> 50 km/h), which has as well been observed in previous research using abstract motion stimuli (Bennett et al., 2010; Matsumiya & Kaneko, 2008). Nevertheless, the average inferred speed over all actual speed levels was still below 50 km/h, indicating that, beyond little discrimination of vehicle speeds, participants generally responded too late.

Since our experiments were presented online, participants used their own hardware setup to complete the study. A specific control of response latencies and validation of timing accuracies was therefore not possible. An interpretation of the response times in absolute terms should hence be treated with caution (see also Woods, Velasco, Levitan, Wan & Spence, 2015 on timing issues in online experiments). However, a tendency to respond too late to the arrival of a looming stimulus has been documented as well in laboratory studies (Matsumiya & Kaneko, 2008; Rolin, Fooker, Sperling & Pai, 2018) and it could be that the relative scarcity of visual features in our traffic scenario and the lack of stereoscopic cues may have promoted the general underestimation of vehicle speeds resulting from an insufficient compensation for vehicle distance (e.g., Rushton & Duke, 2009).

In addition, we can also not rule out that the dual task procedure, which we employed to ensure that participants followed the gaze instructions, may have added to the cognitive load of the task, and may have thus affected participants' response times by driving attentional resources away from the prediction task and promoting a tradeoff between time-to-arrival

prediction and discrimination (Wickens, 2008). An increased cognitive load has been previously shown to affect time-to-arrival judgements (DeLucia & Novak, 1997) and can as well result in both a delayed response (e.g., Conti, Dlugosch, Vilimek, Keinath, & Bengler, 2012) and an increase of the central tendency bias (e.g., Allred, Crawford, Duffy & Smith, 2016). To examine the effect of the dual task procedure on participants' response times in our traffic scenario, we performed a second experiment to which we added a free viewing condition. The free viewing condition did not employ a secondary discrimination task and allowed participants to freely view the virtual scene without any specific instruction on their gaze location. If the secondary discrimination task affected response times independent of the cued gaze location, we would expect to observe differences in the prediction accuracy not only between the free viewing and fixation condition, but as well between the free viewing and pursuit condition. We tested this assumption in the second experiment. In addition, we aimed at confirming our previous findings, which were gained from a relatively small convenience sample, by increasing the number of participants for our second experiment. Simultaneously, we reduced the number of speed levels to keep the overall lengths of the experiment to a reasonable timeframe for online experiments (around 30 mins) despite the addition of a third gaze condition.

Experiment 2

Methodology

Participants

Overall, 40 participants (31 female, 9 male) aged 18 – 45 years ($M = 19.70$ years, $SD = 4.19$ years), who were undergraduate students from the University of Leicester and received course credit for their participation, took part in the experiment. All participants had self-reported normal or corrected-to-normal vision.

Stimuli & Procedure

We used the same virtual scenes as described in Experiment 1. We added a free viewing condition to the experiment, in which participants were instructed to freely view the virtual scene and no specific instruction on gaze position was given. The free viewing condition did not employ a secondary discrimination task. The instructions and discrimination tasks for the fixation and pursuit condition were the same as in Experiment 1, in which participants were asked to either track the approaching vehicle and discriminate the direction of a flashing headlight or to fixate towards the road-crossing area and discriminate the displacement of the fixation cross.

We reduced the number of speed levels to low (30 km/h), medium (50 km/h) and high (70 km/h). The combination of vehicle speeds (low, medium, high), vehicle distances (15 m, 65 m) and gaze conditions (fixation, pursuit, free viewing) resulted in a total number of 18 unique trials. Participants performed 4 repetitions of unique trials resulting in a total number of 72 trials. The vehicle speed and distance were randomized between trials. The gaze condition order was counterbalanced between participants.

Data Preparation & Analysis

The data from one participant was removed from further analyses due to the percentage of correct discrimination during the fixation condition not substantially exceeding chance level (54% correct), raising concerns about the compliance with the gaze instructions. One participant reached 0% correct discrimination during pursuit trials. This was likely due to the participant judging the direction of the headlights from a driver's perspective sitting inside the car instead of judging the direction from an external observer's perspective facing the car. As the discrimination was nevertheless reliable in terms of being correct when accounting for the different perspective (we would otherwise expect around 50% correct if the participants

had guessed) and the participant also reached 100% correct discrimination during fixation trials, it suggested that the participant had correctly followed the gaze instructions. We therefore included this participant and transformed the respective discrimination performance to 100% correct. For all participants included in the experiment, the average percentage correct discrimination was between 0.63 - 1 ($M = 0.92$, $SD = 0.10$) in the fixation trials and between 0.83 - 1 ($M = 0.97$, $SD = 0.04$) in the pursuit trials.

Overall, 1.7% of trials were removed due to participants responding before the vehicle disappeared or due to technical errors during the display of the videos. The remaining trials were filtered for outliers by removing trials in which the absolute error exceeded 5000 ms (3.44% of all trials) and/or the inferred speed exceeded 200 km/h (1.98% of all trials).

We adjusted our analysis according to the reduced number of speed levels and performed a repeated measures ANOVA instead of a linear mixed model to investigate the effects of gaze condition, vehicle speed and distance on the response error.

Results

Figure 4 shows participants' averaged response times and inferred vehicle speeds. Again, the data suggests little differences between gaze conditions in short distance trials. In long distance trials, the increase of participants' response times with increasing times-to-arrival of the vehicle was more pronounced during the pursuit and free viewing conditions compared to the fixation condition.

Figure 4. Response times and inferred vehicle speeds (Experiment 2). (A) shows response times averaged across participants and plotted against the actual times-to-arrival (TTA) of the vehicle. (B) shows inferred vehicle speeds averaged across participants and plotted against the actual vehicle speeds. For clarity, positions of data points in the inferred speed plots were slightly jittered horizontally. Whiskers depict the 95% confidence interval.

We performed a three-way repeated measures ANOVA to investigate the effects of gaze (free viewing, fixation, pursuit), speed (low, medium, high) and vehicle distance (short, long) on the response error (Figure 5). A significant main effect of speed ($F(1.61, 54.7) =$

199.42, $p < .001$, $\eta^2 = .85$) indicated a tendency for the response error to increase with increasing vehicle speeds. We further observed significant interactions between speed and gaze ($F(4, 136) = 9.80$, $p < .001$, $\eta^2 = .22$), speed and distance ($F(2, 68) = 259.18$, $p < .001$, $\eta^2 = .88$) as well as gaze and distance ($F(1.7, 57.8) = 6.73$, $p = .004$, $\eta^2 = .17$). A significant three-way interaction between gaze, speed and distance suggested that the increase of the response error with increasing speed was mainly due to the long distance conditions and varied between gaze conditions ($F(4, 136) = 11.60$, $p < .001$, $\eta^2 = .25$). To investigate this further we calculated the simple main effects of gaze and speed as well as their two-way interactions separately for long and short distance trials. The simple main effects of speed ($F(1.7, 58) = 262.00$, Bonferroni adjusted $p < .001$, $\eta^2 = .89$) and gaze ($F(2, 68) = 3.86$, Bonferroni adjusted $p = .005$, $\eta^2 = .10$) as well as their two-way interaction were significant at long distances ($F(4, 136) = 12.00$, Bonferroni adjusted $p < .001$, $\eta^2 = .26$), but not at short distances. Next, we calculated the simple main effect of speed in long distance trials separated by gaze condition. In all three gaze conditions, we observed a significant main effect of speed on the response error (Fixation: $F(2, 70) = 149.00$, Bonferroni adjusted $p < .001$, $\eta^2 = .81$, Pursuit: $F(1.58, 56.8) = 78.90$, Bonferroni adjusted $p < .001$, $\eta^2 = .69$, Free viewing: $F(2, 76) = 68.10$, Bonferroni adjusted $p < .001$, $\eta^2 = .64$). Pairwise comparisons indicated that in all gaze conditions all speed levels differed significantly from each other (all Bonferroni adjusted $p < .013$). We also calculated the simple main effect of gaze in the long distance trials separated by speed levels. The results indicated that the differences in the response error between the gaze conditions were significant for low speed trials ($F(2, 68) = 14.30$, Bonferroni adjusted $p < .001$, $\eta^2 = .30$). Pairwise comparisons indicated that the fixation condition differed significantly from the free viewing condition ($p < .001$) and the pursuit condition ($p < .001$), but these differences failed to reach significance on any other speed level.

Figure 5. Response error by gaze condition, vehicle speed and distance. Response errors were averaged across participants. For clarity, positions of data points were slightly jittered horizontally. Whiskers depict the 95% confidence interval.

Discussion

Unlike more complex secondary tasks introduced to explicitly increase cognitive load, e.g., observing multiple moving targets (DeLucia & Novak, 1997), our discrimination task was rather simple and primarily served the purpose of ensuring that participants directed their gaze towards the instructed locations. To nevertheless control whether response times were affected by the employed dual task procedure, we compared the time-to-arrival prediction accuracy with and without adding a secondary discrimination task. Overall, the performance in the free viewing condition, which did not give any specific viewing instruction and did not contain a secondary discrimination task, was very similar to the performance in the pursuit condition. This suggests that the discrimination task per se did not considerably affect response times.

On the other hand, when the discrimination cue was used to direct attention away from the approaching vehicle towards the road-crossing area, we observed a similar trend as already noted in Experiment 1: In short distance trials, the prediction accuracy was similar across vehicle speeds and independent of the gaze condition. In long distance trials, the response error increased with increasing vehicle speeds. This trend was again more pronounced when participants directed their attention towards the crossing area compared to when they pursued the approaching vehicle or were free to view the scene as they preferred. The fixation condition showed the lowest response error for slow speeds and the highest response error for high speeds. Although the differences in the response errors between gaze conditions failed to reach statistical significance on all but the lowest speed level, the general trend resembles the results observed in Experiment 1, in which the fixation condition showed a steeper slope in the transition from time-to-arrival underestimation to overestimation.

Again, the inferred vehicle speeds suggested that participants adjusted their response times only little to the actual speed of the vehicle when vehicles were far away and participants directed attention towards the crossing area. We suspect that this might be due to the visual information content provided by distant vehicles: Due to the vehicles' approach angle, distant vehicles occupied a smaller visual angle and translated more slowly on the retina, resulting in a much reduced motion energy compared to vehicles closer to the observer. The clear differences in retinal motion could explain the observed differences between the short and long distance trials, implying that the reduced sensitivity to speed differences when observers direct attention away from the approaching traffic mainly concerns low retinal image speeds of distant vehicles while the discrimination of higher retinal image speeds of closer vehicles remain relatively unaffected by overt attention. This explanation would be consistent with

previous research demonstrating that differences between foveal and peripheral speed discrimination mainly persist for low retinal speeds while these differences become negligible at higher speed levels (McKee & Nakayama, 1984; Orban, Van Calenbergh, De Bruyn & Maes, 1985).

On the other hand, not only did the vehicle's retinal motion differ for long and short distance trials, but as well the eccentricity between the instructed fixation position and the approaching vehicle. The variation in eccentricity could as well account for the differences in time-to-arrival estimates for close and distant vehicles (Regan & Vincent, 1995), potentially confounding the effects of visual angle and retinal motion. To examine the role of eccentricity for time-to-arrival prediction, we conducted a further experiment in which we moved the fixation cross closer to the vehicle's trajectory. If the observed differences between long and short distance trials were due to the differences in the eccentricity between the fixation location and the vehicle, we would expect smaller differences in the prediction accuracy between the pursuit and fixation condition when the eccentricity between the cued location and the vehicle is reduced. In addition to testing the effects of eccentricity, we aimed at testing whether the results observed in the previous experiments would generalize to a more diverse population. In Experiment 2 we tested a very homogenous sample (in terms of age and level of education). In Experiment 3, we recruited both a student sample and a more diverse sample via an online recruitment platform (<https://www.prolific.co>; Palan & Schitter, 2018).

Experiment 3

Methodology

Participants

For each sample, we recruited a comparable number of participants as in Experiment 2. Overall, 36 students, who received course credit for their participation, were recruited from

the University of Leicester (32 female, 4 male) aged 18 – 21 years ($M = 19.31$ years, $SD = 1.01$ years). Furthermore, 37 participants (17 female, 20 male) aged 19 – 50 years ($M = 31.49$ years, $SD = 8.06$ years), who received payment for their participation, were recruited via Prolific. Eligibility for participation via Prolific required to be currently resident in the UK and to be between 18 – 50 years old. All participants had self-reported normal or corrected-to-normal vision.

Stimuli & Procedure

The procedure of the pursuit condition and the discrimination tasks were the same as in the previous experiments. We used the same vehicle speed ranges (20 to 80 km/h, ± 10 km/h) and end distances (15m or 65m) as reported in Experiment 1. During the fixation conditions, participants were either asked to fixate towards the stopping line (fixation-crossing) or towards a point along the road, which was located at a constant distance from the end position of the vehicle (fixation-road). So, while the eccentricity in the fixation-crossing condition varied with the distance of the vehicles (as in Experiment 1 & 2), eccentricity in the newly added fixation-road condition did not and was overall smaller compared to the fixation-crossing condition.

Note, that the absolute eccentricities also varied between participants due to different monitor sizes of participants' hardware setups. To assess eccentricities for each participant, we asked participants recruited via Prolific to perform an adjusted version of the virtual chinrest task prior to the experiment. The task makes use of a standard sized credit card and participants' blind spot location as references for estimating the monitor size and viewing distance (see Li, Joo, Yeatman & Reinecke, 2020 for further details on the task). Based on the assessment of these values we derived the distance in visual degrees between the fixation cross and the vehicle's end position for each participant and fixation condition. Eccentricities

in the Prolific sample varied between 7.56 to 27.55 deg ($M = 13.67$ deg, $SD = 4.25$ deg) in the short distance, fixation-crossing condition, between 9.36 to 17.61 deg ($M = 16.61$ deg, $SD = 5.34$ deg) in the long distance, fixation-crossing condition and between 3.28 to 12.50 deg ($M = 6.11$ deg, $SD = 1.94$ deg) in the fixation-road conditions.

For the student sample, we used participants' self-estimation of their viewing distance to derive eccentricity. Eccentricities in the student sample varied between 6.44 to 20.83 deg ($M = 12.66$ deg, $SD = 3.20$ deg) in the short distance, fixation-crossing condition, between 8.21 to 26.10 deg ($M = 16.06$ deg, $SD = 3.99$ deg) in the long distance, fixation-crossing condition and between 2.79 to 9.26 deg ($M = 5.53$ deg, $SD = 1.43$ deg) in the fixation-road conditions.

The combination of vehicle speeds, vehicle distances and gaze conditions resulted in a total number of 42 unique trials, each of which were repeated 4 times resulting in a total number of 168 trials. The order of the gaze conditions was counterbalanced between participants and the presentation order of trials within each condition was randomized.

Data Preparation & Analysis

For some participants, we found that the distribution of response errors was unusual in terms of very short response times independent of the actual time-to-arrival of the vehicle. We suspected that these participants either misunderstood the task, responding to the vehicle's disappearance rather than to its arrival or that participants attempted to shorten the experimental completion time by responding as quickly as possible. We used linear regressions to extract the slopes of participants' response times in relation to the actual arrival times of the vehicle and excluded participants with slopes < 0.1 in one or more of the three gaze conditions (2 student participant; 2 participants recruited via Prolific; see supplementary material) as these were unlikely to reflect adequate task performance.

In the student sample, the data of 2 additional participants were excluded from further analyses due to the percentage of correct discrimination not substantially exceeding chance level in one or more of the three gaze conditions ($< 53\%$ correct). For all other participants, the average percentage correct discrimination was between 0.61 – 1 ($M = 0.94$, $SD = 0.07$) in the fixation trials and between 0.91 - 1 ($M = 0.97$, $SD = 0.03$) in the pursuit trials. From the data of the remaining participants, 0.67% of trials were removed from the included datasets due to participants responding before the vehicle disappeared or due to technical errors during the display of the videos. The remaining trials were filtered for outliers using the same cutoff values as in Experiment 1, removing trials in which the absolute error exceeded 15000 ms (0.15% of all trials) and/or the inferred speed exceeded 200 km/h (2.40% of all trials). In the Prolific sample, the data of 2 participants were excluded from further analyses due to the percentages of correct discriminations not substantially exceeding chance level in the fixation conditions ($< 55\%$ correct). For all other participants, the average percentage correct discrimination was between 0.86 – 1 ($M = 0.97$, $SD = 0.04$) in fixation trials and between 0.75 - 1 ($M = 0.98$, $SD = 0.05$) in pursuit trials. A further 1.51% of trials were removed from the included datasets due to participants responding before the vehicle disappeared or due to technical errors during the display of the videos. The remaining trials were filtered for outliers by removing trials in which the absolute error exceeded 15000 ms (2.94% of all trials) and/or the inferred speed exceeded 200 km/h (0.32% of all trials).

Results

Although pointing to overall similar trends, the response times and inferred vehicle speeds suggested that participants in the student sample (Figure 6) responded on average earlier than participants recruited via Prolific (Figure 7). We tested whether the previously observed effects of overt attention generalized to the different samples by fitting a linear

mixed model, in which we included the sample affiliation as an additional fixed effect predictor for predicting the response error in each condition. More specifically, the fitted model included gaze condition, vehicle speed, vehicle distance and sample as well as their interaction terms as fixed effect predictors and random participant effects for all within-subject factors and their interactions, i.e., gaze condition, vehicle speed and distance. As in Experiment 1, contrasts for categorical predictors were sum coded (with pursuit, short distance and student sample serving as reference levels) and the speed predictor was centered around its minimum.

Figure 6. Response times and inferred speeds for the student sample (Experiment 3). (A) shows response times averaged across participants and plotted against the actual times-to-arrival (TTA) of the vehicle. (B) shows inferred vehicle speeds averaged across participants and plotted against the actual vehicle speeds. For clarity, positions of data points in the inferred speed plots were slightly jittered horizontally. Whiskers depict the 95% confidence interval.

Figure 7. Response times and inferred speeds for the Prolific sample (Experiment 3). (A) shows response times averaged across participants and plotted against the actual times-to-arrival (TTA) of the vehicle. (B) shows inferred vehicle speeds averaged across participants and plotted against the actual vehicle speeds. For clarity, positions of data points in the inferred speed plots were slightly jittered horizontally. Whiskers depict the 95% confidence interval.

All parameter estimates of the fixed effect predictors are reported in Table 2 and the predicted response errors from the model are plotted in Figure 8. Besides the predicted response error for the student sample being overall lower than for the Prolific sample, we

found significant interactions between the sample and the remaining factors. Across gaze conditions, the response error in the student sample showed an overall steeper increase with vehicle speed while it increased less with vehicle distance compared to the Prolific sample. Differences between the pursuit condition and the fixation condition, in which participants directed attention towards the crossing area, were less pronounced in the student compared to the Prolific sample.

Evaluating the influence of overt attention on the response error across samples, we observed similar effects as already noted in the previous two experiments regarding the comparison between pursuit and fixation towards the crossing area: The significant interaction between vehicle speed, distance and gaze condition (fixation-crossing vs. pursuit) indicated that the increase of the response error in relation to vehicle speed was more pronounced in the fixation compared to the pursuit condition. Interestingly, this comparison failed to reach significance when the pursuit condition was contrasted against the fixation-road condition, in which the overall eccentricity between participants' gaze location and the vehicle's end position was reduced. Only the interaction with vehicle speed was significant suggesting a steeper increase of the response error with vehicle speed across distances when participants directed attention towards the road compared to pursuing the approaching vehicles. All other comparisons between the fixation-road and pursuit condition did not reach significance, indicating that the prediction accuracy was overall more similar in these two conditions.

Figure 8. Predicted response errors (Experiment 3). Panels depict the predicted response error by gaze condition, vehicle speed and distance in (A) the sample recruited via Prolific and (B) the student sample. Shaded areas represent the 95% confidence interval.

Table 2. Effects of gaze, vehicle speed, distance and sample on the response error (LMM analysis, Experiment 3). Contrasts for gaze condition, distance and sample were sum coded. Speed was centered on its minimum (20 km/h).

Fixed Effects	Estimate	SE	<i>t</i>	<i>p</i>
(Intercept)	-0.38	0.29	-1.30	.197
Gaze (Fixation-Road)	-0.11	0.11	-0.96	.339
Gaze (Fixation-Crossing)	-0.57	0.12	-4.53	<.001***
Speed	0.05	0.00	16.71	<.001***
Distance (long)	-1.09	0.16	-6.90	<.001***
Sample (Prolific)	1.00	0.29	3.42	.001**
Gaze (Fixation-Road) x Distance (long)	-0.13	0.07	-1.92	.058
Gaze (Fixation-Crossing) x Distance (long)	-0.40	0.08	-4.82	<.001***
Gaze (Fixation-Road) x Speed	0.00	0.00	2.18	.032*
Gaze (Fixation-Crossing) x Speed	0.01	0.00	7.25	<.001***
Speed x Distance (long)	0.05	0.00	40.79	<.001***
Gaze (Fixation-Road) x Sample (Prolific)	0.12	0.11	1.05	.296
Gaze (Fixation-Crossing) x Sample (Prolific)	-0.18	0.13	-1.46	.150
Speed x Sample (Prolific)	-0.01	0.00	-3.46	<.001***
Distance x Sample (Prolific)	0.57	0.16	3.59	<.001***
Gaze (Fixation-Road) x Speed x Distance (long)	0.00	0.00	0.80	.422
Gaze (Fixation-Crossing) x Speed x Distance (long)	0.01	0.00	6.10	<.001***
Gaze (Fixation-Road) x Distance (long) x Sample (Prolific)	0.06	0.07	0.90	.371
Gaze (Fixation-Crossing) x Distance (long) x Sample (Prolific)	-0.19	0.08	-2.26	.027*
Gaze (Fixation-Road) x Speed x Sample (Prolific)	-0.00	0.00	-1.01	.313
Gaze (Fixation-Crossing) x Speed x Sample (Prolific)	0.00	0.00	2.10	.039*
Speed x Distance (long) x Sample (Prolific)	-0.00	0.00	-2.96	.004**

Gaze (Fixation-Road) x Speed x Distance (long) x Sample (Prolific)	-0.00	0.00	-0.40	.696
Gaze (Fixation-Crossing) x Speed x Distance (long) x Sample (Prolific)	0.01	0.00	2.75	.007**

Note. * significant at $p < .05$, ** significant at $p < .01$, *** significant at $p < .001$.

Discussion

In Experiment 3, we tested the effect of eccentricity on time-to-arrival prediction. Again, we observed the steepest transition from time-to-arrival underestimation to overestimation in long distance trials when overt attention was directed towards the road-crossing area. When the cued fixation location was moved closer to the vehicle's end position, this transition became shallower and the prediction accuracy became overall more similar to vehicle pursuit indicating that the response errors were not independent of eccentricity. Nevertheless, participants still showed a similar (but weaker) central tendency in their response to distant vehicles. Although in both the fixation-road and pursuit condition the eccentricity between the cued fixation position and the vehicle's end position did not vary between short and long distance trials, participants insufficiently accounted for vehicle speed when vehicles were far away suggesting that the prediction accuracy was not only affected by eccentricity but as well by the informational content, e.g., retinal image speed and angular size subtended by the vehicle.

By recruiting two different samples, we replicated the findings of our previous experiments for a more diverse population. However, besides generally longer response times in the Prolific sample, we found that the differences between gaze conditions were also more pronounced in the Prolific compared to the student sample. Upon further evaluation, we noticed that the derived screen diagonals suggested that participants in the student sample used on average smaller displays for completing the experiment ($M_{Student} = 15.59$ inch, $SD_{Student} = 2.58$ inch; $M_{Prolific} = 17.54$ inch, $SD_{Prolific} = 4.84$ inch, see supplementary material).

Correspondingly, the derived eccentricities between the cued gaze locations in the fixation conditions and the vehicle's end position were as well slightly smaller in the student sample. As we showed that eccentricity affected time-to-arrival prediction in our road-crossing scenario, we suspect that this might have contributed to the overall smaller differences.

General Discussion

The aim of the present study was to examine the effects of overt attention on time-to-arrival estimates of approaching vehicles when viewed from a pedestrian's perspective during road-crossing. In three experiments, we assessed the time-to-arrival prediction accuracy when observers tracked the approaching vehicles, fixated towards the road-crossing area, fixated towards the road in front of the approaching vehicles or were free to view the scene as they preferred. The results showed that overt attention had little effect on the prediction accuracy when the vehicles were close to the observer (15m away from the crossing area). When observers predicted the time-to-arrival of distant vehicles (65m away from the crossing area), the prediction error increased with increasing vehicle speeds indicating a transition from time-to-arrival underestimation for slow moving vehicles to time-to-arrival overestimation for faster moving vehicles. This trend was even more pronounced when overt attention was directed away from the approaching traffic. Especially when overt attention was directed towards the crossing area, observers showed a central tendency in their response times suggesting that they took the speed of the vehicle insufficiently into account when estimating its arrival time.

Using a virtual road-crossing scenario, the current study replicates the findings of previous research demonstrating that keeping a moving target foveated facilitates time-to-arrival prediction. Previous studies showed that prediction errors increase with increasing speed of a target when observers fixate towards its arrival location while it remains relatively unaffected by target speed when observers pursue the target (Bennett et al., 2010; Matsumiya

& Kaneko, 2008). In line with our results, these trends were found to be moderated by distance showing that differences between pursuit and fixation are more apparent at longer times-to-arrival and larger target distances. The findings are considered consistent with the assumption that pursuit eye movements that keep the target foveated provide an extra-retinal velocity signal contributing to the accurate perception of its motion (see also Spering & Montagnini, 2011). In the present study, however, we observed a tendency for response errors to increase with increasing vehicles speeds not only when participants fixated towards the arrival location but as well when participants pursued the approaching vehicle, albeit this tendency was less pronounced during pursuit compared to fixation. We suspect that this might be due to the approach angle of the oncoming vehicles. When standing at the curb in a typical road-crossing scenario, pedestrian view vehicles approaching from an oblique angle. Especially when vehicles are far away, the resulting retinal image speeds remain considerably low (e.g., <1 deg/s for a vehicle driving at 50 km/h at a distance of 65 m from the stopping line). Our results suggest that the benefits of pursuit eye movements for discriminating vehicle speeds based on the extra-retinal motion signal might be limited in such cases. The findings from a previous experiment that accurate (spontaneous) pursuit eye movements provided no measurable benefit neither for speed nor time-to-arrival discrimination in a similar road-crossing scenario support this assumption (Sudkamp et al., in press). The increase of the response error with vehicle speed might have further been aggravated by the design of our road scenario that was relatively scarce on visual features and provided observers with little information on the vehicles' distance.

As noted previously, extra-retinal motion signals are not the only benefit considered to underlie the advantage of pursuit for time-to-arrival perception. Foveating a moving target increases the visual acuity with which an observer can sample other relevant motion cues,

such as the rate of expansion of its retinal image. Generally, discrimination sensitivities and prediction accuracies for time-to-arrival and rate of expansion have been found to decrease with increasing eccentricity of a target from an observer's gaze location (Manser & Hancock, 1996; Regan & Vincent, 1995). In line with this, our results show that the prediction accuracy achieved during fixation becomes more similar to the accuracy achieved during pursuit when the eccentricity between the instructed gaze location and the vehicle's trajectory is reduced. To reduce eccentricity, we placed a fixation cross on the road in front of the approaching vehicle, which was closer to its final position before it disappeared. This area has been shown to be frequently sampled by pedestrians when an approaching vehicle is still far away, while gaze moves upwards and lands on the vehicle itself as it comes closer to the observer (Dey, Walker, Martens & Terken, 2019). Specifically for children and older pedestrians and in visually complex road environments, however, deviations from this exploration strategy have been reported with comparably high visual attention being directed towards the central regions in front of a pedestrian instead of the direction of the approaching traffic (Biaassoni et al., 2018; Tapiro et al., 2014, 2016, 2020). Consistent with previous research, our results suggest that in such cases, observers are likely to draw on the historic average motion parameters when faced with uncertain information due to the reduced perceptual sensitivity, which may result in an over- or underestimation of the actual time-to-arrival that is typical of a central tendency bias (Xiang, Graeber, Enke & Gershman, 2021).

Our study has some notable limitations. While we contrasted time-to-arrival estimates for different gaze locations that have previously been found to be frequently sampled by pedestrians (Lévêque et al., 2020), our simulated scenario was rather simple and deprived of other visual features of the road environment, such as road signage, signals, vegetation and buildings and other road users. In a more complex road environment, we would expect overt

attention to be likely more dispersed than represented by our present scenario. Further research is needed to identify and compare other relevant gaze locations and may as well consider the dynamic nature of visual exploration, which we did not address with our current study design. Moreover, because we presented the videos and prediction task online, we suggest interpreting the absolute response errors with caution. Although previous research can give some indication of the average latencies expected in online experiments (e.g., Anwyl-Irvine, Dalmaijer, Hodges, & Evershed, 2021), participants in our experiments used different hardware and web browsers to complete the study leaving their specific latencies unaccounted for. While this limits the interpretation of the absolute response times, it still allows for a relative comparison of response errors between conditions due to the employed within-subject design. If absolute estimates are of interest, similar experiments could be conducted in the laboratory. Finally, we did not use eye tracking to validate whether participants followed the gaze instructions. Instead, we employed a secondary discrimination task to ensure compliance. Prior to the experiments, we tested on different standard sized monitors that the percentage of correct direction discrimination for the headlight and the fixation cross overlaying the crossing area did not considerably exceed chance level when gaze was directed towards the opposite location (response options included “left”, “right” or “no displacement/flashing”; $N = 3$, Cross: $M_{Fixation} = 0.97$, $M_{Pursuit} = 0.36$, Headlight: $M_{Fixation} = 0.33$, $M_{Pursuit} = 0.97$). Additionally, in Experiment 2, we compared the predictions for a free viewing condition without a secondary discrimination task with the remaining conditions showing that the dual task procedure unlikely affected response times. Overall, our results point towards similar trends as previous studies that did use eye tracking to verify gaze location (e.g., Bennett et al., 2010) providing a further indication that the dual task procedure was successful at

directing overt attention towards the cued positions. Nevertheless, replicating studies may benefit from controlling participants' specific gaze behavior on a trial-by-trial basis.

While limiting our ability to monitor gaze and precisely control response latencies, the use of an online experiment procedure enabled us to test time-to-arrival perception in a relatively large and diverse sample (here specifically in terms of age). The convergence of our results with classical laboratory studies indicates good validity, suggesting that similar online experiments could be a suitable approach to test the role of gaze in different road traffic scenarios. We suggest that similar types of experiments could as well provide a valid methodology to evaluate and enrich educational programs targeted towards teaching safer decision-making and crossing behavior to road users of various age groups (e.g., Dommes & Cavallo, 2012; Oxley, Congiu, Whelan, D'Elio & Charlton, 2008).

In conclusion, in the present study we show that overt attention affects time-to-arrival perception for when it is most relevant for road-crossing decisions, i.e., when vehicles are far enough from the crossing area so that the pedestrian could still potentially cross. Our findings inform that in this case attention is best directed towards the approaching traffic or at close proximity to it. Our data also suggest that directing attention away from the approaching traffic may result in biased motion estimates, identifying an unfavorable visual exploration strategy as a potential risk factor for pedestrians. These findings can provide some explanation for the increased difficulty experienced by children and older pedestrians to make safe road-crossing decisions due to allocating relatively less overt attention towards the direction of traffic. Promoting a more favorable visual sampling strategy could thus be a valuable addition to educational safety trainings. Simultaneously the findings also highlight some important implications for traffic planning, e.g., suggesting that pedestrians may benefit from signs and signals being placed such that they direct attention towards the direction of traffic instead of

away from it. They further highlight the need to strictly enforce speed limits at typical crossing points to avoid risky crossing-decisions arising from pedestrians misperceiving arrival times of vehicles that considerably depart from the average speed level. Continued research evaluating the relation between visual exploration and motion perception in more complex road environments can help gaining a further understanding of the perceptual processes underlying road-crossing decisions as well as informing decision makers about appropriate measures to promote pedestrian safety.

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SUPPLEMENTARY MATERIAL

Experiment 1

Figure S1. Distribution of response errors in Experiment 1. Trials were excluded when the unsigned response error exceeded 15 seconds.

Figure S2. Distribution of inferred vehicle speeds in Experiment 1. Trials were excluded when the inferred vehicle speed exceeded 200 km/h.

Experiment 2

Figure S3. Distribution of response errors in Experiment 2. Trials were excluded when the unsigned response error exceeded 5 seconds

Figure S4. Distribution of inferred vehicle speeds in Experiment 2. Trials were excluded when the inferred vehicle speed exceeded 200 km/h.

Experiment 3

Figure S5. Distribution of response errors in Experiment 3. (A) plots the response error distribution for participants recruited via Prolific. (B) plots the response error distribution for student participants recruited from the University of Leicester. Trials were excluded when the unsigned response error exceeded 15 seconds.

Figure S6. Distribution of inferred vehicle speeds in Experiment 3. (A) plots the inferred speed distribution for participants recruited via Prolific. (B) plots the inferred speed distribution for student participants recruited from the University of Leicester. Trials were excluded when the inferred vehicle speed exceeded 200 km/h.

Figure S7. Fitted regression lines illustrating the relationship between the actual time-to-arrival of the vehicle and participants' response times in Experiment3. Fitted slopes < 0.1 were used as a cutoff value to exclude participants. (A) shows regression lines for the sample average and excluded participants recruited via Prolific. (B) shows regression lines for the sample average and excluded participants from the student sample. Inserts show the frequency distribution of slopes across all gaze conditions. Slopes < 0.1 are marked in red.

Figure S8. Estimated screen sizes of participants' devices in Experiment 3. We used the credit size task described in Li et al. (2020) to estimate screen width and height in centimeters: Participants were asked to place a standard sized credit card on their screen. They then adjusted the size of an image displayed on screen until it matched the overlaid credit card. Screen sizes were then estimated based on the pixel to cm density and screen resolution.