Illusory size-speed bias: Could this help explain motorist collisions with railway trains and other large vehicles?

Clark[a], H. E., Perrone[b], J. A., Isler[b], R. B. & Charlton[b], S. G.

[a]School of Psychology, University of Waikato, Hamilton, New Zealand
[b] Traffic and Road Safety (TARS) Research Group

Abstract

Collisions between motorcars and larger transport vehicles are over-represented in New Zealand's serious crash statistics. These types of collisions include incidents between motor vehicles and trains at railway level crossing junctions, and collisions with vehicles such as long-haul trucks at T-intersections. Errors made in judging a large vehicle's speed could, in part, be attributed to motorists being unknowingly subjected to a size-speed illusion. Previous research has found that humans perceive large objects (e.g. trains, trucks, buses) as moving more slowly than smaller objects (e.g. motorcars) travelling at the same speed. Generally these studies have involved participants viewing approaching stimuli from a stationary position. However, the reasons behind the size-speed illusion remains unknown, and research has not yet determined whether a motorist's self-motion has a bearing on size/speed effects. To investigate these issues we tested observers' relative speed estimation performance for a train and a car approaching at a range of speeds and distances, using psychophysical methods. An eye tracker was also used to provide information about where participants fixated and their pursuit velocities. The data show that participants significantly underestimated the speed of the train, compared to the car. A size-speed illusion seems to be operating in the case of the approaching train in our simulation and may also be a factor in other heavy duty vehicle collisions.

Introduction

The rate of railway level crossing collisions is a high profile issue in New Zealand that has warranted close scrutiny over the last 10 or so years. However, the incidence rate has not decreased (Ministry of Transport, 2004, 2005, 2006, 2007, 2008, 2009, 2010). Worldwide, train/motorcar collisions continue to be a major problem with 468 deaths attributed to vehicle collisions with trains at level crossings in Europe, including Great Britain in 2008 (Rogers, 2010). In the same year the United States recorded 220 deaths (excluding pedestrians and 'other'), with the total number of collisions reaching 2248 (excluding pedestrians/'other' (Federal Railroad Administration Office of Safety Analysis, 2008)). In Australia there were 350 fatalities for the ten-year period 2002-2012 (Australian Transport Safety Bureau, 2012). The issue of collisions between motorcars and larger vehicles is not just confined to trains; around 17 percent of New Zealand's annual road fatalities involved trucks. A high percentage of collisions with these vehicles are fatal (e.g., in 2011, 76 percent of motorcar-truck collisions resulted in fatalities) (Ministry of Transport, 2012). Buses do not feature as highly in road crash statistics but the potential for multiple injuries and/or fatalities with this kind of crash is high.

Research into the possible causes of level crossing collisions in particular have focused on a number of different factors, including aspects of driver behaviour and risk-taking (Leibowitz, 1985; Ward & Wilde, 1996; Wilde, 1994; Witte & Donohue, 2000), attention overload (Wigglesworth, 2001), the effects of good or reduced visibility of the railway track (Ward & Wilde, 1996) and driver 'familiarity' with the crossing (Tey, Ferreira, & Wallace, 2011). More recently, the concept of perceptual errors based on the visual information received by the driver has been considered as a possible contributing factor (Clark, Perrone & Isler 2013). This work was based on an early theory put forward by Leibowitz (1985). He proposed that humans have difficulty correctly perceiving a train's travelling speed, and that this was due to an illusory bias in size and speed – a large object seems to be moving more slowly than a small object, even when the small object is moving at the same speed or, in some cases, even slower (Leibowitz, 1985). Leibowitz formulated this theory after observing moving aircraft, however this theory was not empirically tested at the time, and only limited research has been conducted since.

Cohn and Nguyen (2003) carried out one of the first studies to test the Leibowitz hypothesis by using simple rectangular shapes on a computer screen, and measuring when participants' were first able to detect an increase in the object's size (equivalent to a measure of approach speed). They found that response time increased as the starting size of the object increased, indicating that the larger objects 'appeared' to be moving slower than the smaller objects (Cohn & Nguyen, 2003). Barton and Cohn (2007) found similar results when testing the detection of approach speeds using computer generated spheres. Participants tended to indicate that a larger sphere was approaching more slowly than a smaller sphere; even when the larger sphere was approaching up to 57% faster than the smaller sphere. (Barton & Cohn, 2007). However, both these studies used very simple stimuli and only tested a head-on (straight-ahead) angle of approach.

Clark et al (2013) tested Leibowitz's hypothesis using more realistic vehicle stimuli. They used computer simulations of a freight train and a motorcar to measure velocity estimation of these respective vehicles. They found that observers consistently underestimated the speed of the train compared to the speed of the car, even when the relative speeds were identical (Clark et al., 2013). However, all of these experiments required the participant to view the approaching objects from the same 'stationary' position. The observers' position was set a constant five metres from the intersection junction and the vehicle approaching from the right-hand side (oblique angle). However, many real-life decisions to 'proceed through' occur when the motorist is still approaching the level crossing and the approaching vehicle is viewed from multiple distances away from the crossing.

When viewing an approaching train, the line-of-sight angle to the train when the observer is four metres away from the level crossing is quite different from when the observer is 30 metres away. Since this angle determines the optical speed of the train's image on the retina of the observer's eye, it may play a crucial role in the final perception of the train's speed. Therefore, one of our research aims was to uncover whether or not factors such as the point of observation has an effect on the perceived speed of an approaching train.

Eye movement behaviour

Although it has been shown that larger objects appear to be moving more slowly than small objects travelling at the same speed (Barton & Cohn, 2007; Clark et al., 2013; Cohn & Nguyen, 2003; Leibowitz, 1985), the reasons for this illusion are largely unknown. Leibowitz (1985) proposed that eye movement cancellation mechanisms played a role, with the assumption that larger objects are easier to pursue, due to less effort being required (Leibowitz, 1985). However this theory was never empirically tested, and may be at odds with current theories concerning eye cancellation mechanisms (Wurtz, 2008). We decided to test the role of eye movements in the size-speed illusion and used an eye tracker to measure eye movement behaviour (fixation locations). Therefore our two aims were (1) To test whether or not underestimation of a train's perceived travelling speed (relative to a smaller vehicle) still occurs when the distance to the intersection/junction is altered. (2) Measure and compare the eye movement behaviour that occurs while observers view different sized approaching vehicles.

Method

Participants

Thirty two participants (12 males and 20 females) were recruited from the student population at the University of Waikato, ranging in age from 18 to 55 years of age (M=25.03, SD=9.39). All participants had normal or corrected visual acuity (at least 20/20) and were reimbursed for their voluntary participation by either receiving a 1% course credit for their respective psychology course (first year psychology students only), or by way of a 10 dollar petrol voucher.

Apparatus

All computer simulations were run on a Dell OptiPlex 760 Minitower PC with 3GHz processing speed, running Windows 7 Professional 32 bit SP2, and displayed on a VIEWPixx display (Vpixx Technologies) set at 1920 x 1200 pixel resolution and 60Hz. Eye movement data were recorded using an EyeLink 1000 Desktop System (Eyelink 1000, SR Research, Ltd., Ontario, Canada). A chinrest was used to ensure that each participant's head remained fixed for the duration of the trials.

Stimuli

The simulated vehicles for the experiment consisted of a light blue sedan car and a freight train complete with 16 container carriages. The background setting was typical of a New Zealand rural environment (Fig. 1). The dimensions of the train were 186.00m (length), 2.20m (width) and 3.15m (height). For the car, the corresponding dimensions were 3.80m, 1.80m, and 1.45m.

The rural environment scene which served as the background, and the moving vehicles were created using 3DS Max 2010 32-bit (Autodesk, 2010). In order to create realistic stimuli, photos of real-life scenes and vehicles were rendered onto the 3D meshes underlying the background and the car and train. The field of view of the simulated camera creating the images was 39.6° x 30.2° (horizontal x vertical) and the line of sight of the camera was directed 80° from the straight ahead direction (20° relative to the track/road) in order to simulate looking down the track/road, and to include the maximum length of the train at the start of the trials.

Figure 1. Static image of a motor car and freight train as observed by participant, 6m from the intersection/junction. Images have been cropped and do not represent the full field of view experienced by the participants.

Design

The distance (metres) between the participant and the level crossing entry point/intersection junction was set at either 6m, 18m or 36m. This variation of distance between the participant and the crossing entry point changed the visual angle of the approaching object (measured from front to back). For the 6 metre condition, the calculated angle between the vehicle and the track/road (δ) was 3.43 degrees. For the 18 metre condition δ = 10.20 and for the 36 metre condition δ = 19.80.

The comparison vehicle (motor car) travelled at a constant speed of 80 km/h, while the train's speed was randomised from a pre-programmed set of seven speeds separated by 10 km/h increments (60 km/h, 70 km/h, 80 km/h, 90 km/h, 100 km/h, 110 km/h or 120 km/h). A within-subjects, repeated measures design was used, with all the participants viewing the same simulations (three distance conditions x seven approach speed conditions). Each possible combination of speed and distance was repeated twice in one block of trials. The experiment consisted of three blocks of trials, (126 trials in total). A short break was provided between each block of trials, in which the lights were turned on to minimize potential discomfort and reduce dark adaptation.

In half of the trials ('A' trials - 63 in total) the train and car started in the same position – 100 metres away from the junction, but depending on the approaching vehicle's speed would finish at different positions. For the other half ('B' trials) the vehicles started at different positions, but were all designed to finish at the same end point - 75 metres away from the junction. This randomisation was introduced to prevent participants simply using distance travelled as a judgement of the vehicle's speed. Each individual trial consisted of the same pairings - either 'A' trial vehicles (train and car) were paired together, or 'B' trial vehicles were paired together.

Procedure

To signal the commencement of the trial, the monitor screen went blank. Next, the screen showed the background rural setting with the viewpoint orientated in the direction of the railway track or road and off to the right hand side. On each trial, an animated sequence of an approaching vehicle (train or car) was presented followed (1000 ms later) by a sequence showing the other vehicle type. A response screen was then displayed, containing the question "Which vehicle was faster?" (train vs. car, two-alternative forced-choice procedure). Participants were required to respond by either pressing the right mouse button (if they thought the first vehicle was faster) or the left mouse button (if they thought the second vehicle was faster). The next trial commenced 1000 ms after the mouse press. A blank display screen (uniform grey) was displayed for 1000 ms between each sequence and before the response screen to minimize motion after-effects.

Results

Statistical Analyses

We first calculated each individual's point of subjective equality (PSE). The PSE provides an estimate of the point where the train is considered by the observer to be visually approaching at the same speed as the car. The proportion of 'Train faster' responses were calculated and plotted against train speed (generating a psychometric function) for each trial, and the mean PSEs were extracted from these by fitting a logistic curve (Psignfit toolbox (MatLab R2007b, Mathworks)). The mean PSEs were calculated for each condition for the train and compared to the control variable – a car travelling at 80 km/h.

One sample t-tests were conducted in order to determine whether there was any statistically significant result for perceived speed across either the distance conditions, and the comparison vehicle (μ = 80). Inferential analyses showed that there was a significant difference between the perceived speeds of the vehicles for all three distance conditions. The 6 metre condition was significant (*t(31)* = 3.822, *p* < .01), with a moderate effect size, $\delta = 0.676$. The 18 metre condition was also significant (*t(31)* = 6.171, *p* < .001), with a large effect size, $\delta = 1.091$, and the 36 metre condition was significant (*t(31)* = 6.576, *p* < .001), with a large effect size $\delta = 1.162$. A one-way ANOVA showed that there was no main effect of the viewing distance (6m vs. 18m vs. 36m), (F (2,93) = .638, $p > .05$).

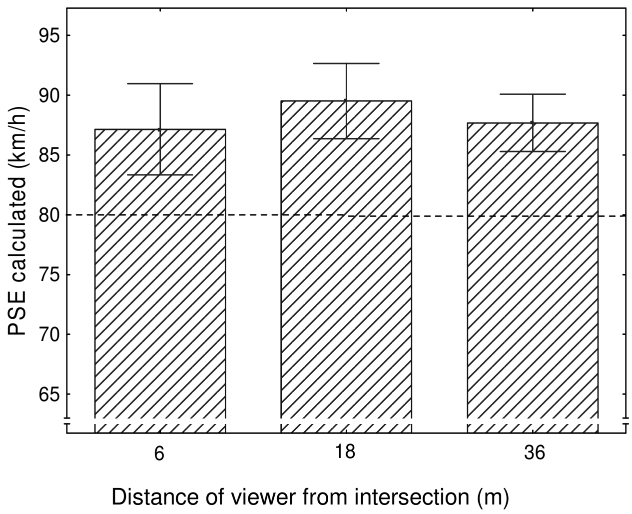

Figure 2. Mean point of subjective equalities (PSE) of train for all participants. PSE is the point at which the train and the comparison vehicle were perceived as identical by the participant. Dotted line represents the comparison car travelling at 80km/h. Error bars represent 95% confidence intervals.

The data show that there were significant differences between the perceived velocities of the train compared to the car in all three distance conditions – the train's speed was underestimated in all three conditions. Out of these, the viewing distance 18 metres from the track had the highest mean percentage of underestimation, with the train perceived as travelling at an identical speed to the car, when it was actually travelling almost 12% faster.

Eye Tracking Data.

X and Y eye positions were analysed and compared against the vehicle image movement on the screen. We calculated from the projective geometry of the simulated scenes, the relative positions for the front of the relevant vehicle and the vehicle's visual centroid (defined below).

For the purposes of this study, we selected the time period 450-500ms into a trial for the main analysis. We found that eye movements had stabilized sufficiently after this time. We will be analysing saccades and 'target overshoot' errors in more detail in later studies. The eye fixations (X,Y) were averaged across trials and the deviations (in pixels) from particular target positions were calculated. Only X position was considered because there was no Y component to the motion of the vehicles (the path was centred on the screen). One analysis considered the deviation from the front of the approaching vehicle and the other analysis took into account the asymmetric shape of objects viewed obliquely. For an elongated object (such as a train), the optical expansion as it approaches is not symmetrical. We considered the option that observers were fixating on a region we termed the 'visual centroid', rather than the front of the vehicles. We therefore carried out an analysis of the eye positions relative to the 'visual centroid' - defined as the weighed vector average of the velocity of the front and the back of the engine (train), or front and back of the vehicle (car).

Graphical analysis of results (see Fig. 3) show that there were significant differences between the eye fixation point on the train and the perfect performance line in all three distance conditions.

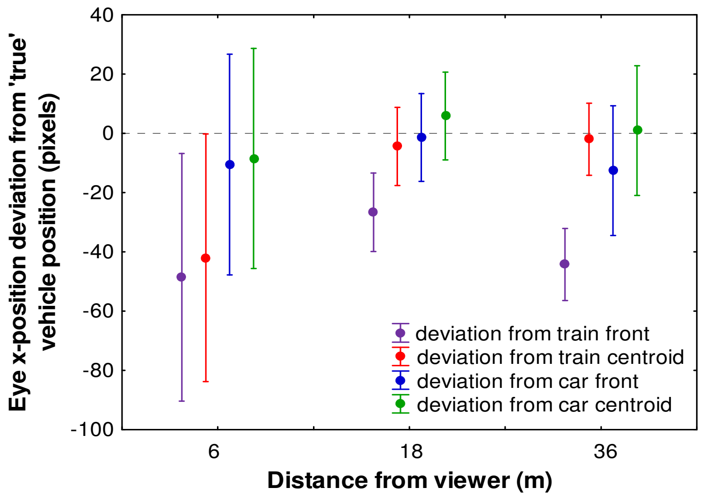

Figure 3. Differences between participants' eye positions and vehicle positions for the time period 450-500ms into a trial. Negative values indicate participants were fixating on regions to the right of (behind) the vehicle positions. Dotted line shows perfect performance line (perfect tracking of a particular part of vehicle). Error bars represent 95% confidence intervals.

As can be seen in Fig. 3, for the larger distances in particular, the participants were more likely to fixate on the centroid of the vehicle rather than the front, and this was more pronounced for the train than for the car. Participants tend to fixate further down the train than its front.

Discussion

Our participants underestimated the speed of the train relative to the car for all distances and so the basic size-speed bias effect first reported in Clark et al., (2013) is confirmed in this current study. The size-speed bias seems to be robust over a range of intersection distances and is not unique to the 5m distance used in the Clark et al., (2013) study.

Our results from Expt. 1 suggest that a possible reason for the size-speed illusion could be related to the eye's fixation position relative to the approaching vehicles. The participants fixate further down the train compared to the car (Fig. 3). In fact they seem to be fixating on a region of the train that has a slower optical velocity (image on the retina) compared to the front of the train or the car. We wondered if these different eye fixations could be causing the slower perceived speed of the larger vehicle (the train). Therefore could we manipulate the size of the illusion by 'forcing' the observers to look at different parts of an approaching vehicle? Specifically, could we prevent the size-speed bias by making the observers look at the front of the train rather than the region where they naturally tend to look (the visual centroid)?

To test this hypothesis we simplified the approaching vehicles and removed all features (colours and textures) except the basic outline shapes. Only the basic perspective shape and motion of the objects were present in the stimuli (Fig. 4). We provided a fixation dot to ensure the observers looked at a particular region of the approaching shapes. Based on our Expt. 1 data, it was expected that the further along the dot was from the front of the 'vehicle', the slower the estimated approach speed. It was also predicted that when participants fixated on the dot placed at the front of the shape, that there would be no significant difference in the estimated velocity between the long shape and the short shape.

Experiment 2

Method

Participants

Nineteen participants (7 males and 12 females) were once again recruited from the student population at the University of Waikato. The sample age range was between 17 and 43 years of age (M=23.79, SD=7.96). All participants had normal or corrected visual acuity (at least 20/20) and were reimbursed for their voluntary participation by either receiving a 1% course credit for their respective psychology course (first year psychology students only), or by way of a 10 dollar petrol voucher.

Apparatus

All computer, eye movement and display equipment were the same as used for Experiment 1.

Stimuli

The stimuli were designed to remove all extraneous visual cues from the environment. Dark grey shapes (boxes) replaced the vehicle stimuli used for Experiment 1 (Fig. 4). In addition, all shadowing was removed in order to minimise the saliency of corner edges. The ‘car’ shape was 3.80m (length) x 1.60m (width) x 1.30m (height) and the ‘train’ shape was 186.00m (length) x 2.18m (width) x 3.15m (height). A white dot (30cm x 30cm in the virtual world) was placed on the car shape at the front. For the train shape, the dot was placed in one of three regions (‘front’ = 0 cm from front, ‘middle’ = 50m from the front, ‘end’ = 180m from the front). The front location was set to be at the same location as the car shape dot.

The background was a light grey colour, with no other stimuli present except for a darker grey horizontal plane which was the same width as the ‘road’ used for the motorcar environment in the first experiment. This was added in order to increase the perspective cues and to help maintain the perception that the objects were ‘moving along a road or track’. The distance (metres) between the participant and the level crossing entry point/intersection junction was set at 18m.

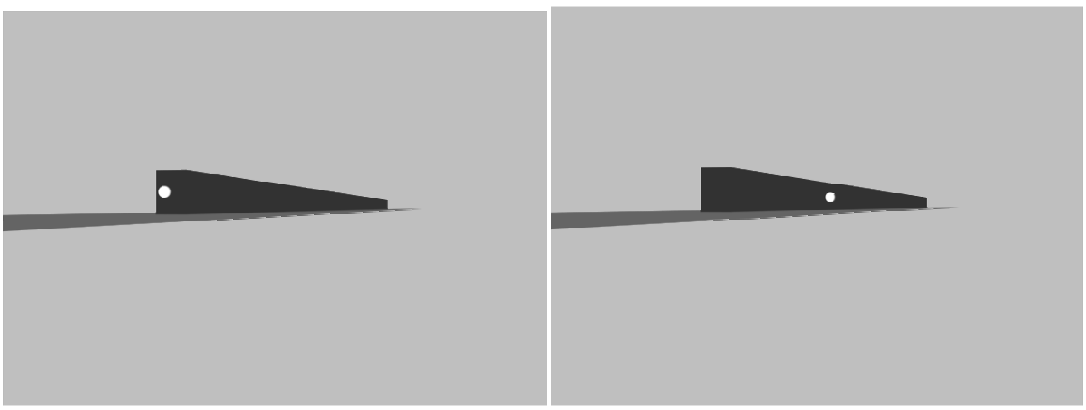

Figure 4. Static image of an ‘abstract’ train shape, 18m from the intersection/junction, with the dot placed at the front and the middle of the shape respectively.

Design

The number of trials and the starting positions for each shape was the same as Expt. 1.

Procedure

Instructions provided to the participant were the same as in Expt. 1, with one addition - the participants were instructed to fixate on the white dot on the box shapes at all times.

Results

Eye Tracking Data Analysis

As the eye position locations were critical to our experimental hypothesis, the (X,Y) eye fixation position data was analysed first. All participant trials were reviewed and compared against the X,Y position of the dot image on the screen. Any trials which showed the participant failing to track to within 2 degrees (97 pixels) of the dot for at least 50 % of that trial were excluded from further analysis. Using this criterion, data from 3 participants were excluded from the analysis below.

Statistical Analyses

As in Expt. 1, the proportion of 'Train faster' responses were calculated and plotted against train object speed and the PSE values extracted from the fitted logistic functions. The mean PSE's were found for each dot position condition. One sample t-tests conducted for perceived speed across against the comparison vehicle (μ = 80) showed that there were significant differences for the 'middle dot' condition ($t(15)$ = 8.592, p < .001), and the 'end dot' condition ($t(13)$ = 3.579, p < .01). The 'front dot' condition was not significant ($t(15)$ = 2.119, p > .05) (Fig. 5).

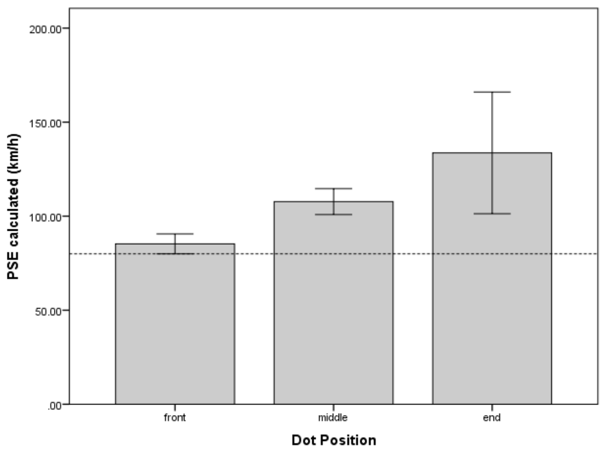

Figure 5. Mean point of subjective equalities (PSE) of abstract 'train' for all participants. Dotted line represents abstract 'car' comparison travelling at 80km/h. Error bars represent 95% confidence intervals.

Discussion

As hypothesised, the data show that there is a significant difference in an approaching object's perceived speed when the eye is fixated on a region other than the front of the object. When our participants were forced to look at the front of both the short (car) and long (train) shapes the size-speed bias was removed (Fig. 5). This suggests that eye movement behaviour may be partly responsible for the illusion where a larger object appears to move slower than a smaller object travelling at the same speed. Our data show that observers tend to automatically fixate closer to an object's visual centroid, which differs according to the size, and the length of that object. On average, this region has a slower rate of image motion on the retina than the front of the object and so it may affect the overall perceived speed of the object.

Conclusion

We have confirmed that there is a size-speed illusion with respect to approaching simulated moving vehicles. In our simulations, large vehicles such as freight trains appear to move slower than smaller vehicles travelling at the same speed. Our results are consistent with earlier studies (Barton & Cohn, 2007; Clark, et al., 2013; Cohn & Nguyen, 2003). We have now verified that the illusion occurs over a wide range of distances of the observer position relative to the road or train track. In addition, we have shown that eye fixations may play a role in this illusion.

It is reasonable to conclude that the results of this study may also apply to other large road vehicles, such as trucks and buses. Large vehicles such as heavy-load trucks approaching T-intersections gives rise to a similar scenario as the level crossing situation we have examined in our experiments. The size-speed illusion is therefore also likely to occur with these vehicles.

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