An investigation into the factors affecting the perception of a train's travelling speed

A thesis submitted in fulfilment

of the requirements for the degree

of

Doctor of Philosophy

in

Psychology

at

The University of Waikato

by

HELEN ELIZABETH CLARK

THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

2017

Abstract

Collisions between cars and trains at railway level crossing junctions continue to occur worldwide, despite efforts to reduce their frequency with educational and practical measures. Many of these collisions occur with car drivers attempting to cross the track in front of an approaching train. The size-speed illusion, first reported by Leibowitz (1985) is a phenomenon whereby larger vehicles appear to move slower than smaller vehicles travelling at the same speed. Clark et al (2013) tested the illusion using laboratory-based experiments, and found that observers routinely underestimated the relative speed of a train, when compared with a smaller vehicle (car). No specific reason for the occurrence of the size-speed illusion has been postulated, but Leibowitz suggested that observer eye movement patterns could be an underlying cause of the illusion.

The aim of this thesis was to investigate how observer eye movement patterns influence the size-speed illusion, and consequently the underestimation of a large vehicle's speed. Experiment 1 tested observers' perceived judgement of simulated trains and cars approaching in depth in a controlled laboratory setting, with eye movements recorded by an eye tracker. Results confirmed the size-speed illusion and eye movement data showed that patterns of saccades, fixations and smooth pursuit behaviours differed in the case of the longer train, with initial saccades being made to a region further from the front of the train.

Experiment 2 and 3 isolated the main types of eye movement patterns that our observers displayed and sought to test whether manipulation of these had an effect on the illusion. Experiment 2 found that manipulating smooth pursuit patterns by placing a target on the front of a long moving object eliminated the illusion. Experiment 3 found that manipulation of fixation and saccadic behaviours with stationary foreground stimuli also reduced the magnitude of the illusion but did not eliminate it entirely.

The final experiment trialled three countermeasures designed to replicate the effects of manipulating eye movement patterns as shown in Experiments 2 and 3. Results showed that the intervention based on manipulation of smooth pursuit (alternating flashing lights on the front of a train) was the most effective in reducing the effects of the size-speed illusion.

Our results indicate that the use of countermeasures which have the effect of changing eye movement behaviour is most effective in reducing underestimations of a train's perceived speed, which, hopefully in future, help reduce level crossing collisions.

Dedication

This thesis is dedicated to the memory of my father

GORDON FRANCIS CLARK

1927-2013

Those we love don't go away

They walk beside us every day

Acknowledgements

A PhD thesis is something that not only encompasses a significant portion of one's life, but also those surrounding people without whom this would not have been possible.

My first thanks and gratitude goes to my chief supervisor Associate Professor John Perrone, who has shown me the way for many, many years. Your patience and support was inspirational and I could not have wished for a better mentor. Thank you also for helping me with the foreign language that is MatLab coding!

A special thanks also goes to both my co-supervisors Associate Professor Robert Isler and Associate Professor Sam Charlton. I acknowledge that I am not the easiest or 'perfect' PhD candidate; however for Robert's kind words and Sam's reality checks, I am grateful, as both have grounded me and pushed me on throughout the years. To all three supervisors, so much thanks for your feedback in both writing and for conferences. I know that if I can get thumbs up from you all, that I have produced a quality piece of work.

To the Psychology technicians, Allan Eaddy, Rob Bakker and Andrew Malcolm, thank you so much for making my ideas a reality, I hope this project was fun for you as well as challenging. Thanks Allan, for giving me all my requested tools, and particularly Rob for being so chilled and encouraging throughout.

I would like to sincerely thank my family, who have been forever patient with the youngest family member's fits and starts. It must be acknowledged that privately, this thesis has spanned the most difficult years for us as a family and I hope that we can remain as strong as ever.

Special mention to friends who have laughed and ranted with me along the way. To my ‘colleague in crime’ Surrey Jackson, I knew you would finish before me! You are an inspiration in how grounded and hardworking you are, which puts me to shame, but has been as much of a driving force for me as anything else. We have been through such a journey together but look how far we have come! Thanks to Clare Browne and Kathleen Doolan as well for the chats, rants and general good times.

Finally I would like to sincerely thank my son Ethan. This piece of work has pretty much been a part of most of your life. I hope that you have benefitted and will continue to benefit in some way from this process, and one day forge your own path in life. You are my shining light in every way.

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Chapter 1. Introduction

"The majority of [level crossing] collisions occur because the driver has made a mistake (didn't look or failed to see the train) or because they thought they could beat the train over the crossing". (TrackSAFE Foundation NZ, 2016).

The prevalence of collisions between motor vehicles and trains at railway level crossing junctions has been a high-profile issue for a number of years in New Zealand. Over the last ten years there has been an average of 22 motor vehicle accidents per year at level crossings, which have involved either injuries or fatalities (Ministry of Transport, 2004, 2005a, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015). Despite improvements in risk management procedures (e.g., upgrading warning protection devices in some areas), and recent efforts to educate drivers of the risk with a comprehensive advertising campaign, there has not been a significant decrease in the number of incidents per year.

While the numbers do not seem high when compared to overall New Zealand road tolls (which range between 366 fatalities to 461 fatalities per year, over the last 10 years), the number of level crossing collisions do account for a high percentage of injuries on railway lines in general. For example, between 1998 and 2004, 29 percent of all railway accidents occurred at, or were associated with level crossing intersections (Ministry of Transport, 2005b). It is also important to note that the impact of a level crossing collision can be far-reaching, and the implications for New Zealand society should not be understated. The most obvious is the tragedy of deaths and injuries which are often preventable. However, there are other potential effects on people who were not those killed or injured. There is emotional trauma for the relatives of the victims, for those who survive a crash, and for witnesses to the accident. Most certainly there is trauma for the train drivers and other crew who suffer emotionally, if not physically. There is even the chance that a train derailment could occur, with potentially disastrous consequences.

Research into possible causes of level crossing collisions have focussed on a number of factors, such as risk taking behaviours, expectations around encountering trains and the motorist's perception of the hazard. Risk-taking has been a prominent theme which can be exacerbated by the motorist's perception that the probability of actually encountering an approaching train at a level crossing is low, therefore information about a 'threat' from an approaching train may be unattended to or ignored altogether (Witte & Donohue, 2000). Level crossing systems are also often designed to the 'worst case' scenario (e.g., the fastest approaching train, the slowest motorist crossing the tracks and the worst weather). The warning system (bells and/or barrier arms) is also set to allow for the fact that a fully laden locomotive with carriages requires a large distance of track in order to brake safely. However, a motorist's perception of the timing of the warning system being activated before the train arrives may be considered as being' too early' and excessively long (Leibowitz, 1985), therefore the motorist may consider disregarding the road laws and proceed through the level crossing, believing that they have plenty of time to do so. Familiarity with the track can often go hand-in-hand with the above, especially in rural settings where locals may feel they 'know when the trains run' (Tey, Ferreira, & Wallace, 2011).

Rural track settings in New Zealand are often set on flat farmland, with long straight tracks running for several kilometres and with few restrictions on visibility. However, good visibility, while usually seen as being less hazardous than restricted visibility, could actually be counterproductive in the level crossing situation. Often motorists tend to be more conservative in their driving behaviour and pay more attention to threats when driving in situations where restricted visibility is an issue. Unrestricted visibility may instead actually encourage potentially more hazardous behaviour on behalf of the motorist, such as approaching at a faster speed or slowing down but failing to stop, particularly if they perceive that there is little threat from a train (Wilde, Hay & Brites, as cited by Ward & Wilde, 1996). Even if there is a train on the tracks, it may be that the motorist believes they have enough time to cross through safely before the train arrives, rather than wait a few seconds (or minutes) for it to pass.

It is possible that errors made in judging a train's arrival could be partly attributed to motorists being unknowingly subjected to a 'size-speed' illusion, which affects an object's perceived travelling velocity. The research presented in this thesis sought to measure the effect of the size-speed illusion on human observers, and by using eye tracking technology, explore the overarching hypothesis that this illusion could be in part explained by differences in observer eye movement patterns when appraising the velocity of small and large moving vehicles.

Chapter 2. The size-speed illusion

2.1. Background

Leibowitz (1985) formulated a theory to explain why humans have difficulty correctly perceiving a train’s travelling speed. He suggested that this illusion in size and speed could be due to the fact that 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. For example, a large aircraft such as a jumbo jet appears to be moving much more slowly than a smaller aircraft, despite the reverse actually being true (Leibowitz, 1985).

Leibowitz postulated his theory but never empirically tested it, and very little follow-up research has been done since that has explored the idea of a size-speed illusion. One such study which did do so was work carried out by Cohn and Nguyen (2003) who tested this apparent size-speed illusion, 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 for computer generated spheres. Participants tended to indicate that a larger sphere was approaching slower than a smaller sphere; even with the larger sphere was programmed to approach up to 57% faster than the smaller sphere (Barton & Cohn, 2007). However, both these studies used very simple stimuli and only tested a direct frontal, head-on angle of approach. Cohn and Nguyen (2003) also noted that while their results supported Leibowitz's hypothesis, the properties of a train are markedly different to the rectangular stimuli used in their experiment. Therefore, they suggested that further research should examine whether their results could specifically apply to trains.

2.2. An illusory size-speed bias and railway crossing collisions

Clark, Perrone and Isler (2013) adopted Cohn and Nguyen's suggestion above, and conducted a series of experiments using a computer simulation of a freight train locomotive (complete with carriages) moving against a background rural environment. The aim was to test observers' judgements of an approaching train's perceived speed, compared to a car. Participants were seated in a laboratory room in front of a computer with a display monitor showing a simulated rural road/railway crossing intersection typical of a New Zealand environment (Figure 2.1). The experimental procedure required participants to make a direct comparison of the two vehicles' speed and to indicate which vehicle appeared to be faster. The vehicles were displayed at three distances along the track or road from the observer. These were 'far' (200m), 'intermediate' (100m) and 'near' (60m) (Figure 2.2). While the observer's 'viewing position' always remained at a distance of 6m from the level crossing, the vehicle's approach would commence from one of three distance points from the observer (randomly selected by the computer programme).

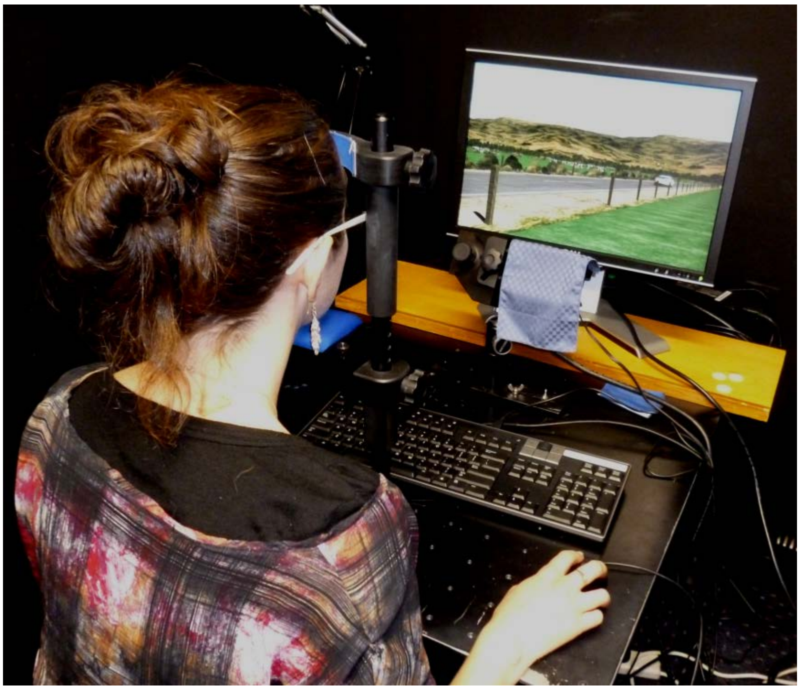

Figure 2.1. Experimental apparatus set up from Clark et al. (2013).

Figure 2.2. Individual frames from Clark et al. (2013) showing examples of the two types of experimental stimuli (train and car) for the ‘near’ condition (60 m down the track/road from the observer).

Results showed that participants significantly underestimated the speed of the train as compared to the car, in both the ‘intermediate’ and ‘near’ conditions. This underestimation was greatest in the ‘intermediate’ condition, with average participant response perceiving a train travelling at 93.3 km/h, appearing to be the same speed as a car travelling at 80 km/h. In reality the train was travelling almost 17% faster. The ‘near’ condition resulted in an average 10% difference between the train and the car, with a train travelling at 87.9 km/h perceived by the participant as travelling the same speed as the 80 km/h car (Figure 2.3).

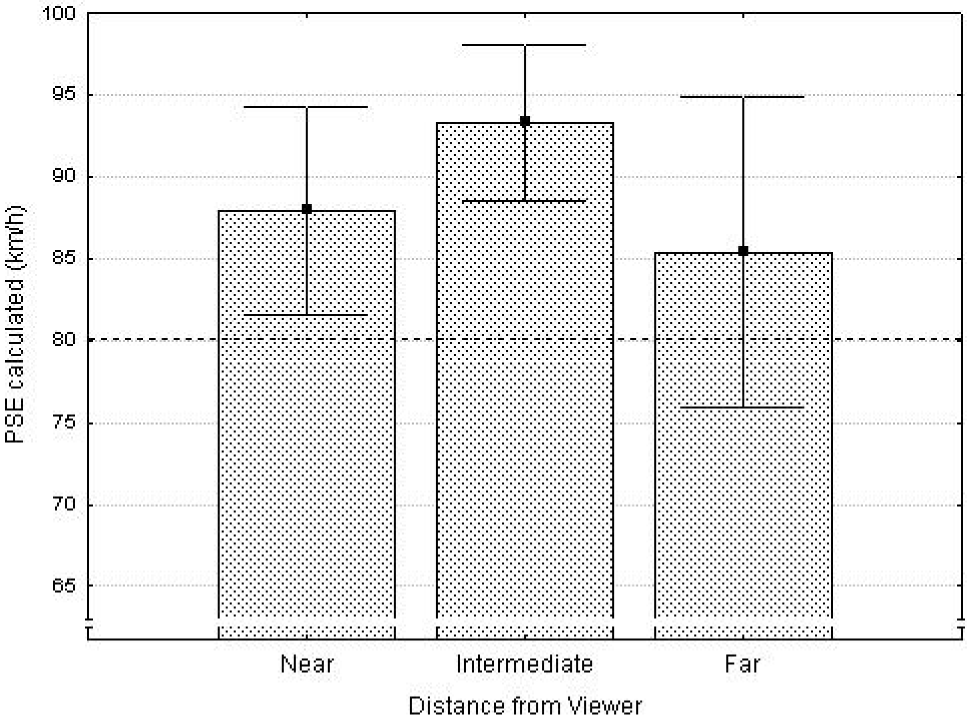

Figure 2.3. Results from Clark et al (2013), which show the mean points of subjective equality (PSEs) of the train for all participants, by distance (near, intermediate, far). Dotted line represents car travelling at 80 km/h. The PSE indicates the point at which the train and car speeds appear identical. PSE values above the dashed line indicate that the train had to be travelling faster than the car in order to appear at the same speed. Therefore the train speed was underestimated relative to the car. Variability bars represent 95% confidence intervals.

Clark et al's (2013) experiment showed a clear effect of the size-speed illusion, with participants consistently underestimating the relative speed of the train, when compared to the car across two of the three conditions tested. While discussing their findings, they noted that very few suggestions had been proposed as to what could be the underlying reason or reasons for this illusion. Leibowitz (1985) himself speculated that a large object requires less of an effort to maintain its form in the foveal region (because it covers a much greater area), and this leads to fewer smooth pursuit eye movements such that the visual system then underestimates the perceived velocity of the object. This theory lacks specifics regarding the nature of the 'effort' and has been largely superseded by current general theories around eye movement cancellation mechanisms (Wurtz, 2008). Therefore, the size-speed effect currently does not have a strong theoretical basis or explanation for why it occurs. A major purpose of this thesis was therefore to address the unanswered questions raised by the results of Clark et al's (2013) speed perception experiment. These questions were in regards to why the size-speed illusion occur; and were as follows: (a) The relationship, if any, between the size-speed illusion and eye movement patterns of observers when they are judging the speed of long objects such as trains; (b) whether there are any differences (either in terms of eye movements, different techniques used, or another unknown factor) between how people evaluate the velocity of larger trains and smaller cars when they attempt to make judgments about that particular vehicle's approach speed; and finally (and most importantly) will (c) answers to these above questions allow for something that can be done to reduce the effects of the size-speed illusion (i.e., if we can uncover a mitigating factor or factors, are we then able to find a way to counteract these?). In order to answer these questions, the experiments in this thesis largely used the same methodology from Clark et al (2013), but importantly eye tracking methods – where an eye tracker was used for the duration of experimental trials - were incorporated in order to test the possible theories for the illusion, first suggested by Leibowitz.

2.3. Thesis overview

This thesis presents data from four experiments that evaluate the role that eye movements play in the size-speed illusion. Three of these experiments (Chapters 3 and 4) have been published in peer-reviewed transportation psychology journals, while Experiment 4 (Chapter 5) is currently under peer review.

The results of the first experiment are presented in Chapter 3. This experiment used a similar methodology and experimental scenario to Clark et al (2013), and had two purposes. Firstly, the aim was to verify whether the effect of the size-speed illusion persists regardless of changes to the angle of the line of sight (by altering one's stationary distance away from the level crossing), and secondly, to measure observer eye movement patterns with an eye tracker in order to discern whether there were differences in eye movements when observers viewed larger, long vehicles in motion (such as trains), as opposed to smaller vehicles such as motorcars. With Leibowitz (1985) suggesting that eye movements could play a role, it was deemed important to include this measure.

Chapter 3 also presents results from Experiment 2, which, following on from the findings of Experiment 1, aimed to isolate a particular pattern of eye movement, known as smooth pursuit. Smooth pursuit occurs when a person is steadily tracking a moving object, without making any of the other types of eye movements (fixations and saccades). The aim of this experiment was to determine whether requiring participants to track specific regions (front, middle or end) of a longer moving object would have an effect on the magnitude of the size-speed illusion.

Experiment 3, covered in Chapter 4 is an experiment conducted with a similar purpose to Experiment 2, in that it was the intention to isolate and investigate the impact of particular eye movement behaviours on the size-speed illusion. However, this time fixation and saccadic (small eye movements (20msec) that occur between fixations) patterns were measured, by adding a fixation marker to the surrounding environment (used in Experiment 1).

All of the above experiments aimed to help resolve questions about whether the factors mentioned have mitigating effects on an observer's perception of a train's travelling velocity. While it is important to identify what types of perceptual errors made by motorists contribute to these collisions, it is also critical that other possible factors are also investigated and interventions are tested. Therefore, the final experiment, presented in Chapter 5 brought together the conclusions of the previous studies in this thesis and sought to use these in order to design and test possible interventions aimed at reducing or even eliminating the size-speed illusion. The findings from Experiments 2 and 3 in particular, as well as previous research around additions to the surrounding environment such as reference markers (Berthelon & Mestre, 1993; Leibowitz, 1955) and reduction of observer lateral visibility (Charlton, 2003; Ward & Wilde, 1996) led to the development of three types of intervention countermeasures, each added to the moving train stimulus from Experiment 1. This experiment was also the only one conducted in a driving simulator (with Experiments 1-3 all taking part in a computer laboratory using a set-up similar to Clark et al (2013)), in order to add ecological validity to an established methodology and to test the translation of the size-speed effect to more realistically sized vehicle stimuli.

In summary, the research presented in this thesis attempted to help explain the reasons behind the unchanging incidence of level crossing collisions, both in New Zealand, and around the world; and, to introduce possible courses of action around education, and additions or changes to current design principles of both railway trains and the surrounding environment of level crossings. The size-speed illusion, possible reasons for it occurring, and ways to counteract it are the focus of the experimental chapters that follow.

Chapter 3. Investigating the role of eye movements in the size-speed illusion of approaching vehicles.

The two experiments in this chapter have been published as a journal article in Accident Analysis & Prevention:

Clark, H.E., Perrone, J.A., Isler, R.B., and Charlton, S.G. (2016). The role of eye movements in the size-speed illusion of approaching trains. *Accident Analysis & Prevention, 86*, 146-154. doi: 10.1016/j.aap.2015.10.028

Abstract

Recent research on the perceived speed of large moving objects, compared to smaller moving objects, has revealed the presence of a size-speed illusion. This illusion, where a large object seems to be moving more slowly than a small object travelling at the same speed may account for collisions between motor cars and trains at level crossings, which is a serious safety issue in New Zealand and worldwide. One possible reason for the perceived size-speed difference may be related to the movement of our eyes when we track moving vehicles. In order to investigate this, we tested observers' relative speed perception of moving objects (both abstract and more detailed objects) moving in depth towards the observer, presented on a computer display and eye movements recorded with an eye tracker. Experiment 1 confirmed first the size-speed illusion when the observers were situated further away (18m, 36m) from the simulated rail crossing or intersection. It also revealed that the eye movement behaviour

of our participants was different when they judged the speeds of the small and large objects; eye fixations were localised around the visual centroid of longer objects and hence were further from the front of the moving large objects than the smaller ones. Experiment 2 found that manipulating eye movements could reduce the magnitude of the illusion. When observers tracked targets (dots) that were placed at corresponding locations at the front of the small object and the long object respectively, they perceived the speeds of the two objects as equal. When target dots were placed closer to the visual centroid, observers perceived the larger object to be moving slower. These results demonstrate that there is a close relationship between eye movement behaviour and our perceived judgement of an approaching train's speed.

3.1. Introduction

The rate of railway level crossing collisions is a high profile issue in New Zealand that has received increased scrutiny over the last 10 years. However, the average incidence rate during this time, 22 crashes per year, has not decreased (Ministry of Transport, 2004-2013). Worldwide, train/motor vehicle collisions continue to be a major problem, with 468 deaths attributed to motor 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), with the total number of collisions reaching 2248 (Federal Railroad Administration Office of Safety Analysis, 2008). In Australia there were 31 fatalities in 2008 alone and 350 deaths in total for the ten-year period 2002-2012 (Australian Transport Safety Bureau, 2012). It is important to note that the impact and related events concerning a level crossing collision, although rare, is potentially catastrophic, and the implications for our society far-reaching in terms of lives affected, health and economic reasons. New Zealand has a large amount of railway level crossings situated in rural areas and these tend to feature prominently in annual level crossing collision statistics. Over 1700 rurally situated level crossings use passive protection devices (crossbucks and other warning signage only) as opposed to the active protection devices (barriers and/or alarm bells) normally reserved for high traffic volume areas.

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). Recently, we have examined the role of drivers' visual perceptual errors as a possible contributing factor (Clark, Perrone, & Isler, 2013). This role of visual perceptual errors was initially suggested by Leibowitz (1985), who, after watching airplanes at an airport suggested that we may have difficulty correctly perceiving a train's travelling speed due to a size-speed illusion – a larger, longer object seems to be moving more slowly than a smaller, shorter object, even when the small object is moving at the same speed or, in some cases, even slower (Leibowitz, 1985).

The role of size-speed illusions in drivers' estimation of train speeds was explicitly tested by Clark et al., (2013) who had participants view simulated trains and cars, and compare the relative velocity of these respective vehicles. We 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). In the experiment the participants viewed the approaching trains and cars from a 'stationary' position 6m (equivalent to the location of a stop or give way line) from a simulated level crossing or intersection, with the train or car approaching from the right-hand side (an oblique angle). Many real-life 'go/ no-go' decisions however, occur when the motorist is approaching the level crossing, therefore this judgment may occur some distance further back from the crossing.

The perspective image of an approaching train is quite different to that of a car, with the front significantly larger than the back. In addition, the line-of-sight angle to the train when the observer is 6m away from the level crossing differs from the perspective angle when the observer is 36m 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.

Although several experiments have shown that larger objects often 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 size-speed illusion are largely unknown. Leibowitz 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 to maintain the image in the fovea (Leibowitz, 1985). However, to our knowledge this explanation has not been empirically tested, and may be at odds with current theories on possible eye movement cancellation mechanisms such as corollary discharge theory, which states that when instructions are issued for the eye muscles to produce a movement, a copy or corollary of those instructions is sent to other regions of the brain to inform them of the impending movement. Motion is perceived when either one or the other signal is received, but is not perceived if both signals are received at the same time (Wurtz, 2008). It is not obvious as to how this eye-movement cancellation mechanism can be differentially affected by large or small moving objects, what impact it has on our perceived speed, or to what degree it is involved in the size-speed illusion.

Based on the above considerations, this current study had two aims: (1) To test whether or not underestimations of a train's perceived travelling speed (relative to a smaller vehicle) still occur when the distance to the intersection/junction is systematically increased. This is undertaken in Experiment 1 as described in the subsequent sections. (2) To investigate the role of eye movements in the size-speed illusion, by examining the eye movement behaviours (fixations, saccades and smooth pursuit) that occur while observers view different sized approaching vehicles, which is undertaken in Experiment 1 and examined more closely in Experiment 2.

3.1.1. Experiment 1

In order to test the above hypotheses, this experiment was designed to measure participants' eye movements, while they were undertaking a speed discrimination task that utilized simulated vehicles.

3.2. Method

3.2.1. 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), held a full driver's license 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 a $10 petrol voucher. All recruitment and test protocols were subjected to, and received ethical approval by the University of Waikato's School of Psychology Human Research and Ethics committee.

3.2.2. Apparatus

All stimuli were presented using a Dell OptiPlex 760 Minitower PC, and displayed on a VIEWPixx display (VPixx Technologies) with a 1920 x 1200 pixel resolution (screen size 48.5cm x 30.3cm) and a refresh rate set at 60Hz. Eye movement data were recorded using an EyeLink 1000 Desktop System (Eyelink 1000, SR Research, Ltd., Ontario, Canada), averaging 0.25° - 0.5° accuracy. A chinrest was used to ensure that each participant's head remained fixed for the duration of the trials and this was located 57cm away from the monitor screen, producing a field of view (FOV) of 40° x 30° (horizontal x vertical).

3.2.3. Stimuli

The simulated vehicles for the experiment consisted of a light blue sedan car, and a freight train with 16 container carriages. The background setting was typical of a New Zealand rural environment. The virtual dimensions of the train were 186m (length), 2.23m (width) and 3.25m (height).   For the car, the corresponding dimensions were 3.81m, 1.65m, and 0.95m respectively.

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 virtual FOV was set to match the screen FOV above, and the line of sight (from the observers point of view) 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 3.1. Sample screenshot of an approaching car and a freight train as observed by the participants, 6m from the intersection or rail crossing. Images have been cropped and do not represent the full field of view experienced by the participants.

The potential confounding factor of the two vehicles having different intensities and colours was controlled for by using the standard colours of a New Zealand freight train and carriages for the train stimuli, and then matching the average luminance of the car image (using a photometer) to the average luminance of the train. A light blue scheme was chosen for the car on that basis (see Figure 3.1).

3.2.4. Design

Three test blocks of 42 trials (total 126 trials) were presented, each with a short break (5 min) between each test block. During each test block the participants viewed an approaching car; paired with an approaching train (the order in which the car or train appeared was randomised). Each stimulus presentation was 1000 milliseconds (msec) in length. During a trial the speed of the car (standard stimulus) always approached at 80 km/h, whereas the train (comparison stimulus) was set to one of seven speeds in km/h (60, 70, 80, 90, 100, 110 or 120) during their 1000 msec presentation. A within-subjects, repeated measures design was used, with all the participants viewing the same simulations (three distance conditions x seven approach speed conditions), with the presentation of trial pairs counterbalanced to eliminate order effects.

The distance between the participant and the level crossing entry point/intersection junction was set at either 6m, 18m or 36m (randomised), producing three different viewing angles of the approaching vehicle. These distances were selected based on the differing appearance of the vehicles from these respective angles (6m acute, 18m oblique, 36m transverse). The calculated angle between the vehicle and the track/road (δ) for the 6m condition = 3.43°, 18m condition δ = 10.20°, and 36m condition δ = 19.80° respectively.

To control for potential confound effects of speed estimates based on distance travelled, or time taken (Clark et al., 2013), the time of each animated sequence was consistent across trials (1000 msec). Start and finish positions of the vehicles were randomised across conditions, to avoid the use of distance as a cue to vehicle speed. In half of the trials ('A' trials- 63 in total) the vehicles started in the same position – 100m up the road/track away from the junction, but, depending on the 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 - 75m away from the junction. Each trial consisted of the same pairings - either 'A' trial vehicles (i.e., train and car) were paired together, or 'B' trial vehicles were paired together.

3.2.5. Procedure

Eye tracking calibration and validation was conducted prior to the start of the experiment, using a 9 point calibration grid. Drift checks were carried out between each trial, with a threshold of <= 2 degrees offset required to proceed. Recalibration was conducted if the participant's head position shifted during the experiment.

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 road or railway track, and off to the right hand side. On each trial, an animated sequence of an approaching vehicle (standard or comparison vehicle) was presented followed (1000 msec later) by a sequence showing the other vehicle type. A response screen was then displayed, containing the question "Which vehicle was faster?" (standard vs. comparison vehicle, two-alternative forced choice (2AFC) 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 msec after the mouse press. A blank display screen (uniform grey) was displayed for 1000 msec between each sequence and before the response screen to minimize motion after-effects.

3.2.6. Statistical Analyses

Firstly, each individual's point of subjective equality was calculated (PSE). The PSE is an estimate of the point where the speed of the train and the car was perceived to be the same by the observer. The proportion of 'Train faster' responses were calculated for each distance condition and plotted against train speed (generating a psychometric function) for each trial. These data were fit with a logistic curve in MatLab (R2007b, Mathworks, Natick, Massachusetts, USA) using the Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997). The returned value at the 50% point of the curve is equivalent to the PSE for that observer. Mean PSEs for all observers were calculated for each condition for the train, and compared to the standard variable – a car travelling at 80 km/h.

One-way ANOVAs were used to determine if there was any statistical difference between observer viewing angle (6m, 18m or 36m) across the train condition, and one sample t-tests were conducted in order to determine whether there was any statistically significant result for perceived speed across each of the distance conditions, compared with the speed of the car (μ = 80).

Eye fixations (X – horizontal co-ordinate position, Y – vertical co-ordinate position) were recorded and X values averaged across trials (there was no Y component to the motion of the vehicles - the path was centred on the screen). 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 closer to the object's centre of mass, rather than the front of the vehicles. We therefore carried out an analysis of the eye positions relative to the 'visual centroid'[1]defined as the

[1]Many articles use the term 'centre of gravity' when referring to a spatially extended object (Vishwanath & Kowler, 2003). This is suitable when referring to a fixed object, however for a moving object, 'centre of gravity' or 'centre of mass' is not necessarily appropriate, due to the non-symmetrical expansion of the image on the retina.

weighed vector average of the velocity of the front and the rear of the train, or front and rear of the standard vehicle (car).

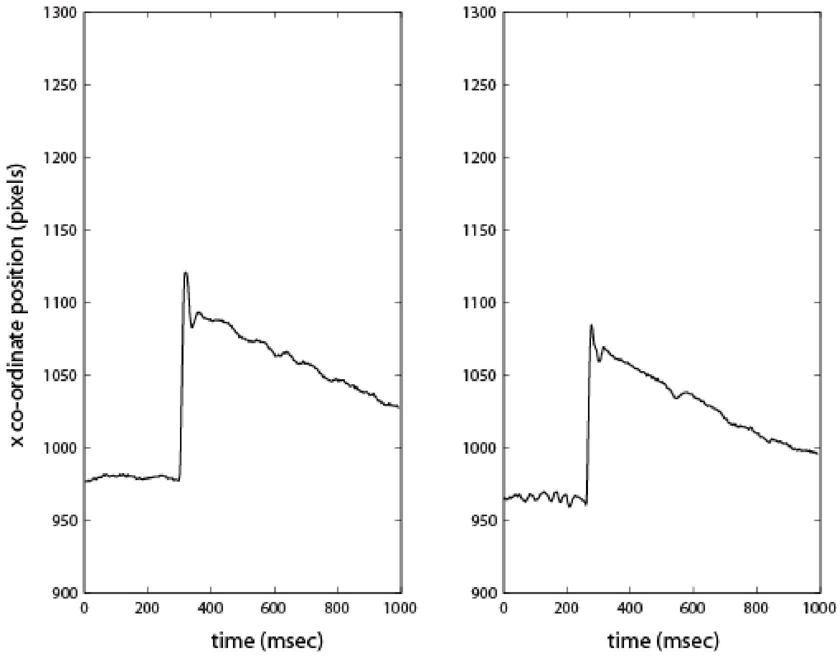

Figure 3.2. Example of an individual participant's x co-ordinate position eye trace for one trial, in the 18m condition. Left graph is the train stimulus and right graph is the car.

3.3. Results

3.3.1. Velocity Estimates

Significant differences were found between the perceived velocities of the train compared to the car across the three distance conditions – the train's speed was underestimated in all three conditions (Figure 3.3).

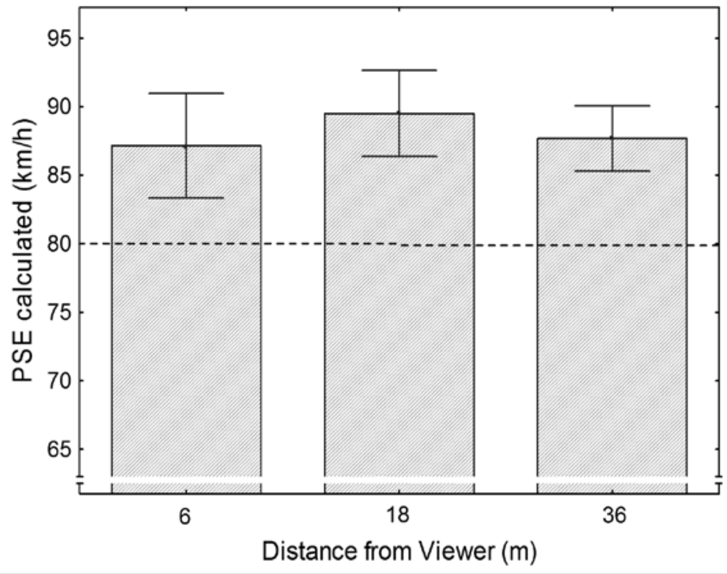

Figure 3.3. Mean point of subjective equalities (PSE) of train for all participants. PSE is the point at which the train and the car were perceived as identical by the participant. Dotted line represents the comparison car travelling at 80km/h. Error bars represent 95% confidence intervals.

Analyses showed that there was no main effect of viewing angle, $F(2,93) = .638$, $p = .531$, however, there was a significant difference between the perceived speeds of the train, compared to the car, for all three distance conditions. The 6m condition was significant ($t(31) = 3.818$, $p = .001$), with a moderate effect size, $d = 0.675$. The 18m condition was also significant ($t(31) = 6.145$, $p < .001$), with a large effect size, $d = 1.086$, and the 36m condition was significant ($t(31) = 6.582$, $p < .001$), with a large effect size, $d = 1.164$.

3.3.2. Eye Movements

In order to look for different patterns of eye movements when observers judged the speed of the train compared to the car, we measured average eye fixation locations relative to a number of key locations on the vehicles. One was the ‘front’ defined as the image location of the nearest edge of the vehicle. Another location investigated was the ‘visual centroid’ of the two vehicles (defined above).

Eye movement analyses showed that there were differences between the eye fixation point on the train and what we termed as the ‘perfect performance line’ (optimal tracking of a particular part of the vehicle) in all three distance conditions (see Figure 3.4). Statistical analyses showed that these differences were significant (6m condition: $t(7) = -2.748$, $p = .029$, $d = 0.972$; 18m condition: $t(7) = -4.773$, $p = .002$, $d = 1.688$; 36m condition: $t(7) = -8.627$, $p < .001$, $d = 3.051$).

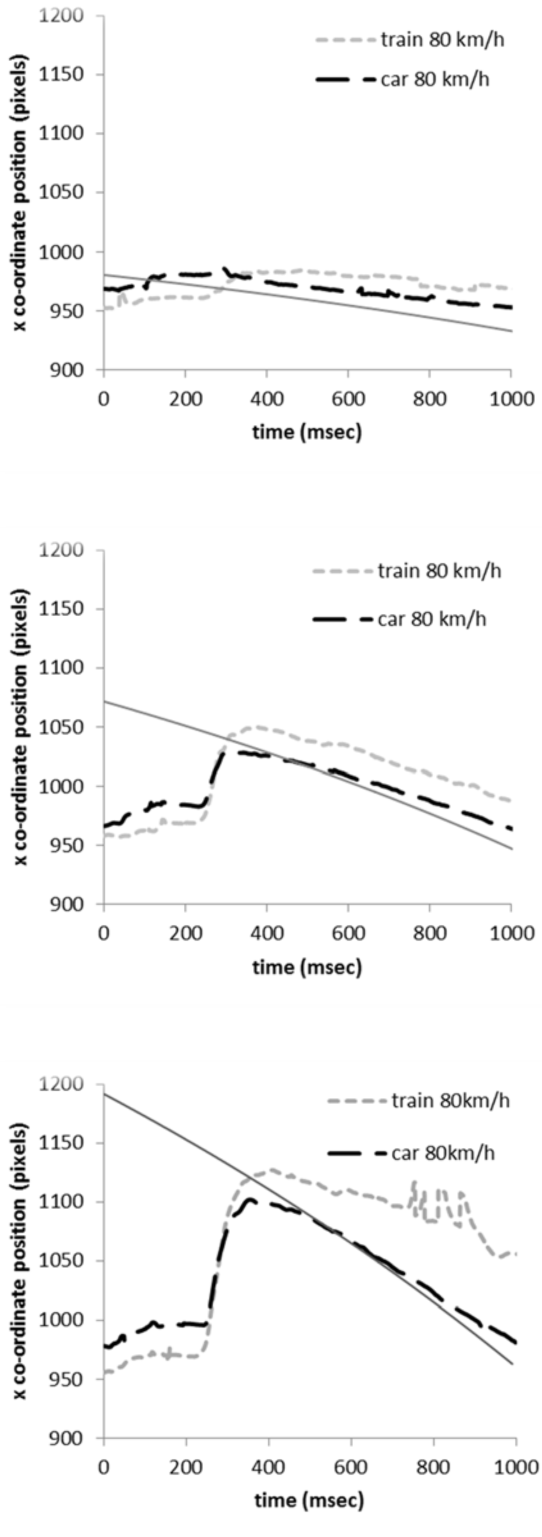

Figure 3.4. Mean x co-ordinate eye position traces for all participants in the 6m (top), 18m (middle) and 36m (bottom) condition, when the train and the car were approaching at the same speed (80km/h). The solid line represents the x co-ordinate position of the front edge of the vehicle over the course of the whole trial.

Figure 3.5. Sample screenshots taken at same temporal and distance location (36m only), showing a typical fixation of a participant on the train and car respectively.

For the larger observer distances in particular (18m & 36m), 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. Our participants tended to fixate farther down the train rather than its front. Because the train's image was so much longer than the car, the net result was that the train was fixated a lot farther from the front compared to the car (Figure 3.5).

3.4. Experiment 1: 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) was confirmed in this current study. The size-speed bias seems to be robust over a range of observer distances from the intersections and is not unique to the 6m distance used in the Clark et al.,

(2013) study, which indicates that the perspective angle to the vehicles is not a crucial factor in the size-speed illusion.

The results from our eye movement analysis suggest that the size-speed illusion could be related to eye movements, particularly where observers fixate an approaching vehicle with their eyes. Our participants fixated farther down the train compared to the car (Figure 3.5). In fact, they seem to be fixating on a region of the train that has a slower optical velocity (image speed on the retina) compared to the front of the train or the car. These different eye fixations could be causing the slower perceived speed of the larger vehicle (the train). The different projected shapes of the vehicles on the retina should be considered when examining the size-speed illusion. The car stimuli used in our experiments is a fairly small rectangular shape, and there is not that great a distance between the front and the visual centroid. However, the train could be classed as a 'spatially extended' object because its retinal image extends over a large part of the visual field. When an observer looks at a spatially extended object, there is a tendency for the initial saccade (and the resulting fixation) to be made to the 'centre of gravity' (COG) or 'centre of mass' of that object (Alvarez & Scholl, 2005; Doran, Hoffman, & Scholl, 2009; Vishwanath & Kowler, 2004). When talking about three-dimensional objects, the COG is consistent with the physical 'midpoint' of the object in the world. However, in two-dimensional projections of 3-D objects the 'retinal COG' can be quite different to the object's physical COG, and this retinal COG can change based on properties such as the angle the object is viewed from (e.g., an acute viewing angle would have a different retinal COG compared to an object viewed from a transverse angle).

The perspective image of a 3D object approaching an observer in depth differs to that of an object viewed directly from the front or side; the leading edge of an approaching 3D object is larger on the retina than the rear edge. This asymmetrical property of objects moving in depth may also have an effect on where observers fixate the object. Findlay (1982) found that two eccentrically located unequal-sized stimuli resulted in greater weighting being allocated to the larger stimulus when observers were asked to saccade to, and fixate on the objects. Although saccades were directed towards the centre of gravity between the two stimuli, the greater size of the near stimulus meant that the landing point of the saccade was shifted closer to the larger, near stimulus than the smaller, far stimulus (Findlay, 1982). In our case, it could be argued that the front edge of the train is equivalent to a larger 'target' and the back edge of the train a smaller 'target'. Therefore, one might expect that a saccade towards the approaching train would land near the COG, but would be weighted closer to the front (larger target) than to the back (smaller target). We found patterns of saccadic behaviour that demonstrated that this was indeed what our observers were doing.

The length of a spatially extended object also seems to dictate saccadic landing positions. In a study analysing eye movement patterns during reading, Vitu (1991) found that words with more than 5 letters tended to have a more 'off-centre' saccadic landing position than words with 5 or fewer letters (Vitu, 1991). This seems to indicate a length-of-target effect. In our experiment this was apparent in the data from the larger train. Analysis of the car saccadic landing positions tended to be closer to the COG, whereas, as mentioned previously, the train's saccadic landing positions could be categorized as being more off-centre.

Therefore, for Experiment 2, we attempted to manipulate the size of the illusion by 'forcing' the observers to look at different parts of an approaching vehicle to see if this would result in a reduction of the magnitude of the illusion. Specifically, we sought to examine whether we could 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).

3.5. Experiment 2

For this experiment we simplified the approaching vehicles and removed all features (colours and textures) except the basic outline shapes (Figure 3.6). We positioned a fixation dot on the objects to ensure the observers looked at a particular region of the approaching shapes. Based on our Experiment 1 data, it was expected that the further along the dot was from the front of the 'vehicle', the slower the estimated approach speed would be. 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 participants' estimated velocity between the long shape and the short shape.

3.5.1. Experiment 2: Method

3.5.1.1. Participants

Nineteen participants (7 males and 12 females) were once again recruited from the student population at the University of Waikato (these participants did not partake in Experiment 1). 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), held a full driver's license 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 a $10 petrol voucher.

3.5.1.2. Apparatus

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

3.5.1.3. Stimuli

The stimuli were designed to remove all additional visual cues from the environment. Dark grey shapes (boxes) replaced the vehicle stimuli used for Experiment 1 (Figure 3.6). In addition, all shadowing was removed in order to minimise the saliency of corners and 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' = 0m 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.

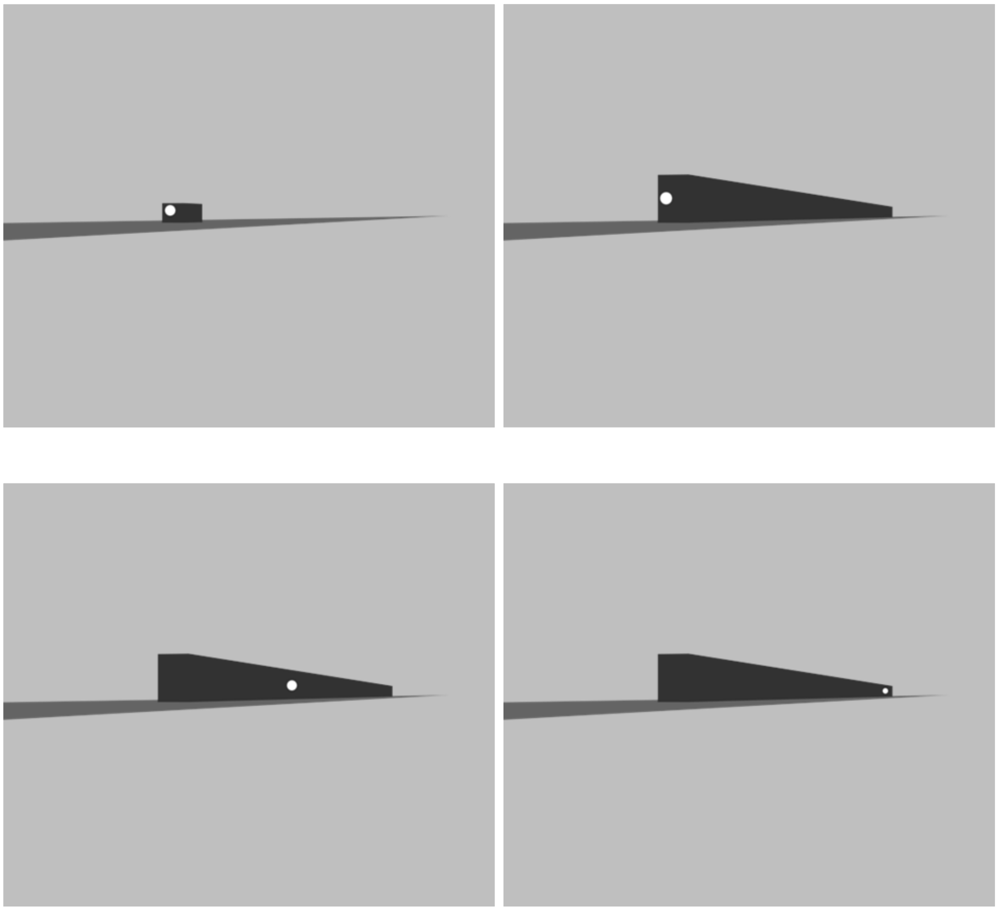

Figure 3.6. Static images of a ‘car’ (top left) and ‘train’ shape, 18m from the intersection/junction, with the dot placed at the front, middle and end of the shape respectively.

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 car 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’. Having the ‘road’ with the same dimensions for both the ‘car’ shape and the ‘train’ shape allowed for the removal of a potential confounding variable in our previous experiments (a small object travelling on a wide surface (road), compared to a large object travelling on a narrow surface (train)). If the width of the surface had an effect on perception in our previous experiments, then this should become apparent in the data from this study because the surface area below the objects was the same and the illusion should disappear. The distance (m) between the participant and the level crossing entry point/intersection junction was set at 18m – the distance condition that produced the largest effect in Experiment 1.

3.5.1.4. Design and Procedure

Each participant undertook three blocks of 42 trials each, amounting to 126 trials in total. The starting positions for each shape were varied using the same format as Experiment 1. Eye tracker calibration procedures and instructions provided to the participant were the same as Experiment 1, with one addition - the participants were instructed to initially fixate, and then track the white dot on the box at all times.

3.5.2. Results

3.5.2.1. Eye tracking data analyses

Since 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 that the participant failed to track the dot with an error of less than 2 degrees (97 pixels) for at least 50% of that trial were excluded from further analysis. Participants whose data sets had more than 10% of trials removed according to the above criterion were excluded from the analysis. Using these criteria, the data sets for 3 participants (/19) were excluded from the analysis described below.

3.5.2.2. Statistical Analyses

3.5.2.2.1. Perceived Speed

As in Experiment 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 (Figure 3.7).

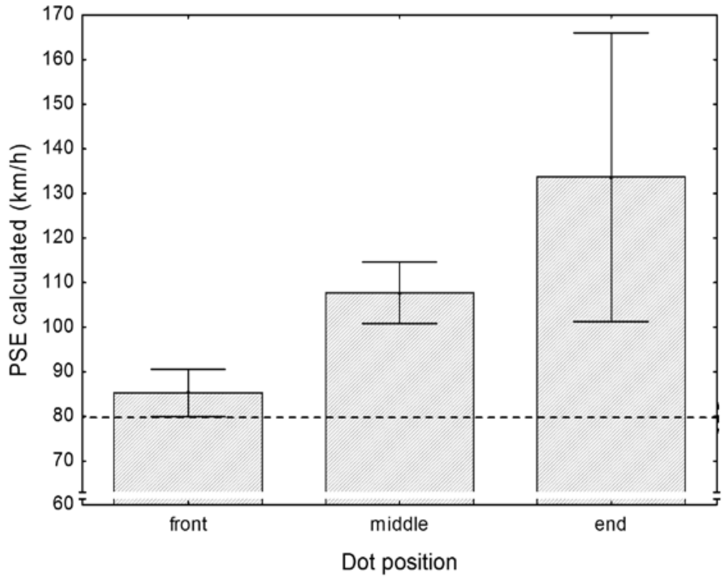

Figure 3.7. Mean point of subjective equalities (PSE) of ‘train shape’ for all participants. Dotted line represents ‘car shape’ comparison travelling at 80km/h. Error bars represent 95% confidence intervals.

One sample t-tests conducted for perceived speed against the ’car’ shape (μ = 80) showed that there were significant differences for the ‘middle dot’ condition ($t(15) = 8.592$, $p < .001$, $d = 2.148$), and the ‘end dot’ condition ($t(13) = 3.579$, $p = .003$, $d = 0.957$). The ‘front dot’ condition was not significant ($t(15) = 2.119$, $p = .051$, $d = 0.530$) (Figure 3.7). This indicates that the size-speed illusion was greatest for the condition in which the dot was located at the end of the virtual vehicle and less for ‘the middle’ dot condition. The illusion was not evident when the dot was at the front of the long vehicle. Therefore both of our two hypotheses for this experiment were supported.

3.5.2.2.2. Eye Velocity

As mentioned previously, trials where participants failed to meet the 2 degree tolerance criterion were excluded from further analysis. However, within this tolerance boundary there is still the opportunity for the eye velocity to vary. We therefore also checked the pursuit velocities that occurred as the observers judged the speeds of the approaching shapes. Paired t-tests conducted for the pursuit velocities between the car shape and the train shape (when both were travelling at 80km/h) showed that there was a significant difference in pursuit velocity between the two for the ‘middle dot’ condition ($t(47) = -6.806$, $p < .001$, $d = 0.982$), and for the ‘end dot’ condition ($t(47) = -10.126$, $p < .001$, $d = 1.462$). However, the ‘front dot’ condition was non-significant ($t(47) = 1.023$, $p = .312$, $d = 0.148$), which indicates the remaining participants were reliably tracking the dot.

3.5.3. Discussion

As hypothesised, the data show that there is a significant difference in an approaching object’s perceived speed when the participants fixated on a region other than the front of the object. When they were required to look at the front of both the short (car) and long (train) shapes the size-speed bias was eliminated. This shows that eye movement behaviour is partly responsible for the size speed illusion. The 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 as well as the amount of perspective generated by the viewing angle. On average, the region around the centroid has a slower rate of image motion on the retina than the front of the object and this may affect the overall perceived speed of the object. Because of the different amounts of retinal image motion involved at different regions of the long vehicles, the pursuit eye velocity required to track something at the front versus the back will differ. When our participants tracked a dot towards the rear of the long vehicles they necessarily made slower pursuit velocities and judged the approach speed of the vehicle to be slower than when they tracked a dot at the front (faster eye pursuit velocity). If observers take into account their pursuit velocity when judging the speed of an approaching vehicle, then this would partially explain the size-speed illusion.

3.6. General Discussion

We have confirmed that there is a size-speed illusion with respect to approaching simulated moving vehicles. In our experiments, large vehicles such as freight trains appeared to move more slowly than smaller vehicles travelling at the same speed. The results are consistent with earlier studies (Barton & Cohn, 2007; Clark, Perrone, & Isler, 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 movement behaviour may play a role in this illusion.

The results from Experiment 1 prompted us to attempt a manipulation of the participants' eye movement behaviour, by requiring observers to track a specific region on the abstract 'train' object. We found that when observers made speed comparison judgements while tracking a region close to the front of the train, the effect of the size-speed illusion reduced considerably between the longer 'train' object and the smaller 'car'. When the middle and end regions of the 'train' were tracked, pursuit velocity was slower, as was judgment of perceived speed. We believe therefore that this demonstrates a direct link between pursuit velocity and an observer's decision about the speed of that object.

While the results from our study present a compelling case for the role of eye movements in the size-speed illusion, it is important to note the limitations of the research with respect to actual train crossing incidents. A complete study of the effects of visual factors involves a downplay of other sensory information (particularly auditory), which may also have an influence on peoples' decisions to cross through junctions in front of approaching vehicles. Nevertheless vision tends to dominate many behaviours and so it is reasonable to conclude that it possibly plays a dominant role in many train crossing accidents. The present research did not explicitly explore differences in eye movement scanning patterns between novice drivers and experienced drivers, differences that have been described in previous studies (Crundall & Underwood, 1998; Underwood, Crundall, & Chapman, 2002). These differences associated with driving experience may play a role in the sorts of visual perceptual errors investigated, but examination of the effects of experience was beyond the scope of this study and remains an area that could be profitably explored in the future.

The realistic stimuli used in Experiment 1 allow us to transfer aspects of actual world settings into a controlled laboratory setting, but this does have some drawbacks. Simulated animated sequences allow for the testing of vehicles relative speed, but it is difficult to accurately match absolute speed. However, the relative speed used in our displays consistently resulted in the larger, longer train being judged as moving slower than the smaller, shorter car. The saliency of background objects other than the vehicles can complicate the eye movement analysis.

Observers in our experiments sometimes made saccades to other objects besides the moving vehicles. This suggests future possible areas for study – particularly in regards to whether reference points in the near environment can improve accuracy in perceived speed judgments. This idea has also been suggested in previous research (Berthelon & Mestre, 1993) and could lead to recommendations for possible intervention strategies.

Experiment 2 isolated smooth pursuit eye movements for investigation; however these were not the only type of eye movement behaviours observed from Experiment 1. Many participants also exhibited fixation-saccade-fixation strategies. If participants make perceived judgements based on this strategy, then the background motion on the retina may have had an impact on perceived speed. We are currently running studies that isolate and explore further this type of eye movement pattern, and what role, if any this behaviour plays in the size-speed illusion (Experiment covered in Chapter 4).

Our results have opened up possible avenues in regards to exploring future practical interventions aimed at reducing level crossing collisions. The link between eye movement behaviour and the size-speed illusion has been verified. We have successfully shown that this illusion can be reduced by manipulating eye movements to targeted areas. Using this information, we can investigate preventative measures in an applied setting, either on the train itself, or placed along the track in proximity to a level crossing. As mentioned previously, stationary reference markers have been shown to be effective in improving perceived speed judgement accuracy (Bertholen & Mestre, 1993). A particularly salient reference marker (e.g., a brightly coloured or lit pole) placed next to the railway line could improve the correct estimation of the speed of the approaching vehicles. Other types of partial occlusion methods have been effective in reducing intersection collisions (Charlton, 2003) which implies that strategies that manipulate eye scanning behaviours in applied settings have been successful in the past. The results of Experiment 2 suggest that another measure may be to place some type of illuminator on the train's front. In a review of what factors may have been behind a decline in level crossing collisions in the United States, Mok and Savage (2005) determined that the addition of ditch lights (two additional lights lower down on the front of the engine) in the late 1990s did seem to have an effect in reducing collisions at level crossings (Mok & Savage, 2005). The success of this initiative, as well as our own findings, support further research into this type of intervention.

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, albeit on a smaller scale. Future research should be expanded to include these types of vehicles.

In conclusion, we have shown that the size-speed illusion that may be a factor in road/rail incidents at level crossings appears to be as a result of eye movements, which differ according to the size and length of the vehicle in question. We have also demonstrated that manipulating observers' eye movements to track specific regions of these vehicles successfully reduced the magnitude of this illusion. These present a compelling case to design and interventions that can translate our findings to real-world situations.

3.7. Summary

Experiment 1 demonstrated that there were different eye movement patterns occurring for short and long vehicles. While Experiment 2 isolated one such pattern (smooth pursuit) and proceeded to determine that manipulation of smooth pursuit was successful in reducing the size-speed illusion, not all of the participants in Experiment 1 displayed smooth pursuit behaviours. Saccading to, and fixating on a specific region of the approaching vehicles occurred regularly. It therefore made sense to isolate and measure these types of behaviours (similar to the methods used in Experiment 2) in order to determine whether there are other techniques that could also reduce the size-speed effect. The next chapter explores strategies that were designed to isolate fixation type behaviours and test possible effects of manipulation of these eye movements.

Chapter 4. Isolation and analysis of fixation-saccade eye movement behaviour in the size-speed illusion.

This chapter has been published as a journal article in Accident Analysis & Prevention:

Clark, H.E., Perrone, J.A., Isler, R.B. and Charlton, S. G. (2017).Fixating on the size-speed illusion of approaching railway trains: What we can learn from our eye movements. *Accident Analysis & Prevention, 99*, 110-113.

Abstract

Railway level crossing collisions have recently been linked to a size-speed illusion where larger objects such as trains appear to move slower than smaller objects such as cars. An explanation for this illusion has centred on observer eye movements – particularly in relation to the larger, longer train. A previous study (Clark et al., 2016) found participants tend to make initial fixations to locations around the visual centroid of a moving vehicle; however individual eye movement patterns tended to be either fixation-saccade-fixation type, or smooth pursuit. It is therefore unknown as to which type of eye movement contributes to the size-speed illusion. This study isolated fixation eye movements by requiring participants to view computer animated sequences in a laboratory setting, where a static fixation square was placed in the foreground at one of two locations on a train (front and centroid). Results showed that even with the square placed around the front location of a vehicle, participants still underestimated the speed of the train relative to the car and

underestimation was greater when the square was placed around the visual centroid of the train. Our results verify that manipulation of eye movement behaviour can be effective in reducing the magnitude of the size-speed illusion and propose that interventions based on this manipulation should be designed and tested for effectiveness.

4.1. Introduction

The rate of collisions between vehicles and railway trains at level crossing intersections is a worldwide issue that has necessitated thorough investigation over the last ten years or so. Recent research (Clark, Perrone, & Isler, 2013) indicates that a factor that may account for these types of incidents occurring is an illusory bias known as the size-speed illusion. The size-speed illusion was a theory proposed by Leibowitz (1985), and referred to the concept that larger moving objects appear to move slower relative to smaller objects travelling at the same velocity or in some instances even faster. In the case of level crossing collisions the observer may perceive the larger, longer train to be moving slower, as opposed to a more familiar, smaller vehicle such as a car. This theory was tested and confirmed by Clark et al. (2013) by using computer generated movie clips of moving vehicles (trains and cars).

More recently, Clark, Perrone, Isler & Charlton (2016) proposed that eye movement behaviour could be a reason for this illusion. They tested the eye movements of observers in a laboratory-based setting with simulated moving trains and cars, set in a rural environment background. They found that participants tended to look further away from the front of a train, as opposed to a car, in a region termed the ‘visual centroid’ - defined as the weighted vector average of the velocity of the front and the rear of the moving vehicle (Clark et al., 2016). For long objects approaching observers in depth, fixating on the visual centroid region results in a slower optical speed on the retina, and therefore eye velocity is slower.

Underestimation of the train's speed, relative to the car was widespread across their participants; however individual observers demonstrated different types of eye movement patterns. Many observers utilised a fixation-saccade-fixation type strategy, where an observer would make an initial fixation to the visual centroid region of the vehicle, and then make catch up saccades and fixations as the vehicle moved along its trajectory. Other participants employed a different type of eye movement - smooth pursuit, where after the initial fixation; they steadily tracked the vehicle's motion throughout the trial.

After this initial finding, the same study isolated and manipulated smooth pursuit eye movements by placing a dot at different regions of train shapes and car shapes. When participants were required to pursue a dot placed at the front of the train shape, the size-speed illusion was eliminated. Pursuing a dot on the visual centroid of the train shape resulted in underestimations of its velocity, consistent with the underestimations of the train in the virtual world setting.

Forcing observers to use smooth pursuit eye movements confirmed the robustness of the size-speed illusion, and also offers one option to reduce the effect of the illusion. We wanted to see if the size of the illusion could also be manipulated by forcing observers to make the saccade-fixation type of eye movement demonstrated by many of our observers.

When fixations occur, the moving vehicle moves past the point of gaze and its speed can be estimated from the image motion near to where one is looking. For the pursuit case, the vehicle image remains relatively stationary on the eye and the speed estimate must be derived from the eye muscle signals (‘extra-retinal signals’) as well as the motion of the background (Wurtz, 2008). It is not known which of these two cases is more conducive for causing the size-speed illusion. Knowing this would help determine the optimum intervention strategy for eliminating entirely, or reducing the size-speed illusion and, by implication, railway crossing collisions that may have occurred as a result of this illusion. Therefore, this experiment was designed to isolate participant fixations to a single region on the screen, which corresponds to an initial fixation made to the front of a vehicle (car or train), or to the visual centroid (train only). Participants’ estimates of the vehicle’s speed were recorded and analysed as in previous studies (Clark et al., 2016).

4.2. Method

4.2.1. Participants

Sixteen participants (6 male and 10 female) were recruited from the student population at the University of Waikato, ranging in age from 20 to 40 years of age (*M*=27.5, *SD*=2.25). All participants had normal or corrected visual acuity (at least 20/20), held a full driver’s license, and were reimbursed for their voluntary participation by either receiving a 1% course credit for their respective course (psychology students only), or a $10 petrol voucher. All recruitment and test protocols were subjected to, and received ethical approval by the University of Waikato's School of Psychology Human Research and Ethics committee.

4.2.2. Apparatus

All stimuli were presented using a Dell OptiPlex 760 Minitower PC, and displayed on a VIEWPixx display (VPixx Technologies) with a 1920 x 1200 pixel resolution (screen size 48.5cm x 30.3cm) and a refresh rate set at 60Hz. Eye movement data were recorded using an EyeLink 1000 Desktop System (Eyelink 1000, SR Research, Ltd., Ontario, Canada), averaging 0.25° - 0.5° accuracy. A chinrest was used to ensure that each participant's head remained fixed for the duration of the trials and this was located 57cm away from the monitor screen, producing a field of view (FOV) of 40° x 30° (horizontal x vertical).

4.2.3. Stimuli

The simulated vehicles for the experiment consisted of a light blue sedan car, and a freight train with 16 container carriages. The background setting was typical of a New Zealand rural environment, consisting of either a stretch of road or a railway track, running across farmland and placed perpendicular to the observer's line of sight. The virtual dimensions of the train were 186.00m (length), 2.23m (width) and 3.25m (height). For the car, the corresponding dimensions were 3.81m, 1.65m, and 0.95m respectively. The light blue colour scheme was selected for the car based on photometer readings from previous studies (Clark, Perrone, Isler, & Charlton, 2016) which matched the average luminance of the car image to the overall average luminance of the train image.

The background rural environment scene and the moving vehicles were created using 3DS Max 2010 32-bit (Autodesk, 2010). Stimuli were created by rendering photos of real-life scenes and vehicles onto the 3D meshes underlying the background and the car and train. The virtual FOV was set to match the screen FOV above, and the line of sight (from the observers point of view) 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.

A bright pink fixation ‘square’ was added to the movie sequence. This square was a stationary object in the virtual world and therefore did not move with the vehicles. The square was placed in the world at the position corresponding to one of two locations for the train – a ‘front’ region and a ‘centroid’ region. For the car, the square was placed at the same position coordinates used for the front region of the train (Figure 4.1).

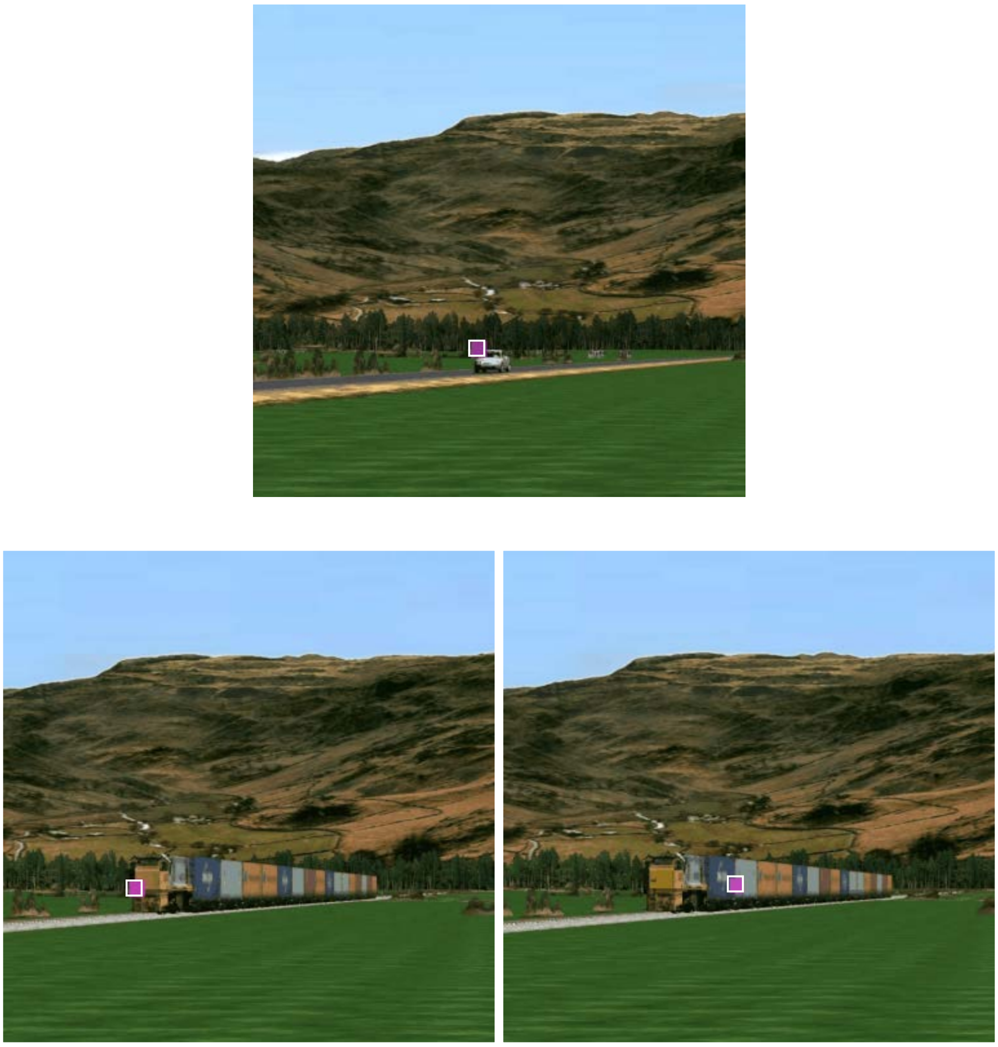

Figure 4.1. Sample screenshot of an approaching car and a freight train with the fixation square inserted at either the ‘front’ location (top and bottom left image), or the ‘centroid position (bottom right image). Images have been cropped and do not represent the full field of view experienced by the participants.

4.2.4. Design

Three test blocks of 42 trials (total 126 trials) were presented, each with a short break (5 min) between each test block. During each test block the participants viewed an approaching car; paired with an approaching train, with the fixation square placed at either of the locations described above (the order in which vehicle appeared first was randomised by the computer programme). Each stimulus presentation was 400 milliseconds (msec) in length. During a trial the speed of the car (standard stimulus) always approached at 80 km/h, whereas the train (comparison stimulus) was set to one of seven speeds in km/h (60, 70, 80, 90, 100, 110 or 120) during their 400 msec presentation. Stimulus presentation time (400 msec) was shorter for this experiment than in previous studies (where presentation times were set at 1000 msec and 3000 msec respectively; Clark et al., 2013; Clark et al., 2016), however this was deemed necessary to match the average time taken to initially make a saccade and then fixate on a specific point in a dynamic scene, before the scene changes.

A within-subjects, repeated measures design was used, with all the participants viewing the same simulations (two fixation square location conditions x seven approach speed conditions), with the presentation of trial pairs counterbalanced to eliminate order effects.

The distance between the participant and the level crossing entry point/intersection junction was set at 18m, done in order to match the 18m condition used in Clark et als'. (2016) smooth pursuit experiment as closely as possible.

4.2.5. Procedure

The trial commenced with a blank (uniform grey) display screen. Next, the screen showed the background rural setting with the viewpoint orientated in the direction of the road or railway track, and off to the right hand side. On each trial, an animated sequence of an approaching vehicle (standard car or comparison train) was presented followed (1000 msec later) by a sequence showing the other vehicle type. A response screen was then displayed, containing the question “Which vehicle was faster?”

(standard vs. comparison vehicle, two-alternative forced choice (2AFC) 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). Participants were also instructed to fixate on the square throughout the duration of the trial. The eye tracker was implemented for the purpose of verifying that participants were indeed looking at the square for the duration of the trial.

There was a 1000 msec delay between the response mouse press and the commencement of the next trial. A blank display screen (grey) was displayed for 1000 msec between each sequence and before the response screen to minimize motion after-effects.

4.2.6. Statistical Analysis

As with the Clark et al. (2016) experiments, we first calculated each individual's point of subjective equality (PSE). This is an estimate of the point where the speed of the train and the car was perceived to be the same by the observer. The proportion of 'Train faster' responses were calculated for each distance condition and plotted against train speed (generating a psychometric function) for each trial. These data were fit with a logistic curve in MatLab (R2007b, Mathworks, Natick, Massachusetts, USA) using the Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997). The returned value at the 50% point of the curve is equivalent to the PSE for that observer. Mean PSEs for all observers were calculated for each condition for the train, and compared to the standard variable – the 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 each of the fixation location conditions, compared with the speed of the car ($\mu = 80$) and paired t-tests were used to determine if there was any statistical difference between fixation square locations for the train condition.

4.3. Results

All participants' eye movement data were reviewed and compared against the X,Y position of the square image on the screen. Any trials which showed that the participant was not fixated on the square (after the initial saccade) for the duration of the trial, with an error of less than 2 degrees (97 pixels) were excluded from further analysis. All our participants met these criteria for the majority of trials and no participants were excluded.

Figure 4.2 shows the mean PSE values compared to the standard vehicle. The bars represent the relative speed the train was actually travelling, when observers perceived it to be moving at the same speed as the car. Data that fall above the dotted line denotes an underestimation of the train's speed compared to the car. For example, a PSE value of 90km/h would indicate that observers perceive a train travelling at 90km/h as moving at the same relative speed as a car travelling at 80km/h (an underestimation of 10km/h).

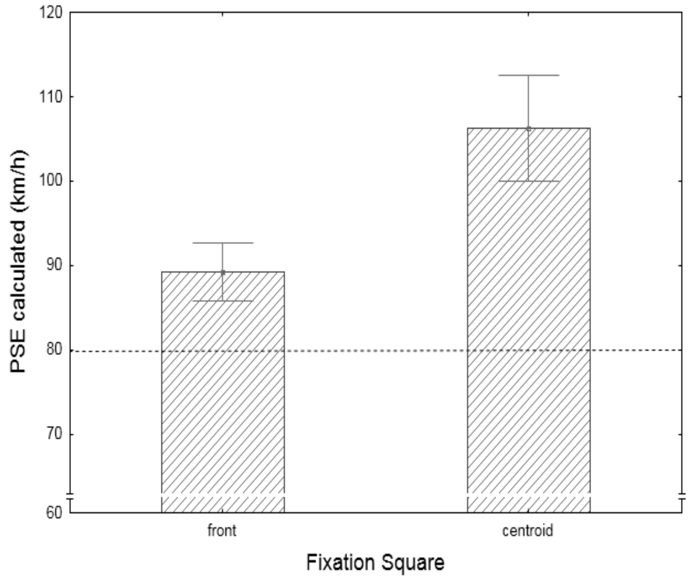

Figure 4.2. Mean point of subjective equalities (PSE) of train for all participants. PSE is the point at which the train and the car were perceived as identical by the participant. Dotted line represents the comparison car travelling at 80km/h. Error bars represent 95% confidence intervals.

Significant differences were found between the perceived speeds of the train, compared to the car, for both fixation square location conditions. The ‘front square’ condition was significant ($t(15) = 5.763$, $p < .001$), with a large effect size, $d = 1.441$. The ‘centroid square’ condition was also significant ($t(15) = 8.992$, $p < .001$), with a large effect size, $d = 2.248$ (Figure 4.2.). Significant differences were also found between the ‘front’ square location and the ‘centroid’ square location for the train stimuli ($t(15) = -5.866$, $p < .001$), with a large effect size, $d = 1.811$.

Fixating a point on the screen and letting the vehicle move past that point produced greater underestimates of the train speed when the point was located near the centroid location compared to when it was closer to the front of the approaching train. This verifies findings from Clark et al (2016) which found a tendency for observers to fixate on the centroid region of the train and hence underestimate its speed. However, the significant underestimation of the train's speed relative to the car when the fixation square was placed at identical locations (i.e., the 'front' square condition) differs from Clark, et al's (2016) smooth pursuit dot experiment, where there were no significant differences between the car and the train, when the dot was placed at the front of the train shape.

4.4. Discussion

We have found that isolation of fixation eye movements have yielded different results to the isolation of smooth pursuit eye movements in the Clark et al. (2016) experiment. There, no significant differences were found between longer and shorter moving objects when participants were required to pursue a dot located on the front of the objects. Here we have found that the fixation square did result in a significant difference between longer and shorter moving objects (vehicles). This suggests that people who employ a fixation-saccade type of eye movement when perceiving objects moving in depth may be underestimating velocity even more so than those who pursue the object. The pursuit case provides an extraretinal signal as to the speed (see above) and this may lead to better estimates of the actual vehicle speed. The data show that fixating a stationary point in front of the train still leads to it being seen as slightly slower than a car when fixating the same point. In both cases the two vehicles (moving at the same speed) go past the same fixation point on the screen, yet the train speed appears slower. Certainly the length of the edges passing the fixation point are different in the two cases with the train having a greater vertical dimension, but exactly how this results in a speed perception difference is not known and requires further study. One way may be to explore differences between observers who fixate on regions of a moving object, as opposed to those observers who pursue (track) the object in a free eye movement setting.

We have previously discussed the possibility of specific intervention methods which could be investigated due to our findings (Clark et al., 2016). Our results here reinforce the potential of future studies on interventions that may manipulate eye movement to targeted areas on either the train itself (e.g., placing some type of illuminator on the train's front), or in the foreground environment (e.g., a salient reference marker or markers such as a brightly coloured or lit pole placed next to the railway line) or utilising a partial occlusion method (e.g., a mesh screen placed parallel to the track over a set number of metres). The latter two interventions are based on manipulating fixations and our results show that these should be further studied, in terms of both effectiveness and acceptability (e.g., by aiding, without distracting, the observer).

In conclusion, we have shown that by isolating fixation eye movements, allows us to explore the effect eye fixations have on the magnitude of the size-speed illusion. We have verified findings from Clark et al. (2016) that eye movements made when observing a large vehicle moving in depth, influences our perception of that vehicles relative speed. The present findings, along with the findings from Clark et al. (2016), confirm that manipulation of eye movement patterns, in terms of both fixation type and smooth pursuit type patterns can reduce or even eliminate this illusion. This reinforces the need to test interventions designed for real-world situations that can manipulate eye movement behaviour, and thereby reduce the size-speed illusion.

4.5. Summary

With the previous chapters confirming that eye movements do differ between short and large objects moving in depth, and the reason for this likely due to a ‘length of target’ effect, the final step was to investigate ways in which the effects of the size-speed illusion could be negated. This provided the opportunity to look at practical countermeasures that could eventually be applied in naturalistic settings. The next chapter presents a study that investigated the effectiveness of three types of interventions that were designed to influence eye movements and are based off the findings of Experiments 2 and 3.

Chapter 5. Designing and utilizing countermeasures in order to combat the size-speed illusion.

This chapter has been submitted to, and is currently under review with Accident Analysis & Prevention:

Clark, H.E., Perrone, J.A., Charlton, S.G., and Isler, R.B. Combating the size-speed illusion: Using eye movement-based countermeasures to reduce railway crossing collisions.

Abstract

The size-speed illusion, when longer objects moving in depth are judged to be moving slower than shorter objects travelling at the same speed, may influence our perception of approaching vehicles, which could explain vehicle collisions at level-crossings. Recently, Clark, Perrone, Isler, and Charlton (2016) showed that this illusion may be related to observer eye movements. When observers tracked trains and cars in a simulated environment, their eye movement behaviour was different when judging the speed of the longer train compared to the smaller car, with eye fixations localised further from the front of the train in contrast to the car. Endeavours to reduce the magnitude of the illusion by manipulating eye movements (both smooth pursuit and fixations), were subsequently found to be successful by using tracking dots placed at strategic locations on the vehicles, or by placing a reference marker in the surrounding environment. The current study examined three level-crossing collision preventative measures, each designed to manipulate observer eye movements. These were: (1) Alternating flashing lights placed on the front of trains. (2) Marker

poles beside the railway line and (3) a mesh ‘shade cloth’ screen along part of the railway line. Results show that the flashing light intervention was effective in eliminating the size-speed illusion, whereas the illusion persisted with the other intervention strategies. We propose that interventions designed to influence smooth pursuit are the most preferable in the vehicle speed discrimination task and potentially for reducing vehicle speed misperception errors.

5.1. Introduction

The prevalence of level crossing collisions between motorists and railway trains continues to be a problem in New Zealand. Media scrutiny and high profile education campaigns including the annual Rail Safety Week have drawn attention to this issue; however the average incidence rate remains at an average of 22 collisions per year (TrackSAFE Foundation NZ, 2016). Worldwide, train/motor vehicle collisions are recognized as a major problem, with the United States averaging 2100 collisions between 2011-2015 (Federal Railroad Administration Office of Safety Analysis, 2016) and Australia averaging around 70 collisions at level crossings in the ten-year period between 2002-2012 (Australian Transport Safety Bureau, 2012). Statistically the European Union nations have a lower rate of level crossing collisions (with many EU countries utilising level crossing barriers as a matter of course) however there were still 506 accidents involving level crossings across the 28 member countries in 2014 (European Union Agency for Railways, 2016).

The ‘size-speed illusion’ refers to the situation where longer objects moving in depth are judged to be moving slower than shorter objects travelling at the same speed. This illusion has been well documented (Clark, Perrone & Isler, 2013; Petzoldt, 2016) as a potential factor in collisions between cars and railway trains at level crossing junctions, where the large, long train's perceived velocity tends to be underestimated by the motorist. This misperception of a train's travelling speed can have potentially disastrous consequences in conjunction with risky behaviours, such as crossing through the junction when a train is approaching.

More recently, it has been shown that our eye movements are a possible contributing factor to this illusion. Since the initial Clark et al. (2013) study, research into observer eye movements when viewing small and large approaching vehicles (cars and trains) has demonstrated differences in fixation and pursuit patterns between the different sized vehicles (Clark et al., 2016; Clark, Perrone, Isler, & Charlton, 2017). One such difference related to the regions on the vehicles where initial saccades and fixations were made. It was established that observers tended to look further along the body of a train, as opposed to a car, in a region we termed the 'visual centroid' - defined as the weighted vector average of the velocity of the front and the rear of the moving vehicle (Clark et al., 2016). This region roughly corresponds to an objects physical centre of gravity and hence is further from the front edge on a longer object. When observers perceive the approaching longer train, fixating on the visual centroid region results in a slower optical speed on the retina, and therefore eye velocity is slower.

Studies targeting manipulation of eye movements have shown some promising results, both in terms of smooth pursuit and fixation strategies.

Clark et al. (2016) demonstrated that placing a reference point ('dot') on the front of spatially extended objects moving in depth which observers were required to track (smooth pursuit strategy) resulted in the elimination of the size-speed illusion. Further research into fixation type eye movements showed a reduction in the illusion when initial fixations occurred at the front region of moving long objects, as opposed to initial fixations localised around the visual centroid (Clark et al., 2017).

Clark et al's eye movement studies have opened up a possible new approach to exploring practical intervention designs aimed at reducing level crossing collisions. A challenge in road safety research, engineering and/or policy is designing interventions that are not only effective, but also economically viable. While barriers that seal off entrances to railway junctions when a train is approaching (such as those in the UK) can be very effective, they are less practical as a measure both in terms of cost and utility in a small country like New Zealand, which has a much smaller population base and less frequent occurrence of trains, in comparison to countries in Europe, Asia and North America. Therefore, other education and intervention strategies need to be explored.

With previous studies (Clark et al., 2016, 2017) showing that the size-speed illusion could be reduced by negating a 'centre of gravity' (COG) effect (i.e., observer eye movements naturally occurring around the COG of a long object), the aim of the current study was to devise and test level-crossing collision preventative measures designed to manipulate observer eye movements in an applied setting. After reviewing these earlier findings, we developed three possible intervention strategies.

The first intervention (‘flashing lights’) consisted of two alternating flashing white lights placed on the front face of a train. The rationale for this intervention came from Clark et al. (2016) ‘dot’ experiment, with the flashing lights deemed salient enough to initially draw attention to, and subsequently cause the observer to track the front region of the train. The second intervention (‘poles’) had two large red-and-white striped poles positioned on the near side of the train track. As mentioned previously, stationary reference markers have been shown to be effective in improving perceived speed judgement accuracy (Berthelon & Mestre, 1993), while Clark et al’s (2017) fixation experiment verified that fixation markers placed at a region where the front of a train crosses were successful in reducing the size-speed illusion. While these studies used one reference marker only, we considered that adding a second should be particularly effective, as participants may also use the ‘crossing time’ between the two poles (the time taken for the vehicle to travel between the two poles) to aid them in making a judgement about the vehicle’s perceived speed. The third intervention tested (‘mesh screen’) had a 150m green mesh shade cloth screen positioned on the near side of the track. This intervention was used to test the effect of partial occlusion of the train on participants’ responses. Applied setting studies have previously shown partial occlusion methods to be effective in reducing intersection collisions between motor vehicles (Charlton, 2003).

Our intention therefore was to compare how effective each of the above interventions were in successfully reducing the size-speed illusion (if at all), by measuring observers' speed judgments of each intervention, relative to the speed of a standard vehicle (motorcar).

5.2. Method

5.2.1. Participants

Twenty two participants (7 male, 15 female) were recruited from the University of Waikato student population to take part, ranging in age from 18 to 45 years (*M* = 26.9, *SD* = 2.38). All participants had normal or corrected visual acuity, all bar one participant had a full New Zealand driver's license, and each participant received a 1% course credit towards their respective studies as reimbursement for their voluntary participation. All recruitment and test protocols received ethical approval by the University of Waikato's School of Psychology Human Research and Ethics committee.

5.2.2. Apparatus

The experiment was conducted in the University of Waikato's driving simulator, consisting of a complete automobile (Toyota Prius) positioned in front of three angled projection surfaces(the details have been previously described in Charlton and Starkey (2016)), with the driver's seat position located 2.32m from the middle projection screen. The virtual scene was projected onto these screens from three projectors mounted on the ceiling above the car. The field of view (FOV) was calculated from the position of the participant's eye while seated in the driver's seat. The test stimuli were presented on the right hand screen and the participants turned their heads to the right so that they were looking along a line orthogonal to the screen ('the straight ahead direction'). When the participant viewed the right-hand screen, relative to the straight ahead direction, the left and right edges of the projected image had horizontal angles of -28.5° and 36.8° respectively, giving a total horizontal FOV of 65.3°. The top and bottom edges of the display were at 29.0 °and -17.6° such that the total vertical FOV was 46.6°.

The front and left screens contained static images (rural landscape) only and were located well into the left peripheral visual fields of the participants as they viewed the right-hand screen, nonetheless the projected images helped create the experience of sitting in a car while looking out the driver's window at a moving train. For the front screen (also relative to the straight–ahead direction when an observer is facing forward) the horizontal left and right edges were at -34.9° and 23° giving a front facing FOV of 57.8°. For the left screen the same numbers were (-36.3°, 18.9°, 55.1°) for horizontal and (-17.5°, 30.8°, 48.3°) for vertical.

The virtual FOV was set to match the screen FOV, and the line of sight (from the observers point of view) was directed 51.88° from the straight ahead direction (38.1° 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. The static images on the left and middle screen were present for the duration of the experiment.

For the purposes of this experiment, the simulator vehicle was used as a prop to add ecological validity and did not provide any driver feedback (audio, brake/accelerator or dashboard performance).

Figure 5.1. Simulator set up used for the experiment. Note: The misalignment of features visible in this image was not apparent from the driver's seating position.

5.2.3. Stimuli

The simulated vehicle stimuli for the experiment consisted of a light blue sedan car, and a freight train with 16 container carriages. The background setting was typical of a New Zealand rural environment, consisting of either a stretch of road or a railway track, running across farmland and placed perpendicular to the observer's line of sight. The virtual dimensions of the train were 186.00m (length), 2.23m (width) and 3.25m (height). For the car, the corresponding dimensions were 3.81m, 1.65m, and 0.95m respectively. The light blue colour scheme was selected for the car based on photometer readings from previous studies (Clark et al., 2016) which matched the average luminance of the car image to the overall average luminance of the train image.

For the flashing lights condition two circular white lights were placed adjacent to each other on the face of the train engine. These lights were designed to ‘blink’ on and off consecutively at a frequency of 1Hz during the course of the video sequence (Figure 5.2).

The other two conditions (mesh and poles) had stimuli added to the surrounding environment. The poles condition included the addition of two large red and white striped vertical poles on the near side of the track. These poles were placed at 85m and 115m along the track (right side) respectively. The mesh condition had a green mesh ‘shade cloth’ type screen, 150m in length, placed 85m along on the near side of the track (Figure 5.2). The mesh cloth was created in Adobe Photoshop and rendered in 3D Studio Max with a 50% transparency level.

The background rural environment scene and the moving vehicles were created using 3DS Max 2010 32-bit. Stimuli were created by rendering photos of real-life scenes and vehicles onto the 3D meshes underlying the background, and the car and trains.

Figure 5.2. Example screenshot of the approaching car (control) and the freight train interventions (flashing lights, mesh fence, reference poles). Images have been cropped and do not represent the full field of view experienced by the participants.

5.2.4. Design

Three test blocks of 42 trials (total 126 trials) were presented, each with a short break (5 min) between each test block. During each test block the participants viewed an approaching car; paired with an approaching train, fitted with one of the three interventions. The sequence order presentation was randomised in order to prevent practice effects (e.g., 50% of the trials had the car presented first, while on the other trials the train appeared first, with the interventions counterbalanced across the trials). Each stimulus presentation was 3 seconds in length. During a trial the speed of the car (standard stimulus) always approached at 80km/h, whereas the train (comparison stimulus) was set to one of seven speeds in km/h (60, 70, 80, 90, 100, 110 or 120) during their 3 second presentation. A within-subjects, repeated measures design was used, with all the participants viewing the same simulations (three train intervention conditions x seven approach speed conditions). The distance between the participant and the level crossing entry point/intersection junction was set at 35m – with the rational for this particular distance based off average vehicle stopping distances for a vehicle travelling at 60km/h (World Health Organisation, 2016), while also factoring in the vehicle already decelerating when approaching the intersection.

5.2.5. Procedure

Participants were seated in the car and verbally provided with instructions about the trials and on how to respond. The participants were advised to look at the vehicles only when making their judgments about the vehicle's speed. This instruction was explicitly given in order to minimise the effects of any possible confounds (e.g., participants using other alternatives such as the time taken to cross a distance between point A to point B).

The middle and left-hand projector screens were set up with the static images of the environment mentioned above. The trial commenced with a blank (uniform grey) display screen on the right-hand screen. Next, the screen showed the background rural setting with the viewpoint orientated in the direction of the road or railway track, and off to the right hand side. On each trial, an animated sequence of an approaching vehicle (standard car or comparison train) was presented followed (1000 msec later) by a sequence showing the other vehicle type. A response screen was then displayed, containing the question “Which vehicle was faster?” (standard vs. comparison vehicle, two-alternative forced choice (2AFC) procedure). Participants were required to respond by verbally indicating whether they thought the first vehicle or the second vehicle was faster. Once the participant responded, the experimenter recorded their answer by either pressing the right mouse button (if the participant responded “first”) or the left mouse button (if the participant responded “second”). There was a 1000 msec delay between the experimenter mouse press and the commencement of the next trial. A blank display screen (uniform grey) was displayed for 1000 msec between each sequence and before the response screen to minimize motion after-effects.

5.2.6. Statistical Analyses

As with Clark et al (2013, 2016, 2017) the data were fitted to psychometric functions (logistic curve) and each participant’s point of subjective equality (PSE) was generated. The PSE is defined as the point at which the standard and comparison vehicle’s speed are perceived to be equal by the participant and is returned from the 50% value of each individual’s fitted psychometric function. One-sample t-tests were subsequently used to compare calculated mean PSE values against the fixed speed of the standard vehicle (80km/h) for each intervention condition, and a repeated measures ANOVA used to determine any significant differences between the interventions.

5.3. Results

Figure 5.3 shows the mean PSE values for each intervention condition, compared to the standard vehicle (car). The bars represent the relative speed of the train when observers perceived it to be moving at the same speed as the car. Data that fall above the dotted line denotes an underestimation of the train’s speed compared to the car. For example, a PSE value of 90km/h would indicate that observers perceived a train travelling at 90km/h as moving at the same relative speed as a car travelling at 80km/h (an underestimation of 10km/h).

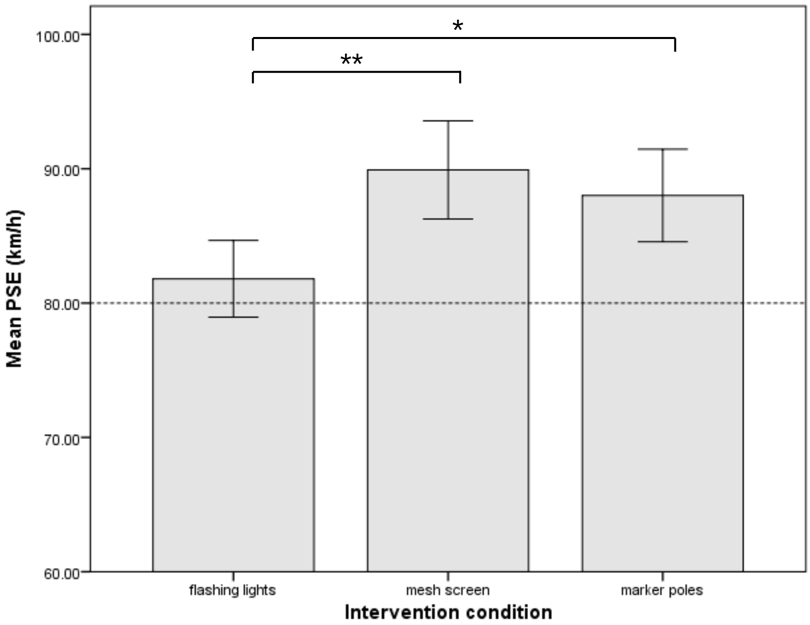

Figure 5.3. Mean point of subjective equalities (PSE) of train for all three conditions. PSE is the point at which the train and the car were perceived as identical by the participant. Dotted line represents the comparison car travelling at 80km/h. Error bars represent 95% confidence interval (CI).

A one-way repeated measures ANOVA on the mean PSE values showed a significant difference between the three types of intervention ($F(2,42) = 10.31$, $p < .001$), with a large effect size ($\eta^2p = .329$). Post-hoc comparisons using the Bonferroni correction showed that the 'flashing lights' condition had a significantly lower mean PSE value, than the 'mesh' condition ($p = .001$) and the 'poles' condition ($p = .005$). There was not however, a significant difference in PSE means for the poles and the mesh conditions ($p = 1.00$). A direct comparison of the participants' mean perceived speeds (as calculated by the PSE) for the train under the flashing lights condition and the car did not detect a statistically reliable difference ($t(21) = 1.31$, $p = .203$, $d = .280$) or any indication of a size-speed illusion when the train was equipped with flashing lights.

Individual PSE values for the flashing light intervention was closest to the standard car speed of 80km/h for the majority of the participants, with many commenting that the train with flashing lights ‘seemed faster’ than the trains without the lights.

5.4. Discussion

We have found that the effects of the size-speed illusion (Clark et al, 2013; 2016, 2017) can be eliminated by manipulating eye movement behaviour with a targeted intervention strategy. The flashing lights intervention, which was designed to manipulate which part of the train the observer fixated, and their smooth pursuit eye movements, significantly reduced the size-speed illusion compared with the two other intervention strategies. When comparing the relative speed of a car travelling at 80km/h, observers reported no differences in perceived speed with a ‘flashing light’ train travelling at the same relative speed. Conversely, significant underestimations of the train’s relative speed, compared to the car were still found with the other two intervention strategies (poles and mesh), which indicates manipulation of fixation eye movement has only a limited effect in reducing the size-speed illusion.

When comparing our results to earlier studies (Clark et al, 2016, 2017), there are similarities with the mean PSE results for both the pursuit and fixation strategies. Clark et al, (2016) required the participants to track a dot placed on vehicles, forcing them to use smooth pursuit eye movements. In that instance the dot placed on the front of the train tracking behaviour reduced the magnitude of the size-speed illusion. The flashing lights intervention appears to verify this strategy.

In contrast, Clark et al's (2017) experiment, designed to explore fixation behaviour (adding a reference 'square'), showed that where initial fixations were made did affect the illusion, but did not eliminate it completely. Our pole intervention was based on this strategy, as well as previous research (Berthelon & Mestre, 1993; H. W. Leibowitz, 1955; Uchida, de Waard, & Brookhuis, 2010); Vishwanath & Kowler, 2004) which suggested that accuracy in estimated speed increases with the addition of a reference marker in the environment. While the magnitude of the illusion was less than our third intervention strategy (mesh fence) the size-speed illusion persisted to some degree. It should be noted that the trial sequence presentation time deviated somewhat from what was used in the 2017 study (400msec), however, our participants' perceptions of speed in the poles condition are consistent with the results of that study regarding fixations localized on the front region of the train.

Our results also demonstrate that the size-speed effect transfers well across different methodologies and equipment. The same basic results were found for both the smaller desktop screens used in earlier studies and the larger displays used in the simulator setting. One reason for using the driving simulator was to provide ecological validity to an already established methodology (i.e., participants seated in a car 'approaching' a level crossing). The results for all our participants follow a similar trend to the earlier studies that were conducted on a 1920 x 1200mm screen, which indicates that the size-speed illusion is consistent across our laboratory settings.

Although the results of our study has provided strong support for the use of an intervention that manipulates observer eye movements, particularly with respect to smooth pursuit eye movement behaviour, there are limitations that should be noted. The experiment tested only trains that were fitted with countermeasures and did not include a comparison with a train that was designed without an intervention strategy; therefore it is difficult to assess how well all of our countermeasures would have performed compared to a standard freight train condition. However, as mentioned above, previous studies using the standard train stimuli (Clark et al, 2013; Clark et al 2016) have consistently found underestimations of a train's relative speed, compared to a car across multiple scenarios, with these underestimations ranging from 8 to 13km/h difference, while other studies (Barton & Cohn, 2007; Cohn & Nguyen, 2003) have had comparable results with small and large approaching objects (rectangular and spherical shapes). Our findings for the flashing light condition on the other hand show virtually no difference in perceived speed compared to the standard motorcar, which appears to verify that this particular intervention strategy makes a difference to observers' perceptions of the train's relative speed.

Because of the physical constraints imposed by the simulator vehicle and screens, we did not record eye movements in this particular experiment, and therefore do not have clear evidence that the flashing lights intervention for example, is solely a result of the light stimulus instigating smooth pursuit behaviour. However, the similarity of our results to the previous pursuit and fixation studies strongly suggest that similar patterns of eye movements occurred as when eye movements were recorded. With regards to the poles intervention, some participants (early responders) tended to respond when the train had just passed the second pole, which seems to indicate that they were using this pole as a reference marker, and therefore it is reasonable to infer that fixations on the poles were occurring. It is difficult to conclude what particular eye movement patterns were occurring in the mesh intervention scenario other than that fixation must have been occurring further down the train compared to the flashing light condition, otherwise no size-speed illusion would have occurred.

While the translation of stimuli from desktop computer screens to a more realistically sized environment was found to be sound, our experiment still lacks certain real-world aspects. Our observers viewed the approaching vehicles from a ‘stationary’ vehicle, which meant that self-motion, a possible confound, was not included in the experimental design. The successful use of the simulator in this experiment should aid in developing experiments that utilize more simulator settings (e.g. forward motion, audio, measurement of acceleration and deceleration) in future.

In conclusion, our study has shown that interventions designed to influence smooth pursuit eye movements are the most effective in the vehicle speed discrimination task. Observers reliably perceive a train with flashing lights on the front as travelling at a similar velocity to a car moving at the same relative speed, as opposed to trains utilising different types of interventions, which appear to move slower. A modified version of our flashing light stimulus shows promise of being an inexpensive, yet effective intervention in the real world.

Chapter 6. General Discussion

Level crossing collisions between road vehicles and trains are recognised as a priority issue both in New Zealand and worldwide. Clark et al. (2013) first explored the idea that this type of collision could be due in part to a size-speed illusion – where a larger, longer vehicle (e.g., train) appears to be moving slower than a smaller vehicle (e.g., car) travelling at the same speed.

The purpose of this thesis was to firstly verify the size-speed illusion, and then to explore factors contributing to it, in particular whether the role of observer eye movements when perceiving moving vehicles plays a part. The overarching theory motivating this set of experiments was that the size-speed illusion can be explained, at least in part, by an observer's eye movement behaviour.

The original research question was to determine whether measurement of eye movements might shed some light onto why observers perceive trains as moving slower, relative to smaller vehicles such as cars. Experiment 1 was designed to verify the presence of a size-speed illusion (Clark et al, 2013), while also recording and measuring participants' eye movement patterns. Participants' relative speed estimations of trains and cars, approaching at a range of speeds and distances were tested in a simulated environment, with an eye tracker recording image (x,y) position and eye velocity as the observers judged the objects' relative speed.

6.1. The size-speed illusion and eye movement patterns

Experiment 1 confirmed the size-speed illusion. This illusion was robust across a range of different stimuli sizes and orientations; it occurred not only at the close observer distance used in the original Clark el al's (2013) study (6m from the crossing), but also when the observers were situated some distance away from the simulated rail crossing or intersection (18m, 36m).

Eye movement analyses revealed that the eye movement behaviour of participants was different when they judged the speeds of the small and large vehicles. Participants tended to make initial fixations localised around the visual centroid, a region of the train that was located further away from the front of the large train approaching in depth, as opposed to the smaller car. This was an important finding, because the retinal motion of the centroid is slower for an object moving in depth compared to the front edge, and this may lead to underestimation of a vehicle's perceived speed.

The findings of Experiment 1 raised the possibility that manipulating observer eye movements could possibly change the effects of the size-speed illusion. With two distinct types of eye movement strategies being explored, (smooth pursuit, and fixation-saccade-fixation) the next two experiments were designed to isolate each type of eye movement pattern for further analysis.

6.2. Smooth pursuit vs. fixation-saccade-fixation strategies

Experiment 2 explored analysis and manipulation of smooth pursuit eye movements. Participants were required to track targets (dots) that were placed at strategic locations of vehicle 'shapes' (front, middle and end). When the observers tracked the dots placed on corresponding locations at the front of the small object and the long object respectively, they perceived the speeds of the two objects as equal (therefore the size-speed illusion was eliminated). When the target dot was placed closer to the visual centroid, observers perceived the larger object to be moving slower. The results from Experiment 2 showed that manipulation of smooth pursuit behaviour (such that eye movements were constrained to be near target areas around the front of the moving objects) was a very effective means of reducing the magnitude of the illusion.

In contrast, Experiment 3 was designed to isolate the other type of eye movement pattern behaviour, namely fixation and saccades. For this experiment (utilizing the same simulated environment as Experiment 1), a 'fixation square' was added to the foreground environment at one of two possible locations, with participants instructed to look at the square at all times while making judgements about the relative speed of a train compared to a car. The results of this experiment also showed some success at reducing the magnitude of the size-speed illusion – the effect of the illusion was much smaller when the fixation square was placed at a location point where the front of the train passed behind it, as opposed to when the fixation square was placed at a region where the train's visual centroid passed behind it.

6.3. Applying the eye movement findings: Testing effective countermeasures to combat the size-speed illusion

Experiments 1, 2 and 3 showed that not only were eye movements apparently related to the size-speed illusion, it was also possible to manipulate these eye movement patterns in order to subsequently reduce or eliminate the illusion altogether. With this finding verified, the logical step was to look at possible interventions that could be appropriate to use in applied settings.

Therefore, Experiment 4 was conducted in order to test the effectiveness of three intervention strategies – each designed to manipulate observer eye movements. The first intervention was fitting a pair of adjacent bright lights to the front of the train engine, which would flash on and off consecutively as the train approached. This design was based on the smooth pursuit findings from Experiment 2. The other two interventions were based wholly or in part on manipulating fixation and saccadic eye movements investigated in Experiment 3, with the addition of fixtures in the static background environment. Intervention two involved the placement of two red and white striped poles along the near side of the train track, while the third intervention tested was the addition of a green mesh screen alongside the track in the foreground – an intervention which also incorporated principles of possible partial occlusion effects on the participants.

The results of Experiment 4 showed clearly that the addition of the flashing lights was the most effective in reducing the size-speed illusion, with observers consistently reporting no perceived difference in speed between the train fitted with the lights and a motorcar travelling at the same speed. Observers also anecdotally reported that the ‘flashing lights’ train appeared to be moving quicker than the other trains (with either poles or screen added). These findings were consistent with the earlier findings of Experiment 2, suggesting strongly that manipulating the smooth pursuit type eye movement pattern is the most effective countermeasure to the size-speed illusion.

6.4. Limitations

This thesis has only looked at one aspect of sensory information available to motorists (vision), and therefore other aspects such as auditory information have not been investigated. Humans rely largely on visual cues to navigate their surrounding environment and therefore this type of sensory information governs behaviour. It is also important to note that for car drivers, the interior of the car is designed to soften outside noise (not to mention other noise may be occurring inside the car – radio going, passengers talking etc.). Nevertheless, auditory cues are apparent in other scenarios, such as for pedestrians crossing railway tracks and therefore could possibly be more of a factor with these types of situations.

Simulated self-motion was not employed in any of the experiments and is a possible confound that should be investigated. Many times a decision of whether or not to proceed through a level crossing or intersection occurs when the motorist is driving towards the crossing. Experiment 1 did include different angles of approach and found no difference in the results, which indicate that the change in visual angle as the distance decreases between the observer’s vehicle and the approaching train had little effect. However, the perceived speed of the approaching vehicle while the observer is moving (which may be more difficult to judge than if one were stationary) and the extent to which variances in the velocity of self-motion exacerbates that difficulty may be possible confounds. Aspects of the background environment can interfere with our perception – e.g., perceived velocity can increase if the background motion is in the opposite direction to the attended object. The approach speed of the motorist is also not necessarily constant. Deceleration when approaching an intersection is likely, while Chihak, et al (2010) found that corrections in one's own speed (acceleration) are often made to clear gaps safely and occur frequently in the last few seconds.

Although the size-speed illusion appears to be a robust explanation for at least one possible cause of collisions between cars and larger vehicles, it seems to be counterintuitive to the problem of collisions between cars and motorcycles at intersections. A small motorcycle should be overestimated in its speed according to the theory behind the size-speed effect, however these collisions frequently occur (Ministry of Transport, 2016). Other theories such as 'look but fail to see' (i.e. inattentional blindness) have been put forward as possible reasons for these types of accidents (Crundall, Humphrey & Clarke, 2008; Horswill, Helman, Ardiles, & Wann, 2005). Inattentional blindness has been anecdotally cited as a possible reason for railway level crossing collisions as well, but was not tested here. However eye tracking methods similar to the studies conducted here remains an option to test whether inattentional blindness is also occurring in intersection collisions.

6.5. Future directions

The research studies presented in this thesis have provided several interesting results that should be pursued in future studies. Verification of eye movement patterns for all the countermeasures tested in Experiment 4 should provide robust evidence for using at least one type of the above countermeasures in the real world. The recent and ongoing development of virtual reality (VR) based research offers a novel method of incorporating controlled experimental methodologies into more naturalistic settings. For example, using a portable VR head mounted system along with eye tracking (e.g., custom-built inside the headsets), it would be possible to run realistic simulated scenarios that used video imagery of an approaching train at a real (unused) level crossing.

The influence of self-motion, as mentioned above, is a question that remains unanswered and further investigations (either simulator based, or VR based experiments) are warranted. Finally, this thesis has concentrated on the motorcar vs. train collision scenario; however there are many other types of road incidents resulting in fatalities and major injury that can be explored. Collisions between small vehicles and heavy road vehicles at intersections may also be in part due to the size-speed illusion. A small amount of unpublished research (not included in this thesis) was undertaken as part of the wider experiments which included trucks and buses for comparison. Results from this data set suggest that the size-speed illusion persists for these vehicles as well, albeit on a smaller scale. Eye movement patterns appear to be similar for these types of vehicles with fixations localised around the visual centroid. It is worthwhile to expand research into these vehicle types as well, given that collisions between cars and heavy vehicles at t/x-intersections occur on a regular scale as well. In addition, pedestrian trespass has recently been an area of interest for rail safety campaigners. As mentioned above, there may be other factors that come into play with regards to pedestrian trespass, (either alongside of, or separate to, the size-speed illusion). This remains an area of little research and therefore should be fully explored.

6.6. Conclusion

In summary, this thesis has explored the role of observer eye movements in the size-speed illusion – an illusion which may in part be a factor in collisions between cars and trains at railway level crossings. This illusion has been verified across multiple experiments in this thesis. Eye tracking technology has provided not only answers to why this illusion may occur, but also provided insight into if, and how the effects of the size-speed illusion can be reduced. The results of these set of studies provides a promising avenue for reducing collisions at railway level crossings in the future.

List of Appendices

School of Psychology

The University of Waikato
Private Bag 3105
Hamilton, New Zealand

Phone +64 7 838 4032
www.waikato.ac.nz

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

Research Participants Needed

Railway level crossing accidents are a persistent problem on New Zealand roads.

I am undertaking a PhD, which is trying to identify whether there are factors contributing to the rate of level crossing accidents associated with visual or perceptual illusions.

- Participants will be required to complete a computer based task, that will help determine why people make judgements to cross a railway level crossing even when there is a train approaching. Participants will also have their eye movements monitored by an eye tracker.
- Participation will require approximately 30 to 45 minutes.
- All enrolled first-year Psychology Students are eligible to receive 1% course credit toward their Psychology course. All other participants will receive a $10.00 petrol voucher as reimbursement for their time and effort.
- All data collected by the researcher will be strictly confidential and accessible only by the researcher and supervisors.
- This study has been approved by the School of Psychology's Research and Ethics Committee.

If you are interested in being part of this research, or have any further questions, please contact me:

Helen Clark
hclark@waikato.ac.nz
Room JK.1.01
Ext 8403

University of Waikato
School of Psychology
CONSENT FORM

PARTICIPANT'S COPY

Research Project: An Investigation into the Factors affecting the Perception of a Train's Travelling Speed.

Name of Researcher: Helen Clark

Name of Supervisor (if applicable): Associate Professor John Perrone

I have received an information sheet about this research project or the researcher has explained the study to me. I have had the chance to ask any questions and discuss my participation with other people. Any questions have been answered to my satisfaction.

I agree to participate in this research project and I understand that I may withdraw at any time. If I have any concerns about this project, I may contact the convenor of the Research and Ethics Committee (Dr Lewis Bizo, phone: 838 4466 ext. 6402, e-mail lbizo@waikato.ac.nz)

Participant's Name:______________________Signature:_________________Date:_______

==

University of Waikato
School of Psychology
CONSENT FORM

RESEARCHER'S COPY

Research Project: An Investigation into the Factors affecting the Perception of a Train's Travelling Speed.

Name of Researcher: Helen Clark

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I have received an information sheet about this research project or the researcher has explained the study to me. I have had the chance to ask any questions and discuss my participation with other people. Any questions have been answered to my satisfaction.

I agree to participate in this research project and I understand that I may withdraw at any time. If I have any concerns about this project, I may contact the convenor of the Research and Ethics Committee.

Participant's Name: ______________________Signature:_______________ Date:_______

University of Waikato
School of Psychology

An Investigation into the Factors affecting the Perception of a Train's Travelling Speed

Information Sheet

Please read the following information carefully. It contains an outline of what the study is about and will help you to understand your role as a participant. Please feel free to ask questions regarding the experiment or the research study in general.

Agreement to participate is entirely voluntary and you may withdraw from the experiment at any time without explanation or repercussion.

The Research Topic

The prevalence of collisions between motor vehicles and trains at railway level crossing junctions has been a high-profile issue for a number of years in New Zealand. Although there is clear recognition of this problem and attempts to raise public awareness via advertising campaigns and education, there has been very little research analysing whether visual or perceptual illusions contribute to these types of collisions. The topic of this research is to investigate whether factors such as self-motion and the point of observation have an effect on ability to perceive the speed of other vehicles. In particular, the study will focus on a motorist's perception of a train's approach speed, when they are arriving at a railway level crossing.

Your role today

When you first arrive, I will explain the experimental process to you, and there will be a short series of training modules to help you gain familiarity with the experiment. Once you feel confident with the procedure the experiment proper will commence.

The experiment will require you to view a number of computer animated sequences that will show either a train or a motorcar approaching from the right hand side. You will be asked to make a direct comparison between the speeds of these approaching vehicles, and indicate which of the vehicles appears faster. This experiment will count for one course credit (first year Psychology students only) or a 10 dollar petrol voucher.

Your eye movements will also be recorded during the experiment by an eye tracker. You will need to keep your head still on the chin rest provided to enable the eye tracker to record accurately.

Time duration

The experiment is expected to last 30 to 45 minutes. During this period you will be provided with multiple breaks. This is to help minimise any discomfort from keeping your head still on the chin rest for a period of time. The room will also be darkened for the experiment. If this is a problem for you, or if you have any other concerns please let me know as an alternative option may be able to be arranged.

Confidentiality

All of your data including your consent forms will be treated in the strictest confidence, with only the research supervisors and myself having access. You will not be identifiable by name, as all data will be coded. All data and consent forms will be destroyed once the research is completed. Participants will remain anonymous and no individual will be able to be identified via publication of research findings.

Ethical approval

This research project has been approved by the Psychology Research and Ethics Committee of the Faculty of Arts and Social Sciences. Any questions or concerns about the ethical conduct of this research may be sent to the Convenor of the Committee, Dr Lewis Bizo: phone 07 838 4466 ext. 6402, email:lbizo@waikato.ac.nz.

Your time and effort is greatly appreciated, please relax and have fun!

Researcher: Helen Clark

hclark@waikato.ac.nz

Room JK.1.01

Ext 8403

Chief Supervisor: Associate Professor John Perrone

jpnz@waikato.ac.nz

Ext 8292

Co-Supervisors: Dr Robert Isler

r.isler@waikato.ac.nz

Ext 8401

Associate Professor Samuel Charlton

samiam@waikato.ac.nz

Ext 6534

Would you be interested in the outcome of this study? Please indicate your choice below.

"I wish to receive a copy of the summary of results and findings"

YES NO (Please circle your choice)

Contact Details

Name: ____

*Postal Address: ____

____

*Email Address: ____

*(Please choose and fill out either (or both) contact address for preferred communication of findings summary).

University of Waikato

School of Psychology

An Investigation into the Factors affecting the Perception of a Train's Travelling Speed

Instructions for Participants

This experiment will be using two computer monitors. You will be seated facing the left-hand monitor. However you will be viewing the computer animated sequence on the right-hand monitor. The left monitor screen will display a still image of a railway level crossing in a rural setting.

The eye tracker chin rest is situated in front of the right monitor screen. Youwill need to turn your head only to face the right monitor screen and place your chin on the chin rest. Make sure that you are able to do this comfortably so as not to place undue stress on your neck and back. The chair should be placed close and the chin rest should be at a comfortable height. There will be multiple breaks provided during the experiment to help minimise discomfort.

The right monitor screen will go blank. This indicates that the trial is about to start. This screen will then be replaced by a rural setting identical to the left monitor screen, except that the angle of shot is now looking down the railway track on the right hand side.

The experiment proper will consist of the following. A vehicle will start to approach you from the right hand side. This vehicle will be either a freight train or a motorcar. The animated sequences will run in pairs (train displayed first, followed by car). Once each pair of sequences has completed, a response screen will display. You will be asked to judge which of the vehicles appears faster. Move the cursor on the screen to indicate your choice, and then press the left key of the computer mouse. The screen will then go blank.

There will be a series of practice trials to help you become familiar with the experiment. Once you are confident with the procedure please let me know and we will commence the experiment proper.

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