VISUAL PERCEPTION AND ANALYSIS OF AN APPROACHING TRAIN AT RAILWAY LEVEL CROSSINGS IN NEW ZEALAND

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Abstract

The prevalence of railway level crossing accidents in New Zealand is a high profile issue that has warranted close scrutiny over the last 10 years. However, the incident rate has not decreased. This research examined the possibility that visual illusions and perceptual errors contribute to an underestimation of a train's arrival time by motorists. The first experiment was designed to analyze whether the Size-Arrival Effect, a theory that states that large-far objects are judged to arrive earlier than small-nearer objects, was applicable to trains. Participants were shown a computer simulation of a moving vehicle (train, motorcar or motorcycle) and asked to indicate when the point was reached where they would no longer cross in front of the approaching vehicle. Approach speeds were systematically varied (60 km/h, 70 km/h, 80 km/h, 100 km/h and 120km/h). Results found that participants adopted the greatest safety gap distance to cross for the train. However, there was no adjustment for velocity when adopting safety gaps for the train and the motorcycle with observers using the same gap distance, regardless of the approach speed. The second experiment sought to examine the Leibowitz hypothesis (Leibowitz, 1985), which proposes an illusory bias; a large object seems to be moving more slowly than a small object travelling at the same speed. Experiment 2 measured participants' ability to make a direct comparison between the speed of an approaching motorcar and a train. Participants were asked to judge which of the vehicles appeared faster, with the distance from the observer varied (far, middle or near). Participants significantly underestimated the speed of the train as compared to the car, in both the 'middle' and 'near' conditions, with the magnitude of underestimation greatest in the ‘middle’ condition. The overall findings offered support for both theories, which indicates that a combination of distance and speed perceptual errors may at least partly contribute to the high rates of level crossing collisions.

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"Level crossing safety is a priority area for action because of the fatal and injury accidents associated with them." (Ministry of Transport, 2005b).

Railway level crossing collisions are an ongoing problem on New Zealand roads. Between 1998 and 2004, there was an average of 20 motor vehicle accidents at level crossings which have involved either injuries or fatalities (Ministry of Transport, 2005b). From 2004 to 2007, the accident rate has varied between 13 accidents to 20 accidents (Ministry of Transport, 2004, 2005a, 2006, 2007, 2008, 2009).

While the numbers do not seem high as opposed to overall New Zealand road tolls (which approximately range between 366 fatalities to 461 fatalities 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 twenty-nine percent of all railway accidents occurred at, or were associated with level crossing intersections (Ministry of Transport, 2005b). It is important to note that the impact and potential impact of a level crossing collision is far-reaching, and the implications for New Zealand society should not be understated. The most obvious is the tragedy of death and injury which is often preventable. However there are other potential effects on people who were not those directly killed or injured. As well as the surviving occupants of a crash and families of the deceased and injured, there is also emotional trauma 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 of a train derailment to occur which potentially could have disastrous consequences.

New Zealand rural areas in particular, have had high incidence of level crossing collisions. (For the purpose of this study, the definition of ‘rural’ is a road that has a speed limit of over 70km/h.). This can occur despite a strong probability of a motorist encountering a level crossing that has either good visibility of the railway track over a respectable distance, and/or warning procedures in place (alarm bells and/or barriers). For example, in 2007 there were a total of 16 accidents overall, with 9 occurring at a rural crossing (56%). Out of these accidents, 5 fatalities occurred overall, with 4 being at rural crossings (80%). Table 1 shows fatality and injury statistics for New Zealand urban and rural regions for the 10 year period between 1999 and 2008, while Figure 1 provides a visual map of the location of these reported accidents.

Table 1.

Reported level crossing accidents involving motor vehicles in New Zealand for the five year time periods 1999-2003, and 2004-2008.

	Urban	**Rural**
1999 to 2004		
Fatal	3	14
Injury	23	20
Total	26	34
2005 to 2008		
Fatal	5	15
Injury	29	24
Total	34	39

Source: Crash Analysis System (CAS) (personal communication, July 16, 2009).

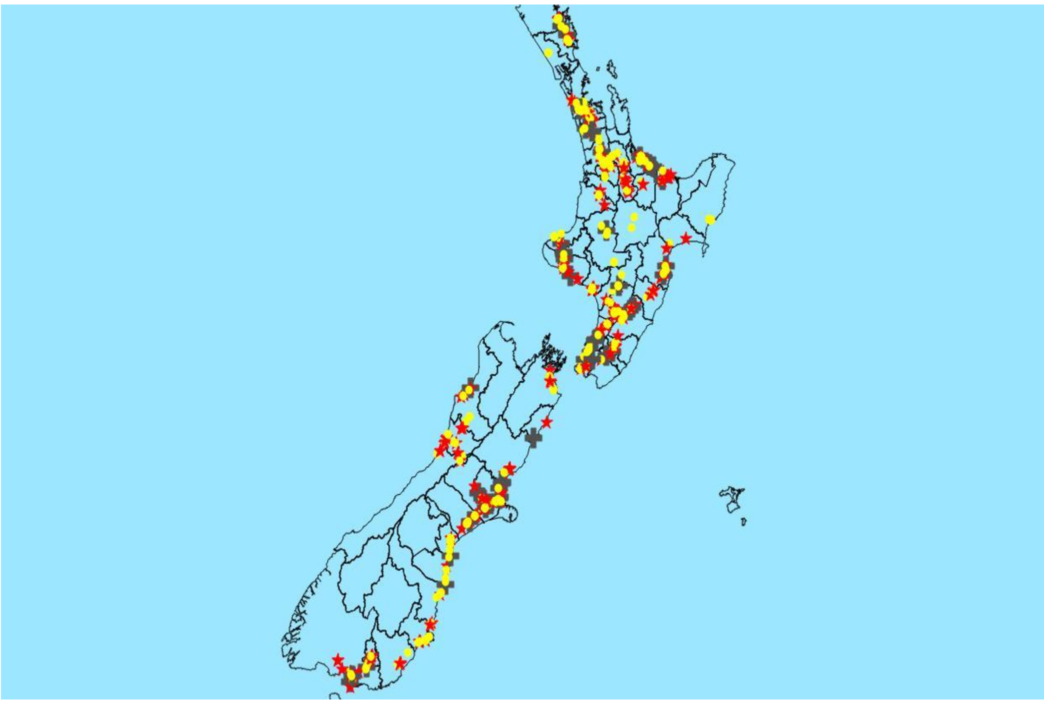

Figure 1. Reported level crossing accidents in New Zealand 1999-2008. Fatalities are indicated by the black crosses, major injuries red stars and minor injuries by the yellow dots.

The above statistics do not take into account the number of ‘near misses’ that occur. These are important to note because a ‘near miss’ could have easily been an injury or fatality at any other time. Near misses are reported to the New Zealand Transport Authority (NZTA) by Kiwirail employed locomotive drivers. Table 2 contains the number of near misses that were reported for the five year period between 2004 and 2008.

Table 2.

Near misses reported by Kiwirail locomotive drivers for the period 2004-2008.

Year	**Near Misses reported by Kiwirail**
2004	17
2005	43
2006	28
2007	31
2008	43

Source: Crash Analysis System (CAS)) (personal communication, August 26, 2009).

There are a good number of risk management procedures put in place by authorities in order to avoid level crossing collisions. New Zealand, like many other countries, employs two methods of level crossing warning protection devices. *Active protection devices* are installed flashing red lights and warning bells, which, when activated, signal that the approaching vehicle must stop and wait for the train to pass and the lights and bells to cease before crossing the tracks. In some cases these are also accompanied by arm barriers which are lowered to prevent passage.

Passive protection devices are visual signage located at the level crossing. These consist of either Stop or Give Way signage and black/white 'X' shaped railway crossing signs (cross bucks) advising of the crossing ahead. In New Zealand currently, passive protection is found on the majority of level crossings, whereas active protection is erected at railway crossings with either poor visibility or high traffic volumes (these are deemed as a higher potential risk of collision area) (Ministry of Transport, 2005c).

Figure 2: Photos of the warning protection devices used in New Zealand. From left - Active protection system with half-arm barrier, active protection with warning bells only, passive protection system.

When trains approach a railway level crossing, they will sound their horn to serve notice of their imminent arrival (this is often required by law in most countries), providing an auditory cue of a hazard. Visually, trains will also have their headlights on regardless of whether it is day or night (Leibowitz, 1985). A train locomotive engine by itself is a very large object. For example, the NZR DC class locomotive engine (the most common engine used for freight shipment in New Zealand) alone has dimensions of 4.30 metres height (not including wheel diameter of 1.25 metres) by 3.01 metres width, with a length of 14.10 metres, not to mention the added length of several carriages and containers that some pull, which can stretch for some kilometres in length. The average locomotive weight is approximately 82 tonnes. A train locomotive can reach a top speed of 100km/h, sometimes 120km/h.

The above risk management systems in place would seem to be more than sufficient to severely limit the probability of having a collision with a train at a level crossing. Therefore in order to determine why motorists will still attempt potentially hazardous crossings, (despite advance warnings); the behaviour of the driver needs to be analyzed.

Driver Behaviour

A Ministry of Transport report (2005c) stated that "Driver error is the biggest contributing factor in level crossing accidents"(p.6). When encountering a railway level crossing, be it either marked with signage or barriers/warning bells, motorists seem to employ a different mindset on how to approach and cross, as opposed to road intersections. The degree of caution taken appears to be reduced (Ministry of Transport, 2005c). This may be because a motorist approaching a railway crossing feels that the probability of encountering an approaching train (perceived threat) as low and insignificant (Witte & Donohue, 2000), therefore they will "ignore information about the threat" (p.128).

The probability of encountering a train may be even lower in New Zealand than in other countries. Rail is not a common form of public transport with the exception of the capital city Wellington, and to a lesser extent Auckland. Freight trains are the type that are most likely to be encountered, however even this would be very unlikely, and depends a great deal on location.

In his review of level crossing collisions in North America, Leibowitz (1985) pointed out several factors that may contribute to driver behaviour at level crossings. Railway crossing warning protection systems are often developed to “the worst case” design (p.559). For example “...lights, bells and gates are activated in sufficient time to accommodate the fastest train, the slowest motorist and the worst weather” (p.559). The warning system also needs to allow for the fact that a fully laden locomotive with carriages requires a large distance of track in order to brake safely. In reality, the timing of the warning system being activated before the train arrives is often considered “too early” and excessively long by the average motorist (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.

Another issue to consider is visibility. If the visibility of the railway track is impeded by obstacles, (for example by trees lining the track), or if the track itself is laid out in a manner that visibility extends only a little way down, it would be reasonable to expect that motorists would be more likely to approach these level crossings with more caution. However despite good visibility being associated with being less hazardous, good visibility may actually be encouraging potentially more hazardous behaviour on behalf of the motorist (Wilde, Hay & Brites, as cited by Ward & Wilde, 1996). This is consistent with *Risk Homeostasis Theory* (Wilde, 1994a). The basis of risk homeostasis theory is that when people are faced with a subjective estimation of risk in whatever activity they happen to be engaged in (be it estimated risk to their safety, health or other), they will accept that risk *to a certain level* in exchange for the perceived benefits of that activity (Wilde, 1994a). The weighing up of subjectively estimated risk and benefits tends to be an internal process (built up after previous exposure to similar situations) and is so deeply ingrained that people are mostly not consciously aware of what they are doing (Wilde, 1994b).

If a train track has impeded visibility, risk homeostasis theory would propose that a motorist would perceive the risk of continuing through the level crossing as being at an unacceptable level. Being unable to clearly see whether a train is approaching (risking a potential collision), would outweigh the benefit of proceeding across immediately with no hold ups. When railway tracks with greater unobstructed visibility are encountered however, perceived risk is more likely to be reduced to a subjective acceptable level, which could account for failure to give way and faster approach speed behaviours by motorists (Ward & Wilde, 1996). In New Zealand, railway lines in rural areas are often long and straight, and are generally surrounded by flat farmland, resulting in little visual impairment of the track.

Then there are those motorists who engage in deliberate 'risk-taking' behaviours. Typically these people are making conscious decisions to try to 'race the train' with little or no regard for the road laws or personal safety. Witte and Donohue (2000) looked at the cognitive process of assessing possible risk outcomes against the perceived benefits of proceeding through a level crossing, by using the extended parallel process model (EPPM). This model is based on 'fear appeal' – a research area that focuses on what constitutes an effective risk message. Many educational campaigns (e.g., risks of smoking, drink-driving adverts) use fear appeal to induce anxiety in the target audience, because they will highlight risk and consequence of the behaviour or behaviours. Witte and Donohue (2000) applied EPPM processes to level crossing behaviours that could be undertaken by motorists. For example motorists may firstly "…appraise the threat of the hazard by determining whether they think the threat is serious (e.g. 'is a collision with a train harmful?') and whether they think they are susceptible to the threat (e.g. 'is it possible that I will have a collision with a train?')" (Witte & Donohue, 2000, p.128). If the motorist feels that one or both of the above applies, then wariness and fear levels are heightened, which then leads to the second cognitive process – the recommended course of action, taking into account safety laws and considerations. For example if there are warning bells activated the motorist will determine whether their responsibility to uphold road laws is of greater importance than their own personal situation, and if they have sufficient control of their impulses to obey or not (Witte & Donohue, 2000). However if the motorist feels that there is neither a threat severity nor vulnerability to it, then they are likely to ignore the recommended course of action (Witte & Donohue, 2000).

With level crossing controlled by passive warning systems, the responsibility of the decision making process falls to an even greater extent on to the motorist. This is because the removal of warning devices also removes sensory information aids of imminent threat. Therefore the judgement of perceived threat is now entirely up to the motorist and adherence to road laws become less of a decision factor as well.

When a motorist approaches a passive crossing there are two competing contexts that they perceive. On one hand an encounter with a train is possible and potentially extremely harmful. On the other hand the probability of that encounter is rare and even more unlikely to lead to harm (Ehrlick, 1989, as cited by Ward & Wilde, 1996). The context of perceived risk and the level of willingness of taking risks are therefore weighted against the improbable chance of occurring. Which one wins out will manifest itself in the behaviour that subsequently occurs.

The above findings point to motorists making decisions based on their own thought process of perceived risk first and foremost, even if this decision is contrary to road law. But how is the conclusion of perceived risk first formed? The basis of this judgement seems to rely on external cues available to the motorist, and the most obvious of these are visual or perceptual. Therefore, it is reasonable to ascertain that visual information received and interpreted by the driver plays an important role in the driver’s decision to proceed through the level crossing or not. The perception of the approaching train therefore is the main focus of this thesis examining whether there could be a possible link between perceptual error and level crossing collisions.

Speed Perception and Velocity curves

Rosenbaum (1975) defined velocity as "the rate of change of position in time" (p.396). Although constant velocity in the world may be thought of as linear, this is not the case when distance and perspective is considered. An object may be in reality approaching at a constant speed; however the optical image of that object on the retina does not have a consistent, steady rate of expansion. At far away distances the rate of expansion of the image and angular change increases slowly (Leibowitz, 1985). However as the distance decreases, the visual rate of expansion will then increase rapidly. A decision to cross in front of an approaching motor vehicle is likely to be made when that vehicle is still some distance away (for example 70 metres). At that distance, the optical expansion rate is increasing slowly, giving the impression that the vehicle is travelling more slowly than is actually the case. This can result in underestimation of the vehicle's arrival time (Leibowitz, 1985).

The accuracy of arrival time has also been found to be influenced by the length of the arrival time, in that if time to contact is more than 2 to 3 seconds away, perceptual information received at this distance is not sufficient enough to reliably estimate arrival time (Barton & Cohn, 2007; Carel, 1961, as cited by Schiff & Oldak, 1990; McLeod & Ross, 1983, as cited by Schiff & Oldak, 1990; Schiff & Detwiler, 1979, as cited by Schiff & Oldak, 1990).

Previous studies have inferred poor ability to perceive speed of an approaching train. Meeker, Fox and Weber (1997) tested the theory that as a train's speed increases; the likelihood of probability of crossing would decrease (due to the notion that this also impacts on the time available to cross). However, they found no relation between these two variables and concluded that when approaching trains are at some distance away from the level crossing, the perception of their apparent speed seems to be rather difficult for vehicle drivers to judge (Meeker et al., 1997). It is apparent that motorists' perception of crossing risk and the ability to accurately predict the speed of approaching trains is poor (Mok & Savage, 2005; Savage, 2006). This inability to determine the approaching speed can at least in part be explained by the rate of expansion **(**ROE**)** or optical change of an object on the retina, and can be seen when velocity curves are plotted. A velocity curve shows the angular velocity of an object relative to an observer at distance (D) away. As the object approaches, the closer it gets to the observer, the faster it's ROE on the retina relative to its point on the curve. For example an object moving at a constant velocity will have a slower ROE at 100m distant, as opposed to 20m distant, where the ROE increases substantially.

Figure 3 gives examples of angular velocity curves. For distances greater than about 20 metres, they can be represented by hyperbolic functions (Leibowitz, 1985) that illustrate the non-linear expansion rate.

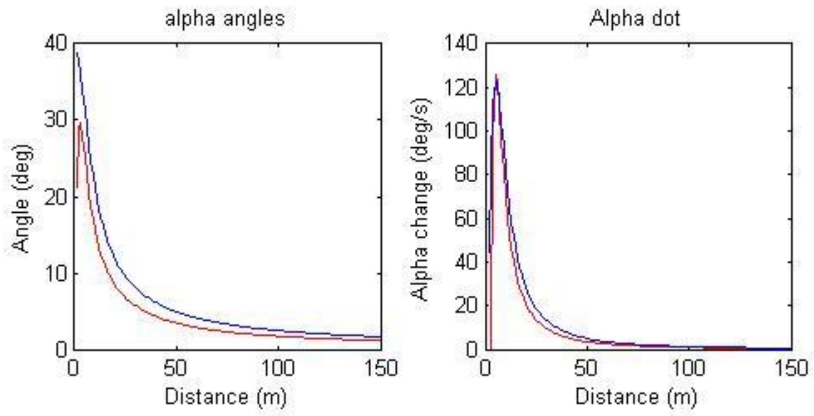

Figure 3: Accelerated rate of expansion (ROE) curves/hyperbolic functions (Leibowitz, 1985).

The other property that can influence perceptual estimates of expansion rates and arrival times is the angle of the approach. Typically, the greatest underestimations occur when an object is approaching head-on (angle of approach = 0°). Oblique approaches result in smaller underestimations than head-on, but are still less accurate than transverse approaches (Schiff & Oldak, 1990). Therefore as the angle of approach increases, the more accurate the estimate of arrival time will be (Schiff & Oldak, 1990). The angle of an approaching train to a motorist is more likely to be oblique than transverse, unless the motorist is a great distance away from the track.

Time-to-Contact and the Size-Arrival Effect

Time-to-Contact (TTC) or Time-to-Arrival studies look at how accurately humans can judge when particular approaching objects will either collide with them (Lee, 1976), or pass them by (Schiff & Oldak, 1990). Using TTC measures, DeLucia (1991) proposed a theory known as the Size-Arrival Effect. This states that larger, far objects are perceived to arrive sooner than smaller, near objects. This can lead to overestimation of arrival time for smaller objects (when an object is perceived to arrive later than it actually does), and underestimation of arrival time for much larger objects (when an object is perceived to arrive sooner than it actually does). DeLucia (1991) found that when two squares approaching at the same speed were judged by participants, the larger, further away square's arrival time was underestimated and vice versa.

More recently, research has looked at the implications of the Size-Arrival Effect in applied road safety research. Caird and Hancock (1994) found that when comparing four different sized vehicles (motorcycle, compact car, full-sized car and van), the smaller the size of the vehicle, the more likely it would be that that the arrival time (TTC) would be overestimated. Horswell, Helman, Ardiles and Wann (2005) also found that in the case of motorcycles, car drivers tend to overestimate TTC even more so than with other vehicles. They suggested that motorcycles approaching at intersections were subjected to a time-to-arrival illusion; that is, that car drivers tended to underestimate the arrival time of motorcycles at intersections and because of this, they would be more likely to pull out into a smaller gap in front of the motorcycle than they would adopt for cars.

Crundall, Humphrey, and Clarke (2008) also found differences between cars and motorcycles when the stimuli were presented for a short timeframe (250 ms). However, they found no difference in TTC judgements when participants had no time restrictions imposed (i.e., the participants could take as long as they liked to decide).

Although these studies offer support to DeLucia's research in applied settings, the largest vehicle used in these studies has been a van. There are therefore many larger sized vehicles that have not been covered by previous research (e.g., buses, trucks and trains).

A train has different proportions to other types of vehicles, most notably its length. A locomotive alone has similar dimensions to a bus, but when carriages are added, the length increases immensely in a lot of cases. Because of this elongated length, the optical expansion of the train as it approaches is not symmetrical, whereas smaller objects like motorcars are more symmetrical. Asymmetrical object expansion, relevant to the image of an approaching elongated object tends to result in a less accurate TTC judgement (Gray & Regan, 2000; cited by DeLucia, 2004). Also a train, when viewed from head-on shares at least one characteristic with a motorbike, in that both have a longer vertical axis than a horizontal axis, whereas a motorcar has the opposite axes properties. Asymmetrical expansion is a property of elongated objects, and will be considered again below, along with other differences.

The Size-Arrival Effect theory would suggest that motorists should adopt greater safety gaps in order to cross in front of trains, because of their much greater size and apparent earlier arrival time. Therefore the theory does not really explain why collisions between cars and trains at level crossings occur so frequently. However, we will still test this theory because if it is correct, then it would strongly suggest that the perception of approaching trains (and other motor vehicles) could be dependent on other factors as well. There is however another theory which applies more specifically to trains, that has not been studied in depth, as outlined below.

The Leibowitz Hypothesis

Leibowitz (1985) suggested that judging a train's speed and distance is subject to an illusory bias. 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 faster. Leibowitz formulated this theory after making observations of moving aircrafts. 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.

In order to further explain this hypothesis, Leibowitz (1985) pointed out the role of smooth eye pursuit movements. Smooth pursuit of moving objects "...is determined by the actual velocity of the object being tracked (which) in turn determines the apparent speed of the object" (p.560). The Leibowitz hypothesis was studied further by Cohn and Nguyen (2003), as described below.

Cohn and Nguyen (2003) conducted a study that analysed human perception of a rectangular object's increase in size. This involved a measurement of when participants were first able to detect that the object was increasing in size. The object was a light grey two-dimensional rectangular shape, with the surround being either dark grey, or no surround. The object would 'approach' the observer, as its relative depth in space to the participant decreased. Participants were required to respond once they detected that the object was approaching. This enabled reaction time to be used as the measure of accuracy (Cohn & Nguyun, 2003). Their findings were that the time needed to make the necessary decisions increased as the starting size of the object increased (Cohn & Nguyen, 2003).

Barton and Cohn (2007) expanded further on the above study by using computer based trials of virtual approaching spheres. The control sphere was set at a diameter of five feet (1.52 metres), and approached the participant at a fixed speed of 35 mph (56.35 km/h). The manipulated sphere was ten feet (3.05 metres) in diameter and approach speeds were randomly varied between trials, with the speeds ranging from 25 mph (40.25 km/h), to 75 mph (120.75 km/h), increasing in intervals of 10 miles per hour. The participants' task was to identify which of the two spheres was moving faster.

As with Cohn and Nguyun's (2003) experiment, results showed that participants were inclined to indicate that the smaller sphere was approaching faster than the larger sphere, even when the larger sphere was approaching up to 20 mph (32.18 km/h) faster than the smaller sphere. Barton and Cohn (2007) determined from these results that human observers mainly rely on monocular cues, as opposed to binocular cues when making estimates and conclusions about an approaching object's speed. Specifically, they found that distinguishing the approach speed of the sphere was affected by its distance from the viewer. The starting few seconds of the sphere's approach was found to be very difficult to differentiate between speeds, compared to the latter part of the approach (Cohn & Nguyun, 2003). This concurs with the rate of expansion model, where objects far away from the observer increase in optical size much more slowly, as opposed to those objects when they are nearer.

When discussing their findings, Cohn and Nguyun (2003) brought up the possibility of applying their findings to analysing speed perception and misjudgement of trains, although this was only in the context of pointing out the differences between simple computer simulations and real-life objects. Since their study, computer simulations have advanced enough to provide more realistic visual cues to the level that they can act as substitutes for real objects (e.g., cars and trains) in the laboratory, under controlled conditions.

The two theories described above (Size-Arrival Effect and the Leibowitz hypothesis) appear to result in different predicted outcomes. The Size-Arrival Effect predicts that the larger the object, the higher the overestimation of its arrival time. Conversely the Leibowitz hypothesis argues that a larger an object is, the greater the underestimation of its speed. Both theories however, agree that size appears to have an illusory effect.

Eye Movement Behaviour

Crundall et al. (2008) suggested in their study of the perception of motorcycles, that motorists may not 'see' the motorcycle if the eyes do not land on it when surveying approaching traffic. This could happen in particular if the approaching motorcycle is not in the region of focussed attention (i.e., where the observer is scanning for hazards), but closer to the observer (i.e., close to the intersection). The image of the motorcycle could "...appear in the parafovea (an area of the retina with reduced acuity)." (p.160), and could well be missed by the observing motorist if not being specifically attended to (Crundall et al., 2008).

Applying fixation to a train would be a little different, in that the point would not be whether the motorist is fixating on the train at all, rather where exactly (or what part of the train) the motorist is fixating. Because of a train's elongated length, it is possible that there is competing areas for the focus of attention. For example, there could be salient points on one or more of the carriages, or the eye may be appraising the approaching train by pursuing (tracking) down the length of the carriages.

Alvarez and Scholl (2005) undertook research that sought to measure where subjects tended to focus their attention on when viewing what they termed 'spatially extended' objects. Representations of these objects were lines of differing lengths that moved in varying directions around a computer screen. Subjects were required to press a response button when they detected the appearance of a circular probe on one of the lines. These probes could appear randomly on either the centre or one of the ends of a line (Alvarez & Scholl, 2005).

Results of their study indicated that centre probes were more likely to be detected correctly than probes that appeared on the end points. In addition to this, as the length of the lines increased, subsequently accuracy for centre probes increased, and conversely accuracy of the end point probes decreased (Alvarez & Scholl, 2005). These findings led Alvarez and Scholl to propose that a) cognitive processes of attention were more likely to be directed towards the centre of elongated objects, rather than the ends, and b) attention towards the centre became more amplified as the length of the object increased. They termed these effects "attentional concentration" and "attentional amplification" respectively (Alvarez & Scholl, 2005; Doran, Hoffman, & Scholl, 2009).

Vishwanath and Kowler, (2003) found that with elongated objects, the eye's first fixation point or saccade tends to land on the object's visual centroid[1]. In their research Vishwanath and Kowler (2003) mentioned that the most natural scanning behaviour was sequential saccading; (i.e., making a series of saccades when assessing a target object). Their study simulated sequential saccading by instructing the participants to first look at a 'start disk', then to the target, then to a second disk, back to target, back to start disk. Under the sequential saccading condition, initial eye movements consistently landed on the target's centroid more

[1] Vishwanath & Kowler (2003) used the term centre of gravity (COG) in their paper. The definition of centre of gravity is "the average location of the weight of an object". (NASA, 2008). This term generally refers to an objects physical property, whereas this thesis is concerned with the visual properties of the object. Therefore for the purposes of this thesis, the term visual centroid – the geometric centre of an objects shape; will be used.

so than other conditions tested (Vishwanath & Kowler, 2003). This applied even when the shape of the object in question was such that the centroid was not located on the object at all (for example, an ‘L’ or a ‘□’ shape).

In everyday life occurrences, an observer tends to look at a spatially elongated object ‘as a whole’ rather than at smaller targets inside or around the object (McGowan, Kowler, Sharma, & Chubb, 1998). Based on Viswanath and Kowler’s (2003) findings above, in order to achieve this, the eye will make a series of sequential saccades to the object’s centroid.

Why does where observers look matter? As discussed earlier, when an object is travelling at a constant speed (velocity) towards the observer, at far away distances, the rate of expansion and angular change of the optical image on the retina increases slowly. However, as the distance decreases, the rate of expansion will then increase more and more rapidly.

Therefore, at any given instant in time, the optical image of an elongated object would have inconsistent expansion rates occurring at different parts of the retinal image. The rate of expansion at the front end would be occurring much faster than at the middle, and subsequently the middle would be faster than the end of the object. Figure 4 provides an illustration of this.

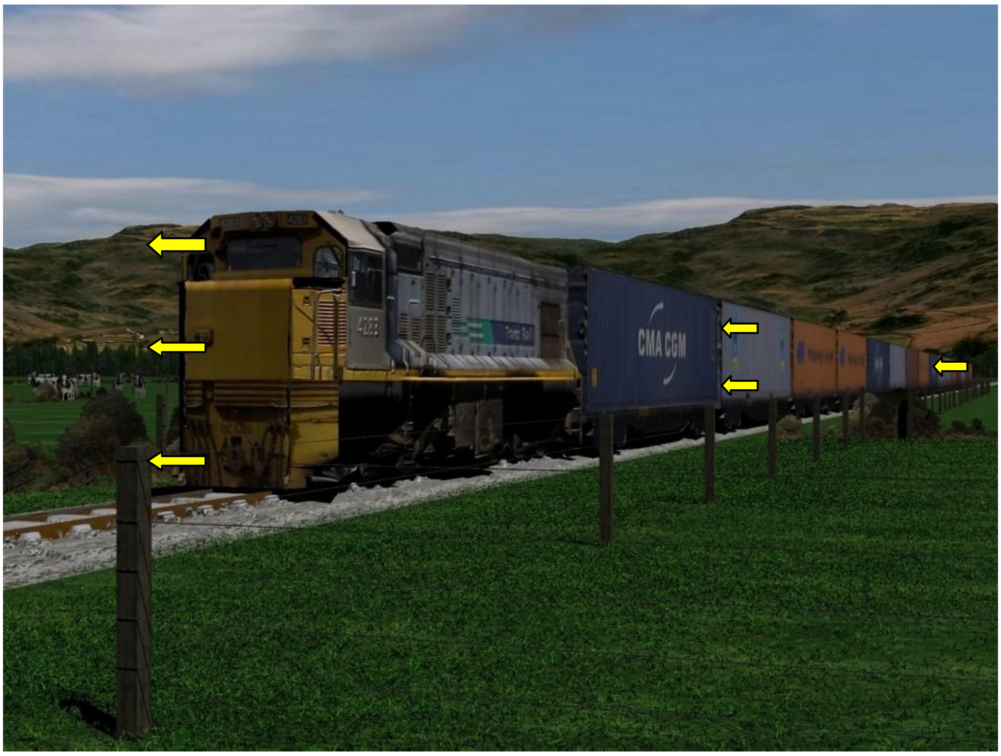

Figure 4. An example of how rate of expansion (ROE) works on the optical image of an elongated object (e.g., train) at a given point in time. The numbers of arrows represent level of acceleration of ROE.

If a motorist is fixating on the centroid region of the train, rather than the front of the train, then speed and approach estimates based on the observed speed at that point and that instant, would be wrong. The perceived speed of the train while looking at the middle would be estimated as being slower, relative to the perceived speed when looking at the front. It is also possible that there are competing areas for fixation. For example, there could be salient features that draw attention to that region of the train, or the observer may be pursuing (tracking) down the length of the carriages.

Crundall et al (2008) suggested that eye tracking measures could be implemented to determine whether fixation plays a part in the perceptual processing of approaching vehicles. Therefore, in the study reported in this thesis, an eye tracker will be used to determine participants' eye movement behaviour. Both saccadic and smooth pursuit eye movements will be recorded while participants view motor vehicles, particularly a train. This will enable the participants' eye movement patterns to be analysed. Questions like, 'do particpants' eyes track the length of the train, and then return to the front, or do participants try to pursue the train with their eyes as it approaches?', and 'do fixation and saccadic eye movement behaviours follow a typical pattern among observers?' can then be answered.

In summary, perceptual errors made by motorists may contribute to the high occurrences of collisions with trains in level crossing collisions. Therefore the goal of this research is to try to identify whether there are factors contributing to the rate of level crossing collisions associated with visual or perceptual illusions. In particular, the research is examining whether drivers visually misperceive the arrival time of an approaching train at a level crossing and therefore adopt unsafe crossing gaps. The research is focusing on two questions: 1) Is the speed of the train being underestimated, and therefore causing drivers to cross when it is unsafe to do so? 2) Does the length of the train (locomotion + carriage containers) cause eye fixations to be directed towards the middle of the train such that drivers are not focussing on the front end at the critical moment of deciding whether to cross?

The types of perceptual processing that occur when appraising an approaching train are unknown at this stage. The Size-Arrival Effect and the Leibowitz hypothesis are two theories that have contrasting outcomes when it comes to a large vehicle such as a train. Therefore each will be analyzed in separate experiments.

The first experiment's focus will be on participant's application of judging safe crossing gaps for different vehicle stimuli (freight train with carriages, motorcar and motorcycle). Participants will be asked to indicate when the point is reached where they would no longer cross in front of the vehicle approaching. This is designed to measure the upper threshold gap distance adopted by the participant as being ‘safe’ to proceed. Experiment 1 will also enable the Size-Arrival Effect to be assessed. In essence, do large vehicles appear to be arriving earlier than small vehicles?

It should be noted that simulations and virtual worlds do not necessarily match the absolute velocities of real-world settings. However, it is the relative similarities or differences in safety gap distances adopted between the vehicle conditions that are of interest here. The first experiment will also evaluate eye fixation and smooth pursuit of participants by using an eye tracker. Data obtained by the eye tracker will be used to assess whether eye movement behaviour differs in regards to tracking a train, as opposed to tracking a car and/or a motorcycle. It will also determine where initial fixations occur on the object during appraisal. This will help establish if there is a difference between vehicles in regards to centroid fixations in particular, as well as any other differences.

Experiment 1

Method

Participants

Five male and 19 female volunteers were recruited to take part in this experiment. The participants ranged in age from 17 to 44 years. All of the participants recruited had normal or corrected visual acuity. The majority of the participants were first year University of Waikato students, who were reimbursed for their time by way of 1% course credit for their respective psychology courses. Participants who were not first year psychology students were reimbursed for their participation by way of 10 dollar petrol vouchers. All elements of the experimental process were subjected to and received ethical approval by the University of Waikato Psychology department's Human Ethics committee.

Apparatus

All computer simulations were run on a Dell OptiPlex 760MT Minitower PC, running Windows XP Professional 32 bit SP2. The stimuli were displayed on two computer monitors. The left-hand monitor was a 19" Digital UltraSharp LCD flat screen. The right-hand monitor was a DELL 21" P1130 Trinitron CRT screen. Both monitors used screen refresh rates of 60Hz. A picture of the experiment set-up is provided in Figure 5.

Eye movement data were recorded using a SR Research Ltd – EyeLink 1000 Desktop System (Eyelink 1000, SR Research, Ltd., Ontario, Canada). A chinrest was used to ensure that each participant's head remained fixed for the duration of the trials. The position and height of the chin rest was set so that participants' eyes were vertically and horizontally aligned to the centre of the right-hand monitor screen.

Figure 5: Experimental apparatus set up. The photograph on the left demonstrates how the two monitors were aligned. The photograph on the right shows the full set up for the experiment.

The room used was windowless and painted black to reduce glare. All lights (except for essential computer monitors) were switched off for the duration of the experiment except when short breaks were provided.

Stimuli

The rural environment scene which served as the background for the moving vehicles was rendered using 3DS Max 8 (© Copyright 2010 Autodesk, Inc. All rights reserved.) photos of real-life scenes and vehicles were rendered onto 3d meshes.

The frames in each computer animated sequence were created using the 3DS ‘render farm’, which consisted of 52 dual core PC’s with 2G RAM each (This amounted to 104 virtual CPUs for rendering). Frames were combined to make a computer animated sequence (1024 x 768 pixels resolution at 60 Hz’s) using QuickTime Pro (QuickTime™ Version 7.6.2 (515) ©1991-2009, Apple Inc. All rights reserved).

Figure 6: Individual frames showing examples of the three types of experimental stimuli (train, car, motorbike).

The experiment was written in MatLab (R2007b, Mathworks, Natick, Massachusetts, USA), using the Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997).

Questionnaire

All participants were given a questionnaire to complete before the commencement of the experiment. The questionnaire was designed to examine individual participants' attitudes and driving behaviours around level crossings and their familiarity with level crossings (for example, how often would they encounter a level crossing while driving, or how often would they encounter a train passing through). A copy of the full questionnaire can be found in Appendix A.

Design

A within-subjects, repeated measures design was utilized for this experiment, with all of the participants viewing the same simulations (three vehicle types crossed with five approach speed conditions – described in more detail below). Each of the possible vehicle/speed combinations was repeated six times, with the trial running order randomized by the computer programme. There were three blocks of 30 trials each, adding up to a total of 90 trials.

Procedure

Prior to the commencement of the experiment each participant was provided with an instruction sheet fully outlining the experimental process, and the questionnaire to complete. They were told that the experiment was intended to test how their perceptual judgment affects their decisions about when to proceed through a railway level crossing. Participants were seated directly facing the left-hand monitor, 56 cm away. This monitor displayed a still frame image that portrayed a scene containing a road crossing over railway tracks in a ‘t’ type intersection setting. This was orientated in order to give the impression that the participant was in a motor vehicle ‘approaching a railway level crossing’ and was set in a rural environment.

The right-hand monitor screen was programmed to run a computer simulation of a vehicle approaching from the right hand side, with the same background scenery as the still image. The vehicle displayed was a freight train complete with carriages, a motor car or a motorcycle; with the vehicle type randomised across conditions. While the participant’s body was orientated towards the first monitor, their head was turned rightwards towards the second monitor, to replicate how a motorist turns their head to look for approaching traffic at a level crossing or ‘t’ intersection. The participants were required to place their chin onto the chin rest, in order to keep their head still, to enable the eye tracker to record eye movement behaviour accurately. All stimuli were presented without audio sound.

To signal the commencement of the trial, the right monitor screen went blank. This screen was then replaced by a rural setting identical to the left monitor screen, except that the angle of shot was now orientated in the direction of the railway track on the right hand side. For each trial, the computer simulation would run an animated sequence on the right-hand monitor of a vehicle approaching from the right hand side. At the commencement of each trial, an internal timer would begin counting (milliseconds). Participants were required to indicate when they felt that the vehicle had reached the point where they would no longer consider crossing in front of it. Participants' decision responses were made by pressing the left button of the computer mouse. All participants were instructed to press the mouse immediately when they felt this threshold point had been reached. This stopped the timer. The response time recorded was used to measure the upper threshold gap distance adopted by the participant as being 'safe' to proceed. The screen then went blank, and after a small period (about two seconds) another trial would begin.

Variation of the approach speed of the vehicles was also incorporated into the trial and included one of five randomly selected speeds (km/h). The possible speed levels were 60 km/h, 70km/h, 80km/h, 100km/h or 120km/h. Participants' eye movements were recorded during the experiment in order to obtain a measure of where the participants were focussing (fixation point) during the vehicle approach. Up to five practice trials were provided beforehand in order to familiarize the participant with the experimental process (the actual number varied between participants). After each 30 trial block the participants were given a short break and the room lights turned on.

Results

Response times were converted to safety gap distances by firstly subtracting the response time for each trial from the overall computer animated sequence time. ST is defined as the time in milliseconds that the entire computer animated sequence ran for, and is given by the equation

$$ST = (D \times 60 \times 60)/ v.$$

Where: D (distance) = 222 (metres that the vehicle covered during the trial).

v (velocity) = actual speed in km/h (60, 70, 80, 100, or 120).

Consequently safety gap time - which was the time remaining in the sequence *after* the response recorded was then found from:

$$SGT = ST – RT.$$

Where: SGT = safety gap time

RT = response time

Finally safety gap times were converted into safety gap distances, from the following equation.

$$SGD = v' \times SGT.$$

Where: v´ = v, converted to metres per second.

Means and standard deviations for the set allowed safety gap distances are shown in Table 3, for each vehicle type and speed condition. The mean safety gap distances for all participants, for the three different vehicle types across the speed conditions are shown in Figure 7, along with fitted regression lines and 95% confidence intervals.

Table 3.

Calculated means and standard deviations for the allowed safety gap distance (metres).

	Train	Car	Motorcycle
60 km/h			
Mean	86.78	54.99	47.57
SD	47.83	29.14	25.33
70 km/h			
Mean	89.68	60.63	49.86
SD	47.45	33.16	23.9
80 km/h			
Mean	93.08	61.69	52.37
SD	47.92	31.5	25.21
100 km/h			
Mean	98	66.17	52.64
SD	48.85	30.69	24.75
120 km/h			
Mean	106.51	74.52	58.8
SD	47.7	31.85	24.46

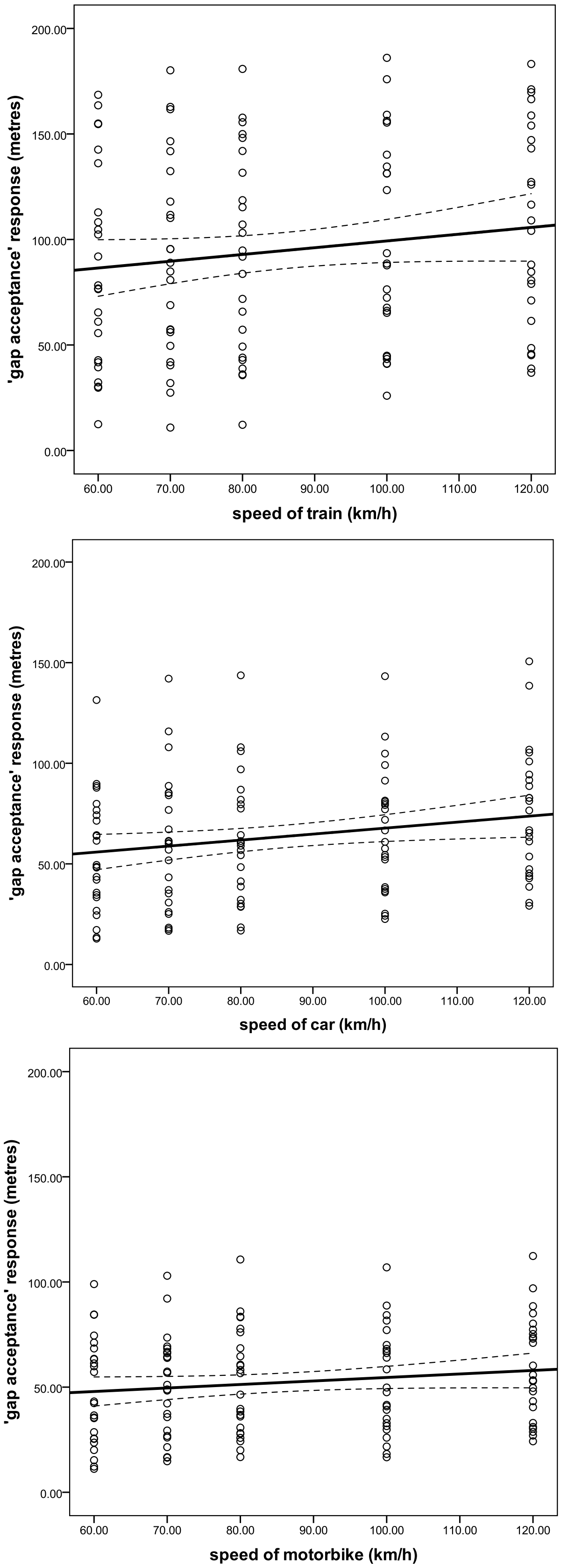

Figure 7: Fitted regression lines and 95% CI, showing participant mean safety gap acceptance for train, car and motorcycle respectively.

As can be seen in Figure 7, the slopes and intercepts change across the vehicle conditions. The confidence interval error lines also indicate quite high variability in the safety gap distance responses. Significant changes in the slope would indicate that the participants were taking the speed of vehicle into account. To test this, linear regression analyses were conducted on the collective participant mean reaction time data for all conditions. This was done in order to determine whether gap acceptance values increased as speed increased (slope) and whether the gap acceptance differed across the three vehicle conditions (intercept). Table 4 shows details of statistics generated by the analyses.

Table 4.

Results of linear regression analysis. Slope indicates adjustments made for speed of vehicle and intercept indicates adjustment made for type of vehicle.

vehicle	**slope**	**95% CI lower**	**95% CI upper**	R^2	F	p
train	0.321	-0.077	0.718	0.021	2.553	0.113
car	0.297	0.038	0.557	0.042	5.152	0.025*
motorbike	0.167	-0.038	0.372	0.022	2.595	0.11
	intercept					
train	67.236	32.01	102.463			0.001**
car	38.023	15.02	61.027			0.001**
motorbike	37.895	19.707	56.084			0.001**

* $p < 0.05$

** $p < 0.001$

If speed was a factor in participants' selection of safety gap distances, then it would be expected that all slopes generated would differ significantly from zero. As can be seen by Table 4, slopes for the train condition and the motorbike condition were not significant (*ps* > .05); therefore participants' gap acceptance distances did not increase linearly with an increase in speed. On the other hand, the car condition did record a significant slope ($p < .05$) albeit a small one. In other words, the participants did not seem to be taking the speed of the vehicle into account.

Intercepts produced from the regression analysis indicated that there was a difference between the three vehicle conditions in regards to the allowed distance gap. To follow up on this, a three-way repeated measures MANOVA was conducted in order to confirm the intercept results, and whether or not gap acceptance differed between vehicle types at each level of speed. The results of the MANOVA found that vehicle type was significant (Wilks' Lambda = .684, $F(10,130) = 2.722$, $p < .01$). Further Post-Hoc analyses found a significant difference between reaction responses for the train and the car at all speeds (Games-Howell = *ps* < .05), and also between the train and the motorbike at all of the speeds (Games-Howell = *ps* < .01). However there were no significant differences found between the car and the motorbike at any of the different speeds (Games-Howell = *ps* > .10). Table 5 provides details of the post-hoc analyses.

Table 5.

Results of Games-Howell post-hoc analysis, conducted in order to determine significant differences in participant safety gap acceptance between each vehicle condition.

			Mean		95% Confidence Intervals	
speed (km/h)	vehicle		Difference	*P*	Lower Bound	Upper Bound
60	train	car	31.7902	.022*	3.9069	59.6735
	train	motorbike	39.2076	.003**	12.1663	66.2488
	car	motorbike	7.4174	.617	-11.6828	26.5176
70	train	car	29.0450	.047*	.3165	57.7735
	train	motorbike	39.8157	.002**	13.2390	66.3923
	car	motorbike	10.7707	.408	-9.5031	31.0446
80	train	car	31.3814	.028*	2.8851	59.8777
	train	motorbike	40.7080	.002**	13.6526	67.7634
	car	motorbike	9.3266	.500	-10.6501	29.3033
100	train	car	31.8263	.027*	3.1261	60.5266
	train	motorbike	45.3558	.001**	17.9652	72.7464
	car	motorbike	13.5294	.224	-5.9901	33.0489
120	train	car	31.9935	.025*	3.4996	60.4873
	train	motorbike	47.7158	.000**	20.9125	74.5191
	car	motorbike	15.7223	.146	-4.1740	35.6186

* $p < 0.05$

** $p < 0.001$

Eye Tracking Data

Because of technical limitations with the equipment, it was not possible to synchronize the eye tracker with the animated sequences. It was therefore difficult to compare the eye velocities with the speed of the vehicles in the sequences. In order to obtain qualitative estimates of the eye movement behaviour, the eye position data (x, y) at each frame was superimposed on the animated sequences and visually analyzed.

Eye movement behaviour analysis consisted of: a) identifying the initial fixation point when the participant first looked at the train and: b) identifying where the participant was looking when the decision to no longer cross was made. Also general eye fixation and saccadic behaviour was noted for the duration of the animated sequence. Figure 8 provides an example of the animated sequence with the (x, y) eye position marker overlaid.

Figure 8: Example of eye tracking data overlaid onto stimuli. The fixation cross represents where the participant is looking at the time of this particular frame of the computer animated sequence.

Results for the initial fixation point (first looking at the train) were variable across participants and conditions. There was no obvious point within the scene that consistently generated more fixation responses than any other. The most common point of fixation was the front right corner of the train face (as shown in Figure 8), which accounted for 20.8% of responses. This was followed by the back end of the train (16.7%). The remaining initial fixation points were distributed over other various parts of the train.

Similar to the first fixation point analysis, the fixation point where each participant was looking when they made the decision to cross also varied. Here the most common point was the front left wheel of the train with 20.8% of responses. No other point generated more than 9% of responses. If responses were classified into more general regions, for example whether the front region, middle region, or rear region of the train were where participants fixated on, then the front region was most evident in both analyses, recording over 58% of responses in both cases.

Saccadic eye behaviour was evident in the computer sequence analyses, with almost 74% of participants making saccades to other features in the scene. The fence posts easily dominated saccadic behaviour, with 56.5% of participants regularly making saccades to one or more fence posts. It should be noted here that three participants did not once look at the train during the entire approach; rather they tended to look at features in the scene, such as the fence posts.

In summary for Experiment 1, it was found that participants adopted the greatest safety gap to cross under the approaching train condition. Participants adopted similar sized safety gaps for the car and the motorcycle conditions. However, there was no adjustment made for speed when determining safety gaps for the train and the motorcycle. Observers used the same gap regardless of whether those vehicles were travelling 60km/h, or 120km/h. In contrast to this, participants did allow distinctive safety gaps for the car when it was travelling at different speeds.

The eye tracking data analysis found that there were different points on the train that participants looked at, with the front right corner of the train face being the most common point for initial fixations. The front left wheel was the most common feature of the train that participants were looking at when the decision to cross was made. Saccades were often made to other features in the environment while the vehicle approach was in progress, in particular the fence posts.

Discussion

Experiment 1 was designed to test the hypothesis that the approach of the three vehicles (train, car and motorcycle) would be perceived differently by observers, and therefore would contribute to the participants adopting distinct safety gaps for each vehicle. The outcome of Experiment 1 partially, but did not fully, support this hypothesis.

Experiment 1 also explored the premise of determining where observers initially fixated on an approaching train (a moving elongated object) during judgment of safe crossing distances. It was predicted that the train would have fixations mainly occurring around the train's visual centroid. This hypothesis was not supported by the eye tracking data analysis.

Analysis of the data found that participants adopted the greatest safety distance gap to cross under the train condition, followed by the car. Participants adopted the smallest safety gap for the motorcycle. However although participants overall employed a larger safety gap for the train, compared to the car and the motorbike, there was no significant difference found between the car and the motorcycle.

These findings are somewhat contrary to previous research, which has found significant differences between motorcycles and larger vehicles (Caird & Hancock, 1994; Crundall et al., 2008; Horswill et al, 2005). However, a closer look at these earlier studies indicates that time restrictions used as part of the experiments may have contributed to this. Crundall et al. (2008) reported differences between cars and motorcycles when the stimuli were presented for a short timeframe (250 ms). However they found no difference in time to contact (TTC) judgments when participants had no time restrictions imposed (i.e. they could take as long as they liked to decide). The explanation offered by Crundall et al. for this was that the initial fixation was enough to distinguish a motorcycle from a car, provided that the motorcycle was actually perceived in the first instance.

Experiment 1 employed no set time limit for participants to observe the approaching vehicles; therefore it is possible that the lack of time restrictions here may help explain why there was no significant difference between the car and the motorcycle.

As a whole, participants adopted a greater safety gap for the train, which could indicate that they believed the train was going to arrive sooner than it actually was. If so, this is consistent with the 'Size-Arrival Effect' theory, which states that larger, far objects are perceived to arrive sooner than smaller, near objects (DeLucia, 1991). An issue here was the large variability of the response data for the train condition. The safety margins adopted for the train was far more variable amongst participants, as opposed to the other vehicles, with a larger standard deviation recorded for each of the speeds. This indicates that individual participant differences were more pronounced for the train condition, as opposed to the car and the motorbike.

An interesting finding was in regards to the participants making no significant adjustment for speed when adopting safety gaps for the train and the motorcycle, (i.e. observers tended to use the same gap regardless of whether those vehicles were travelling at 60km/h or 120km/h). This was not predicted and brings into question the ability of participants to competently make allowances for speed disparity. Parsonson, Isler and Hansson (1999) found in their study of driver behaviour at rural t-intersections that distance from the observer, rather than approach speed, was the primary method used in determining a safe gap to proceed. They suggested this was due to observers struggling to perceive correct speed, which was shown by slower vehicles speeds being overestimated, whereas faster vehicles speeds were underestimated (Parsonson et al., 1999). Other studies have suggested that when an observer makes a judgment of the last possible moment that they would cross an intersection, the gap chosen was the same distance regardless of the oncoming vehicle's approach speed (Hills, 1980, Parsonson, Isler & Hansson, 1996). Experiment 1 used this method of 'last possible crossing moment' and has produced similar results. Connelly, Conaglen, Parsonson and Isler (1998) suggested that the ability to concurrently estimate speed and distance accurately was "...too complex even for experienced adults." (p.444).

Eye tracking data found no real consistency in eye movement behaviour, except that participants tended to make saccades to other features in the scene (fence posts, bushes, etc), as well as the vehicle, with the fence post(s) being the most popular feature. Individual participants fixated on different points on the train, ranging from the front wheels to the back end, with the most common points of fixation being the front right corner (initial fixation), and the front left wheel (point of fixation when decision to cross was made).

No known previous studies have looked specifically at eye fixation patterns for moving, spatially extended vehicles (such as trucks, buses or trains), and it is possible that eye movement behavior is different when the visual system is presented with objects that have more than one distinguishing feature. Indeed Vishwanath and Kowler (2003) discussed the differences of real-world objects which are three-dimensional in nature. They pointed out that features such as lighting luminance, texture, or a salient local feature may become the focus of saccades (Vishwanath & Kowler, 2003).

In summary, it has been found that, for the train and the motorcycle condition, the participants did not appear to be taking the speed of the approaching vehicles into account when they made their decisions for the smallest possible safety gaps. This suggests that the observers were struggling to accurately perceive the velocity of those particular vehicles. Although participants did appear to perceive a change in velocity for the car condition, previous studies have suggested that a motorcar's speed is more likely to be underestimated at higher speeds (Hills, 1980; Parsonson et al, 1996; Parsonson et al, 1999). Therefore even though observers allowed for velocity changes in the car condition, their perception of the car's relative speed may still have been underestimated. If this is the case, does this underestimation also occur in the real world when observers try to judge the speed of other types of vehicles (particularly ones that they are less familiar with)? Bear in mind also that the Leibowitz hypothesis suggests that a large object seems to be moving more slowly than a small object even if it is actually travelling at a greater speed. If a motorcar's speed is more likely to be underestimated at higher speeds (Hills, 1980; Parsonson et al, 1996; Parsonson et al, 1999), then to what effect could this also transfer to trains, if the relative speed of the train is already being underestimated? In order to answer this, firstly it needs to be established whether the Leibowitz hypothesis is accurate.

Therefore the purpose of Experiment 2 was to determine whether observers could reliably discriminate between the approach speeds of a train, compared to a car. To test this idea, the experimental procedure will involve participants making a direct comparison of the two vehicles' speed and indicating which vehicle appeared faster. The participant will be asked to judge which of the vehicles appears faster. This employs the use of a two alternative forced choice design (2AFC), in order to establish the point of subjective equality (PSE) between the trains's perceived speed, relative to the car. The PSE determines the point where the two speeds look the same to the participant. The animated sequences shown here will be short excerpts taken from different stages of the simulations shown in the first experiment. As mentioned above, simulations make absolute speeds difficult to match. Therefore it is the relative difference in the comparison of the car and train's speed that will be measured. This experiment is based on the theories of Leibowitz (1985).

Previous research carried out (Barton & Cohn, 2007; Cohn & Nguyen, 2003) has provided support for Leibowitz's theory. Therefore for Experiment 2, it is hypothesized that when observers are asked to compare the relative speed between the car and the train approaching them, the train travelling at the same speed as the car will appear to be moving slower to the viewer, and that a train that appears to be moving at the same speed as the car to the viewer, will, actually be travelling at a higher speed (km/h).

Experiment 2

Method

Participants

Three male and seven female volunteers were recruited to take part in this experiment. The participants were recruited at the University of Waikato and ranged in age from 20 to approximately 50 years of age. The participants were recruited were psychology undergraduate and graduate students, except for two of the recruits, who were not university students. All of the participants recruited had normal or corrected visual acuity. Participants were reimbursed for their participation by way of 10 dollar petrol vouchers.

Apparatus

Apparatus used for this experiment was the same as Experiment 1, with the exception of the Eyelink (Eyelink 1000, SR Research, Ltd., Ontario, Canada) eye tracking device, which was not used in this experiment.

Stimuli

Stimuli used were identical to Experiment 1, except for the omission of the motorcycle. As with Experiment 1, the experiment was written in MatLab (R2007b, Mathworks, Natick, Massachusetts, USA), using the Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997).

Questionnaire

All participants were given the same questionnaire used in Experiment 1 to complete before the experiment.

Design

Like the first experiment, the experimental process employed a within-subjects repeated measure design, with all of the participants viewing the same simulations (three distance conditions crossed with seven approach speed conditions – described in more detail below). Each of the possible distance/speed combinations were repeated twice, with the trial running order randomized by the computer programme. This added up to a total of 126 trials. In addition, this experiment utilized a two alternative forced choice (2AFC) design, where the participants were required to select one of two options presented to them after each trial (again described below).

Procedure

As with Experiment 1, each participant was provided with an instruction sheet outlining the experimental procedure prior to commencement. This second experiment used the same computer animated sequence as Experiment 1, but this time only a small extract of the sequence was shown. This extract shown was either from the beginning, middle, or end of the original complete sequence. Participants were advised that they would be shown two animated sequences, with each pair showing an extract of an approaching motorcar, followed by an extract of an approaching freight train. After the two sequences were shown, a response screen appeared with two text statements, one on the left of the screen and one on the right of the screen. The statement on the left of the screen read “Train faster than car” in blue text. The statement on the right side read “Train slower than car” in red text. Participants were told that they were required to click on the option that they considered being correct for that particular trial. Once the response was entered the screen went blank and then the next trial would begin.

The individual component of each trial consisted of a motorcar animated sequence that ran for 1 second in length, followed by a freight train sequence of the same length. The motorcar was always travelling at the speed of 80km/h. The train's travelling speed would vary across trials, with a randomly determined speed of 60 km/h, 70 km/h, 80 km/h, 90 km/h, 100 km/h, 110 km/h or 120 km/h displayed. This approach speed was randomly selected by the computer programme. In order to stop the participants from simply using the length of the animated sequence to judge the speed of the vehicles (faster vehicles would cover the same distance in a shorter time period), the length of the sequences were randomized by ± 166 milliseconds (equal to ± 10 frames ('jittered')).

The distance that the vehicles appeared from the viewer at the start of the trial consisted of three starting points, a 'far' distance, a 'middle' distance and a 'near' distance respectively. These distances were selected by finding the corresponding frame for the starting point of 240 m, 120 m and 20 m away from the observer. In each individual trial, the pairing of the car and the train would begin from the same distance away.

Figure 9: Individual frames showing the three distance conditions 'far', 'middle' and 'near' respectively, for the train.

There were 126 trials in total, split into two blocks of 63 trials each, with a short break in between each block of trials. Up to five practice trials were provided beforehand, in order to familiarize the participant with the experimental process (the actual number varied slightly between participants depending on how quickly they became familiarized with the procedure). As with the first experiment, the lights were switched on during the breaks to minimize potential discomfort and to prevent dark adaptation.

Results

Proportions were calculated for each condition, by dividing the number of trials the participant responded ‘train faster than car’, by the total number of trials in that condition. A psychometric function (Logistic curve) was fit to individual participants’ data points using the PsignFit toolbox version 2.5.6 (see http://bootstrap-software.org/psignifit/) which implements the maximum-likelihood method described by Wichmann and Hill (Wichmann & Hill, 2001). This was done in MatLab (R2007b, Mathworks, Natick, Massachusetts, USA). An example of this is shown in Figure 10, looking at an individual participant’s psychometric function for one condition.

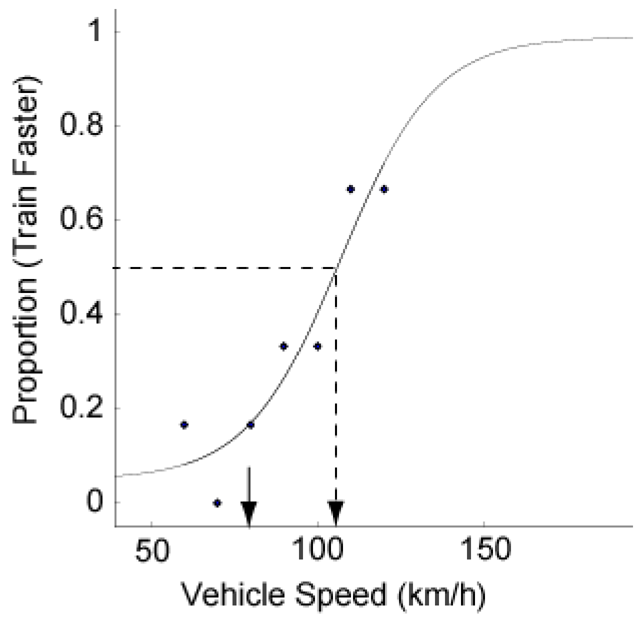

Figure 10: Psychometric function for participant 6 for the 'middle' condition. The dotted line represents the PSE (α), where the train and car speed were perceived as identical by the participant.

The Psignfit software returned a value for the 50% point (alpha), or the point of subjective equality (PSE), and for the slope of the curve at this location. The PSE provides an estimate of the point where the train is considered by the observer to be visually approaching at the same speed as the car. The PSE can be used to establish to what degree participants underestimated or overestimated the speed of the train compared to the fixed speed of the car. For example, given that the car was always travelling at 80km/h, any PSE value greater than 80km/h reflects an underestimation of the train's speed relative to the car's speed. The train had to be travelling at a greater speed than that of the car, in order for it to appear to be at the same speed.

The Psignfit software also provided the 20% and 80% confidence intervals for the PSE estimate. Full details of participants' psychometric functions are illustrated in Appendices B, C and D, while 20% and 80% confidence intervals for all participants and conditions are located in Appendix E.

Table 6, Table 7 and Table 8 shows the calculated PSEs (α) for each individual under the three conditions and the difference thresholds (car - train) for each. A positive number indicates an underestimation of speed (i.e. a train travelling at the same speed as the car was perceived by the observer as travelling slower) while a negative number shows an overestimation (i.e. train perceived as travelling faster than car travelling at same speed).

Table 6.

Individual participants' PSE and difference thresholds calculated for perception of train speed, for the 'far' condition.

Participant	PSE (km/h)	SD	Difference threshold (car (80km/h) - train)
1	69.88	16.71	10.12
2	90.03	14.65	-10.03
3	85.06	20.32	-5.06
4	82.65	5.26	-2.65
5	94.55	7.73	-14.55
6	77.81	14.37	2.19
7	78.59	15.55	1.41
8	43.69	39.47	36.31
9	95.22	14.76	-15.22
*11	105.4	21.01	-25.4
Mean α	82.288	16.99	-2.288

*Participant 10 excluded from final analysis as the psychometric function fitting procedure unable to provide a satisfactory fit, because of his extremely variable data.

Table 7.

Individual participants' PSE and difference thresholds calculated for perception of train speed, for the 'middle' condition.

Participant	PSE (km/h)	SD	Difference threshold (car (80km/h) - train)
1	99.44	17.73	-19.44
2	108.1	15.02	-28.1
3	121.7	40.85	-41.7
4	87.45	9.54	-7.45
5	119.6	15.94	-39.6
6	107.1	14.13	-27.1
7	87.71	13.11	-7.71
8	87.24	15.15	-7.24
9	102.6	12.6	-22.6
*11	88.24	10.94	-8.24
Mean α	100.918	13.25	-20.918

*Participant 10 excluded from final analysis as the psychometric function fitting procedure unable to provide a satisfactory fit, because of his extremely variable data.

Table 8.

Individual participants' PSE and difference thresholds calculated for perception of train speed, for the 'near' condition.

Participant	PSE (km/h)	SD	Difference threshold (car (80km/h) - train)
1	105.2	7.11	-25.2
2	96.73	12.37	-16.73
3	94.09	7.4	-14.09
4	78.08	4.02	1.92
5	101.8	4.13	-21.8
6	82.5	17.16	-2.5
7	87.9	8.27	-7.9
8	76.91	11.74	3.09
9	100.8	9.19	-20.8
*11	89.37	3.14	-9.37
Mean α	91.338	10.031	-11.338

*Participant 10 excluded from final analysis as the psychometric function fitting procedure unable to provide a satisfactory fit, because of his extremely variable data.

Mean PSEs were calculated for each condition across all participants and compared to the control variable – a car travelling at a constant speed of 80 km/h. Figure 11 shows the mean PSEs obtained for the three conditions with 95% confidence intervals displayed. The dotted reference line indicates the car speed constant (80km/h).

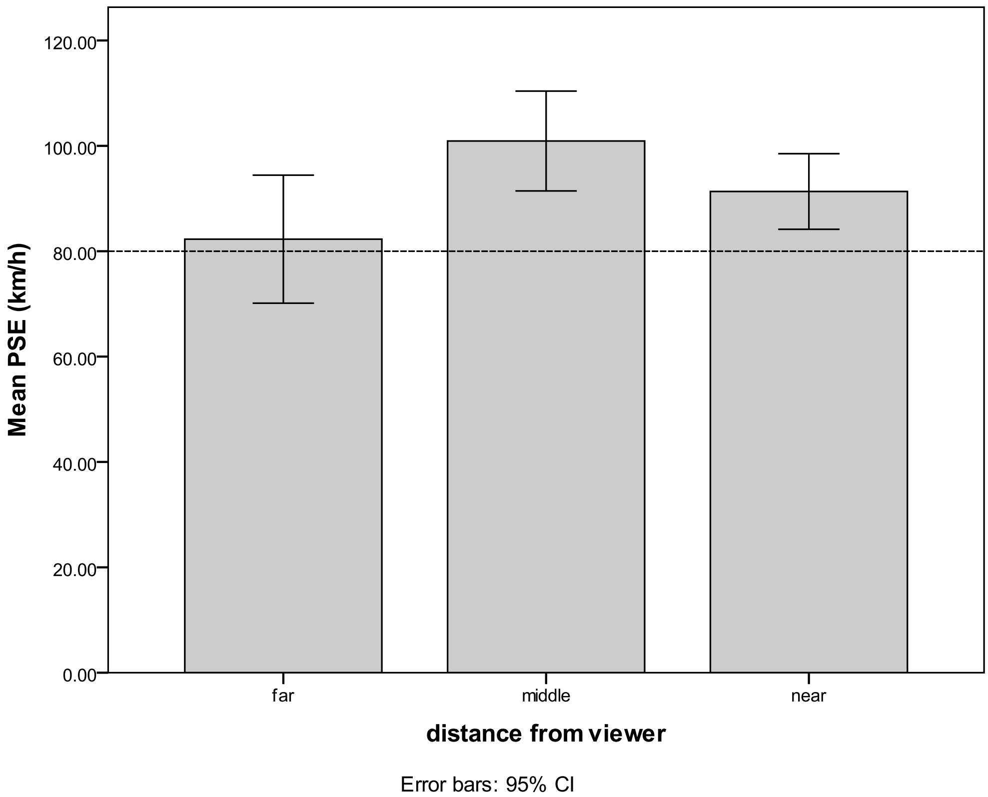

Figure 11: Bar graph showing mean PSEs of train for all participants. Bars represent 'far', 'middle' and 'near' conditions respectively. Dotted line represents car comparison (80km/h).

In order to determine whether there were any significant effects of perceived speed, a one way repeated measures ANOVA was conducted, comparing the calculated mean speed for all participants as a whole, across each of the three distances, against the speed of the car (80 km/h). Results found that there was a significant difference across the conditions (F (3, 27) = 8.738, p < .001). Further pairwise comparisons found significant differences between the train and the car for both the ‘middle’ distance (Bonferroni = p < 0.01), and the ‘near’ distance condition (Bonferroni = p < 0.05). The result for the ‘far’ distance condition was not significant (Bonferroni = p > 0.10). This is confirmed by the bar graph, with both the ‘middle’ condition and the ‘near’ condition showing a significant effect, with both the means and error bars above the reference line.

As a whole, the participants tended to underestimate the speed of the train, compared to the car, although there were individual differences of the magnitude of the underestimation. The ‘middle’ condition resulted in the highest mean PSE result, indicating a greater overall underestimation at this distance. This was followed by the ‘near’ condition, with the ‘far’ condition result showing a slight underestimation. In other words, participants ‘saw’ the train moving slower than the car, when both were actually travelling at the same speed in the computer simulation.

In summary, collective analysis of the psychometric functions outlined above showed that participants significantly underestimated the speed of the train as compared to the car, in both the ‘middle’ and ‘near’ conditions. This underestimation was greatest in the ‘middle’ condition, with average participant response perceiving a train travelling at 100.9 km/h, appearing to be the same speed as a car travelling at 80 km/h. In reality the train was travelling 20.9 km/h faster. The ‘near’ condition resulted in an average 11.3 km/h difference between the train and the car, with a train travelling at 91.3 km/h perceived by the group as travelling the same speed as the 80km/h car.

Discussion

The outcomes of Experiment 2 supported the predicted hypothesis that a computer simulated animated sequence of a train travelling at the same speed as a motorcar, would be visually perceived to be moving slower to the observer, and that a train that appeared to be moving at the same speed as the car to the observer, was in fact travelling at a higher speed (km/h).

All three conditions had raw data that showed underestimation of the train's speed, relative to the car, with two of the three conditions ('middle' and 'near') being statistically significant. Further analysis of the results obtained found that the 'middle' condition had the highest underestimation levels, as opposed to the other two conditions. This occurred across virtually all participants, with eight out of the ten participants recording their largest result in this condition. This suggests that there is a strong illusory bias toward a fast train being perceived as moving much more slowly than a smaller vehicle (for example, a car) travelling at the same speed. The magnitude of this illusion was very large at times in this condition, with underestimations of up to almost 40 km/h difference occurring. The 'middle' condition was designed to be at the critical point where a decision made to cross could potentially have a significant outcome. With the 'far' condition, the outcome was not as significant because there was a large enough gap allowance to get safely through regardless of the speed. The 'near' condition did not realistically allow for a chance to cross.

The results here are consistent with the findings of Barton and Cohn (2007) who found that when two objects (spheres) were approaching at the same speed (mph) in a computer simulated trial, the larger sphere was consistently perceived by observers to be moving slower than the smaller sphere. Barton and

Cohn (2007) used eight approach speeds (mph) but started from the same distance point each time. The current results show that distance from the observer also plays a part, with differences between the vehicles becoming more acute at intermediate distances.

Cohn and Nguyen (2003) also found that larger objects appear to move more slowly than smaller objects. In their study, two-dimensional rectangular shapes were used to represent a train. The rectangular object would increase in size (rate of increase 3 milliseconds/degree) to give the relative impression that the object was ‘approaching the observer. Observers were asked to respond when they first noticed that the object was approaching them. Cohn and Nguyen found that participants took longer to respond when the object in question was larger than when it was smaller, indicating that the larger object ‘appeared’ to be moving slower. In discussing their findings Cohn and Nguyen noted that while their results supported the Leibowitz hypothesis, they noted that the properties of a train are markedly different to the rectangular stimuli their experiment used. They suggested that further research should examine whether their results transpired to these properties. This experiment has attempted to address that suggestion, and similar results have been found, with the larger object (in this case the train) ‘appearing’ to be moving slower than the smaller object (the car in this experiment).

The findings of this experiment also support the theories of Leibowitz (1985) that the train’s size could impact on its perceived speed. According to his theory, large vehicles such as trains should look to be moving slower than smaller vehicles. The results of Experiment 2 supported this theory.

It should be noted too, that not one participant recorded ‘faster’ responses 100% of the time, in any of the speed conditions, even when the train was travelling 120 km/h, compared to the car’s 80km/h (a difference of 40 km/h!). This raises the question of what speed would confidently be assessed as being faster on 100% of the trials. If one cannot easily distinguish a 40 km/h difference, then this has a major bearing on whether or not observers can accurately predict when a train will arrive.

Questionnaire Results

36 participants (29 female and 7 male) responded to the questionnaire given to them before Experiments 1 and 2. Responses regarding risky behaviour undertaken at level crossings, found that the majority of respondents erred on the side of caution at level crossings with active protection devices installed. Specifically 91.7% of respondents had never crossed through a level crossing with the warning bells activated, and more than 97% of respondents had never crossed when the barrier arm was down.

However responses regarding behaviour at passive level crossings showed nowhere near the same amount of caution. These level crossings are controlled either with ‘Stop’ or ‘Give Way’ signage. In terms of whether respondents stopped and checked first before proceeding through, 41.6% of respondents indicated that they either only did this sometimes, or never at all.

In regards to the questions regarding respondents’ attitude towards the timing of activation of warning protection devices, it was found that over 36% of respondents felt that warning protection devices were, at least in some cases activated too early. Familiarity with encountering level crossings varied across the respondents with 27.8% encountering them every day, 25% once or twice a week, 22.2% once or twice a month and 25% only rarely. Of those encounters however, 75% of respondents indicated having actually encountered a train only rarely, or never at all. Not one person indicated that they commonly encountered trains.

General Discussion

The purpose of this study was to determine whether certain types of visual illusions contribute to railway level crossing collisions. Two potential areas for investigation were identified. The first was whether the size of a train influenced observers' perception of its arrival time, and the second was whether that size also influenced how observers perceived the speed that it was travelling at.

The outcomes of the two experiments conducted, show that perceptual errors in both distance and speed estimates occur when observers evaluate approaching vehicles, and that this can impact on their decision to cross in front (i.e., adopt safety distance gaps to proceed through). Experiment 1 tested the hypothesis that the approach of three different sized vehicles (train, car and motorcycle) would be perceived differently by observers and therefore, would contribute to the participants adopting distinct safety gaps for that vehicle. Results showed that this did occur but was only significant in the case of the train, where participants were more conservative in their gap estimate. Results also showed that participants were selecting the same sized safety gap regardless of the approach speed of the vehicle, which indicated that they weren't really taking the speed of the vehicles into account.

Experiment 2 further explored this finding by testing the theory developed by Leibowitz (1985), that larger objects (such as trains) are perceived to move more slowly than smaller objects, even when they are actually travelling at the same speed. Experiment 2 hypothesized that a computer animated sequence of a train travelling at the same speed as a motorcar would be visually perceived to be moving slower to the observer, and that a train that appeared to be moving at the same speed as the car to the observer, was actually travelling at a higher speed (km/h). This hypothesis was supported across two of the three conditions tested.

Experiment 1 also explored the premise of determining where observers initially fixated on train (a moving elongated object) during appraisal. It was predicted that eye movement patterns for scanning the train would have fixations mainly occurring on the train's visual centroid. This hypothesis was not supported by the eye tracking data analysis. Instead it was found that participants' fixations ranged all across the train from the front to the back end, with the most common fixation points occurring at the front of the train.

Relationship to Previous Findings

As mentioned previously, Experiment 1 revealed a significant difference in the chosen safety distance gaps between the train and the car, as well as between the train and the motorbike. Participants allowed a larger safety gap for the train, as opposed to the other two vehicles. However, no significant difference was found between the car and the motorbike. This lack of difference between the two smaller vehicles is contrary to previous research (Caird & Hancock, 1994; Crundall et al., 2008; Horswell et al., 2005). This may have been due to the long presentation time (up to 10 seconds) those participants had in order to make their judgments. Crundall et al. (2008) found a similar effect, when time restrictions on observers were removed.

Another difference that occurred between the three groups was in safety gap estimation across different speeds. In both the train and the motorcycle, the slope of the regression lines were not significantly different from zero, which point to participants using similar safety gaps distances, regardless of the speed of the approaching vehicle. However, this was not the case for the motorcar which did record a significant result in the regression slope. This reason for this is unclear at this stage, although it could be due to a higher observer familiarity with motorcars (this will be discussed in more detail below).

The above finding for Experiment 1 suggested that distance, rather than speed was the decisive factor when making a decision about proceeding through a level crossing or intersection. This is consistent with previous research (Hills, 1980; Parsonson, Isler, & Hansson, 1996; Parsonson, Isler, & Hansson, 1999). The reasoning behind this is that humans are generally poor at correctly estimating a vehicle's speed, with slower speeds generally overestimated and faster speeds underestimated (Parsonson et al., 1999; Scialfa, Guzy, Leibowitz, Garvey, & Tyrrell, 1991). The eye movement behaviour data also possibly indicated that static distance cues were being used. Observers tended to make saccades to features in the environment, for example fence posts. These features could have being used as 'markers' to determine where it was no longer safe to pull out. This was evident particularly when successive saccades were being made to the same feature.

Experiment 1 used a method of comparing three different types of vehicles at five approach speeds. This allowed observers to compare vehicles and make decisions about when to cross in front of the approaching vehicle. However in reality, observers cannot continually compare trains with cars and other motor vehicles at the same time. Trains are encountered in isolation, and in New Zealand, very rarely.

Experiment 2 revealed that observers significantly underestimated the speed of the train, compared to the speed of the car, at both the 'middle' and the 'near' distances. This finding was consistent with earlier research (Barton &

Cohn, 2007; Cohn & Nguyen, 2003; Leibowitz, 1985). The 'far' distance did not result in either a significant underestimation or overestimation of the train's speed compared to the car.

It was interesting to the author, and unexpected, that out of all the conditions, it was the 'far' condition that failed to show any significant under or overestimation. The rate of change in the optical size of an approaching object is small at large distances and therefore quite difficult to differentiate (Schiff & Oldak, 1990). It is possible that the outcome here was due, not to good visual perception, but instead to a complete inability to perceive any sort of difference in the relative speeds of the vehicles. This is consistent with the velocity curve discussed in the first section of this thesis (see Figure 3). At large distances the slope of the curve is flat, indicating that the rate of optical change is very small and difficult to discriminate, which could result in highly inaccurate responses. This would imply that the results obtained for the 'far' condition were truly random. Barton and Cohn (2007) commented that when an approaching stimulus is perceived, changes of speed in the first 3-4 seconds of the approach appears to be barely noticeable, compared with the final 2-3 seconds. (Barton & Cohn, 2007). Schiff (1986, as cited by Schiff & Oldak, 1990) mentioned that objects with radial and to a lesser extent oblique approaches have nonlinear optical rates of change. When rates of optical change are small, judgments of velocity estimates are relatively inaccurate. Accuracy of estimates becomes higher when the rate of change is able to be clearly discriminated (Schiff & Oldak, 1990). The simulations used in these experiments had the advancing vehicles travel at an oblique approach.

The Experiment 2 findings suggested that speed estimation may still have a role to play in level crossing collisions. The underestimation of a train's speed, relative to the speed of a car, could be a critical component of poor decision making to proceed through a level crossing in front of a train, and warrants further investigation.

Questionnaire Highlights

Analysis of the questionnaire answered by participants found several interesting results. For example in response to the question "Do you feel that warning bells and/barrier arms are activated too early?" over 36% of respondents said "Yes" or "Sometimes". This question could indicate frustration at being kept waiting for a train for what the motorist believes is an unreasonable length of time. This could lead to risky behaviour of proceeding through a level crossing, despite warning devices being activated. Witte and Donohue (2000) used similar types of questions when complying a frustration index to test for risky behaviour at level crossings, and found that higher frustration levels tended to directly impact on higher levels of risky behaviour displayed.

The question regarding passive warning system controlled crossings ("At a railway crossing where there are no warning bells or barrier arms, do you stop and check for trains before crossing?"), yielded even higher potential risky crossing behaviours, with 41.6% of respondents indicating "Sometimes" or "No, never" as their answer. Reasons provided as to why participants chose not to stop included that they either "...knew that the line was rarely used", or that they "...knew what time of the day trains used a particular line". One person was more worried about the car travelling too close behind them, so would rather not stop in case there was a rear end collision. Another person relied on "instinct". A common reason provided was that the visibility of the tracks extended a long way down, so it was presumed that a train would be seen (or heard) in plenty of time. This is a reasonable assumption to make as rural areas have long straight railway lines with good visibility. However, this may in fact be counterproductive as people are more likely to approach with caution if their view is impaired by something like trees. An uninterrupted view could lull a motorist into a false sense of security. This was discussed by Wilde, Hay and Brites, as cited by Ward and Wilde (1996). Motorists who approach an intersection or level crossing whose lateral sightline is impeded, are more likely to recognize the situation as hazardous and therefore their approach behaviour is more likely to be cautious, due to the obvious nature of the hazard. (Wilde et al, as cited by Ward & Wilde, 1996). The other problem that could occur here is that if people are less likely to stop and check at railway crossings, this behavior may eventually become the norm (because people will form a habit of not stopping).

The questionnaire also asked participants to comment on whether they felt confident in their ability to accurately judge when a train would arrive. Most respondents believed that they were able to accurately determine this, although a couple did mention that they found it difficult sometimes, due to not being able to tell the speed of the train. Quite a few respondents made statements such as they "...would err on the side of caution." and "...were still very wary." This could indicate why, in Experiment 1, the train safety gap response data was much more variable than the other two vehicle conditions, with individual responses ranging from very conservative gaps adopted, to some individuals whose gap acceptances did not change across the three conditions (i.e., the gaps selected for the train, car and motorcycle were almost identical). .

New Zealand is quite different from other countries in that apart from two or three of the largest cities, light rail is not used for public transport. Many cities have only one or two railway lines running through them and residents may not necessarily encounter these on their regular journeys. The questionnaire respondents were largely from the same city (Hamilton), yet their replies to the question "How often do you encounter level crossings?" occurred almost evenly over the four possible responses ("Every day", "Once or twice a week", "Once or twice a month", and "Rarely"). Regardless of whether the person passes through level crossings all the time or not, encounters with trains passing through at those crossings were indicated to be either "Rarely" or "Never" 75% of the time. This highlights just how unfamiliar New Zealand road users actually are with trains.

It is a suggestion therefore, that due to that unfamiliarity, when a train is encountered, an interpretation of its speed could be based on a heuristic; for example, a mental comparison with a much more familiar object in a similar environment. The conclusion to draw from this is that perception of a train's travelling speed may be mentally compared to that of which motorists are more familiar with, a car, and that a person's subjective knowledge of a car's speed is used to form a judgment of the train's apparent speed. This is consistent with what other researchers have suggested. Leibowitz (1985) mentioned that "motorists are experienced at judging the velocities of other vehicles" (p.560). Scialfa et al (1991) theorized that people are competent in determining a vehicle's velocity by using what they termed "subjective velocity scales" (p.61). In other words, an observer can make an estimate of a vehicle's velocity based on prior knowledge. Cars are encountered every day by motorists in both urban and rural settings. The speed limits in New Zealand are generally 50 (sometimes 60) km/h in built-up areas and 100 km/h for the open roads. It would be reasonable to assume that over time, motorists build up subjective knowledge about the approximate speed that another car is travelling at, and can draw on that heuristic when making estimates about the approaching velocity of a motorcar. Subjective knowledge about a train's velocity is not readily available because there is little or no prior experience to draw from. It is possible that when estimating the speed of the train, observers drew on their relative knowledge of vehicle velocity, based on how fast a *motorcar* approaches at 50km/h for example.

Experiment 2 however has highlighted that the relative speed of the two vehicles are not comparable with observers constantly underestimating the train's approaching speed, when evaluating it against the speed of the car. Hence observers may be unaware that a train, apparently travelling at a particular speed, is actually moving faster (Leibowitz, 1985).

If motorists believe that a train is going at, say 80km/h because to their observation it *looks* as though it is going at the same velocity as a car travelling at 80km/h, (retrieved from a heuristic they are familiar with), a risky decision to proceed through the level crossing anyway could occur. In reality, the train may be travelling up to 20km/h faster, and therefore would arrive at the contact point much sooner than anticipated.

Methodological Issues

A main issue of the study is that it did not allow for participant self-motion to be factored in (this refers to the participant 'driving towards' the intersection or level crossing). In reality, many decisions whether to proceed through or not, occur as motorists are approaching the crossing, rather than when they are already stationary. Therefore forward motion must be taken into account, as well as the changes in subtended angle between the train and the observer. The angle of approach of the train becomes more oblique as a motorist gets closer to the tracks. These issues were unable to be examined here due to equipment limitations but it is a very important point to consider. Experiment 1 suggested that distance, rather than speed was the decisive factor when making a decision about proceeding through a level crossing or intersection. Whether this would also be the case when forward motion is applied to the situation needs to be further examined. This could possibly be investigated by utilizing more sophisticated equipment, such as a driving simulator, and even employing the use of virtual reality environments that allow for self motion and changes in the environment.

Another potential problem with the study was whether the motorcycle, car and train comparisons of Experiment 1 were a fair assessment to draw inferences from. The car and the motorcycle shared more common properties with each other (both were presented on a road surface, the ordinal difference in size and length was a great deal closer). It may be possible to introduce vehicles such as trucks and buses into the mix, with their physical properties closer to that of a train. The road vs. railway track issue should not be ignored either, due to the contrasting properties (small motor vehicle on a wide surface; large train on a narrow track). It would be interesting to determine if the size of the travelling surface, relative to the vehicle has some sort of illusory bias as well. This would be difficult to test with the current experimental settings because it removes the realism of the environment (a motorcycle on a railway track?) but research using simpler stimuli could perhaps follow up on this.

Future Directions

Recently the author was made aware about a proposal mooted by the Chris Cairns Foundation (http://www.chriscairnsfoundation.co.nz/) intended for use in New Zealand primary schools. It involved using an educational tool, such as a CD Rom, to help children become aware of the dangers that railway trains possess. Ideas of what the programme could contain included guessing the speed of a train, among others. The work undertaken in this research would be quite compatible with educational programmes such as the Chris Cairns Foundation idea. In particular, the experimental procedure designed to test motorists perceptions of a vehicle's speed (see Experiment 2) would be easily transferable to the primary school model, either in its present form or with modifications if necessary. Another place that could make use of this would be as part of defensive driving courses and programmes currently run by the Automobile Association New Zealand. The advantage of this type of method is its interactive nature, which allows for practical learning and first-hand awareness.

As previously mentioned, distance appears to override speed in the judgment of safe crossing gaps (Connelly, Conaglen, Parsonson, & Isler, 1998; Hills, 1980; Parsonson et al., 1996; Parsonson et al., 1999). However, when directly comparing the velocity of a train to that of a motorcar, the velocity of the train was constantly underestimated. Which of these two findings is the primary issue for level crossing collisions specifically? This needs to be further explored, and further work in this area may need to focus on which one may be peculiar to trains.

The experiments conducted in this thesis used computer simulations of motor vehicles in rural environments. While these were designed to be as realistic as possible, it needs to be considered whether the computer simulations were able to accurately replicate real-world events. Therefore it is also proposed that where possible, experimental procedures incorporate actual vehicles and settings. For example, an experiment based on making inferences about a vehicle's perceived speed could translate easily to involving an actual vehicle, although head-to-head comparisons between different vehicles would be difficult. This would help to determine though, whether illusory biases seen in the computer simulations are equally as strong or more or less so, in real-life stimuli and environments.

The present study aimed to explore the possibility that perceptual illusions contribute to the high incidence of railway level crossing collisions. The findings of the study offered partial support to the Size-Arrival Effect theory developed by DeLucia (1991), but some of the findings were inconsistent with previous research. Observers tended to use distance as a cue to judging when it was safe to cross in front of an approaching vehicle, and did not allow for differences in speed. Eye movement behaviour was not consistent across participants, with individual observer fixations occurring along different points of the train. However saccades to features in the background scenery were a common occurrence among participants.

The research findings also showed support for the theories of Leibowitz (1985). Participants significantly underestimated the speeds of approaching trains as opposed to motorcars, by as much as 20km/h. This underestimation could have severe implications if motorists are unaware of the illusory bias.

Railway level crossing collisions have resulted in a high number of fatalities in New Zealand. Many of these may have been at least partly due to the visual illusions explored in this study. It is anticipated that the information garnered by this research could guide further avenues of exploration, leading to very beneficial and perhaps life-saving applications.

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Appendix A.

Questionnaire presented to all participants immediately prior to commencing Experiments 1 and 2 (overleaf).

Visual Perception and Analysis of an Approaching Train at Railway Level Crossings in New Zealand.

Questionnaire

Thank you for your time. Please complete this questionnaire before commencement of the experiment. All questions are entirely voluntary.

Please circle the relevant response:

Gender: Male Female

Age Group:	18 – 25	45 – 54
	26 – 34	55 – 64
	35 – 44	65+

Level of vehicle license held:

Full license	Restricted license
Learner license	No license

Do you require the use of corrective aids (e.g. spectacles) while driving?

Yes No

Level crossing behaviour:

Have you ever crossed through a railway level crossing when the warning bells have been activated?

Yes No

Have you ever crossed a railway level crossing with the barrier arm down?

Yes No

Have you, or somebody you know ever had a level crossing accident or near miss?

Yes – accident

Yes – near miss

No

Do you feel that warning bells and/barrier arms are activated too early?

Yes

No

Sometimes

At a railway crossing where there are no warning bells or barrier arms, do you stop and check for trains before crossing?

Almost always

Sometimes

No never

If you answered no or sometimes, what would be the main reason for this?

(Please comment briefly)

____

Do you feel confident in your ability to accurately judge when a train will arrive?

(Please comment)

____

____

How often do you encounter level crossings?

A – Every day

B – Once or twice a week

C – Once or twice a month

D – Rarely

For your answer above:

How often would you encounter a train passing through?

A – Most of the time

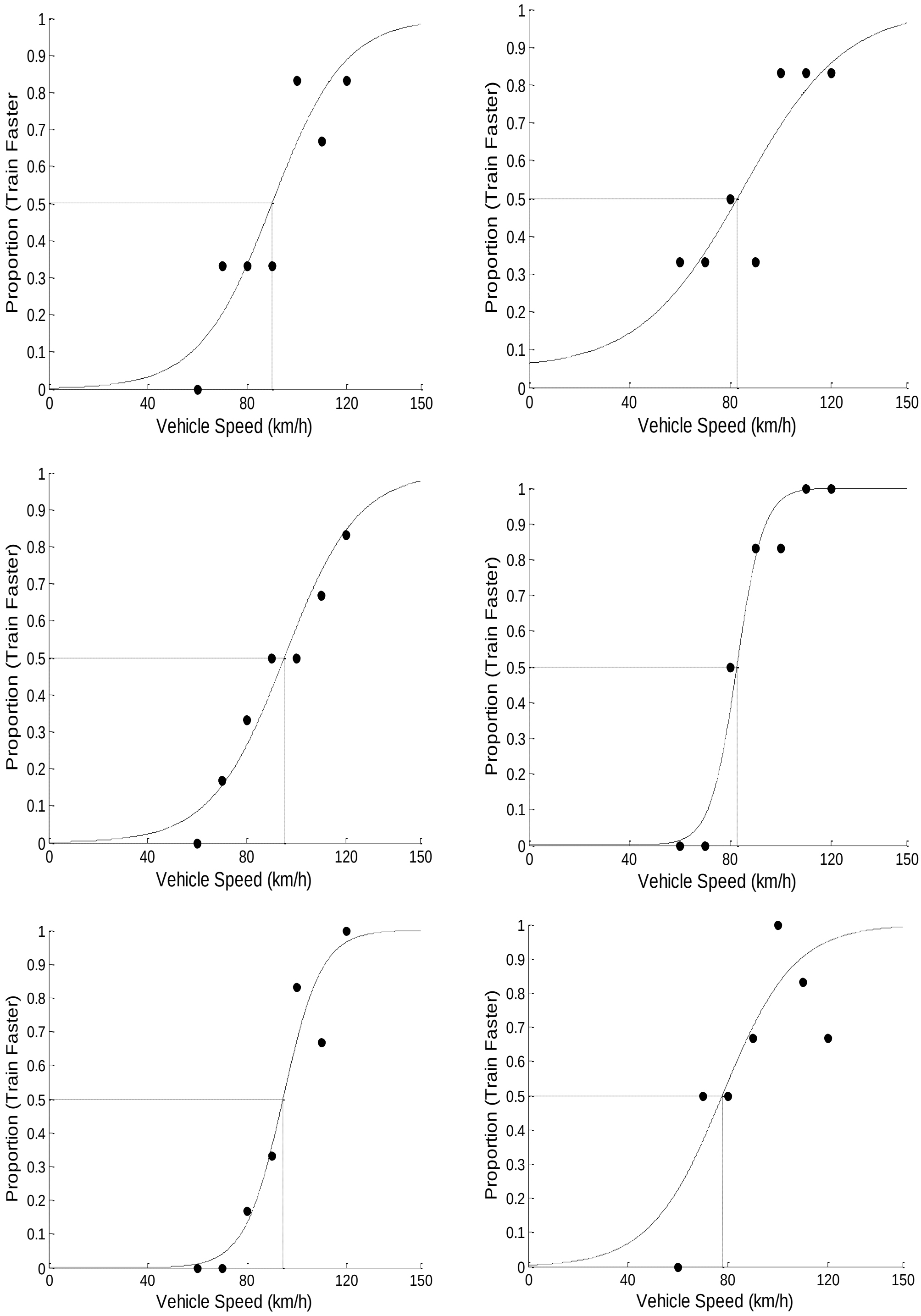
B – Sometimes

C – Rarely

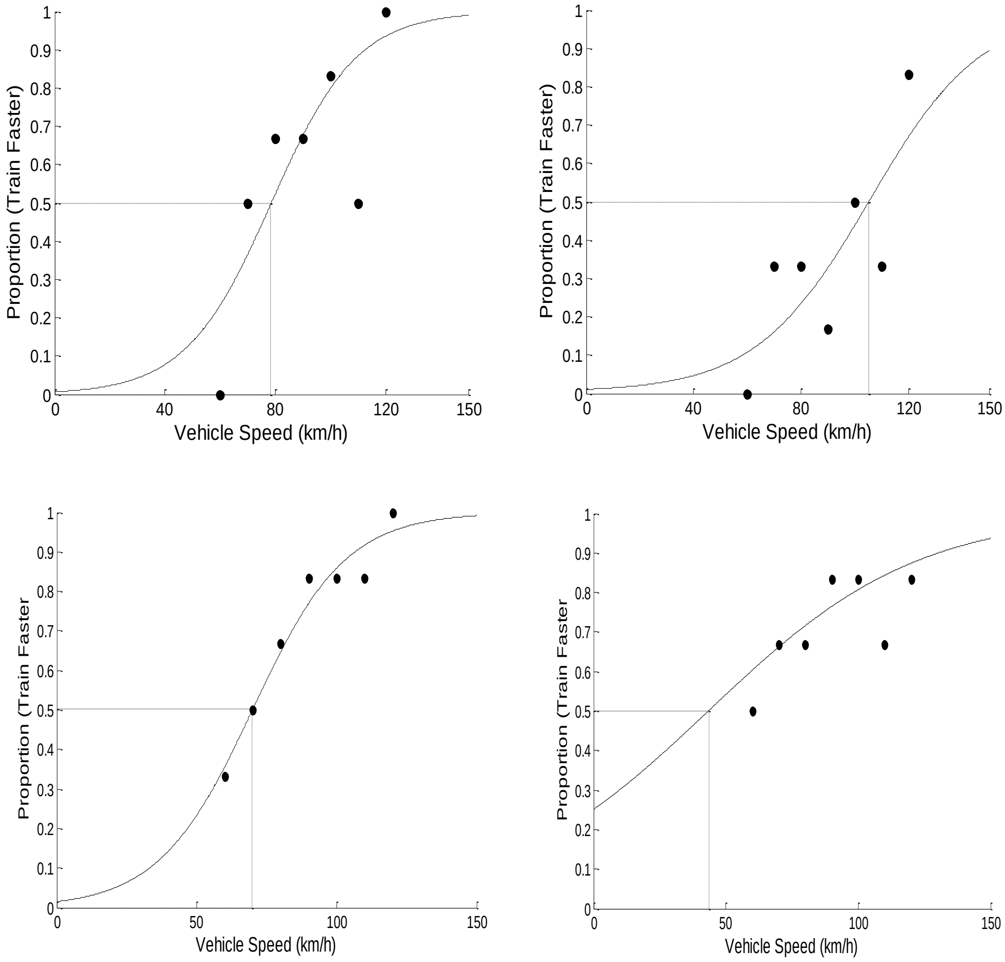
D – Never

Thank you for your information. We will now conduct the experiment.

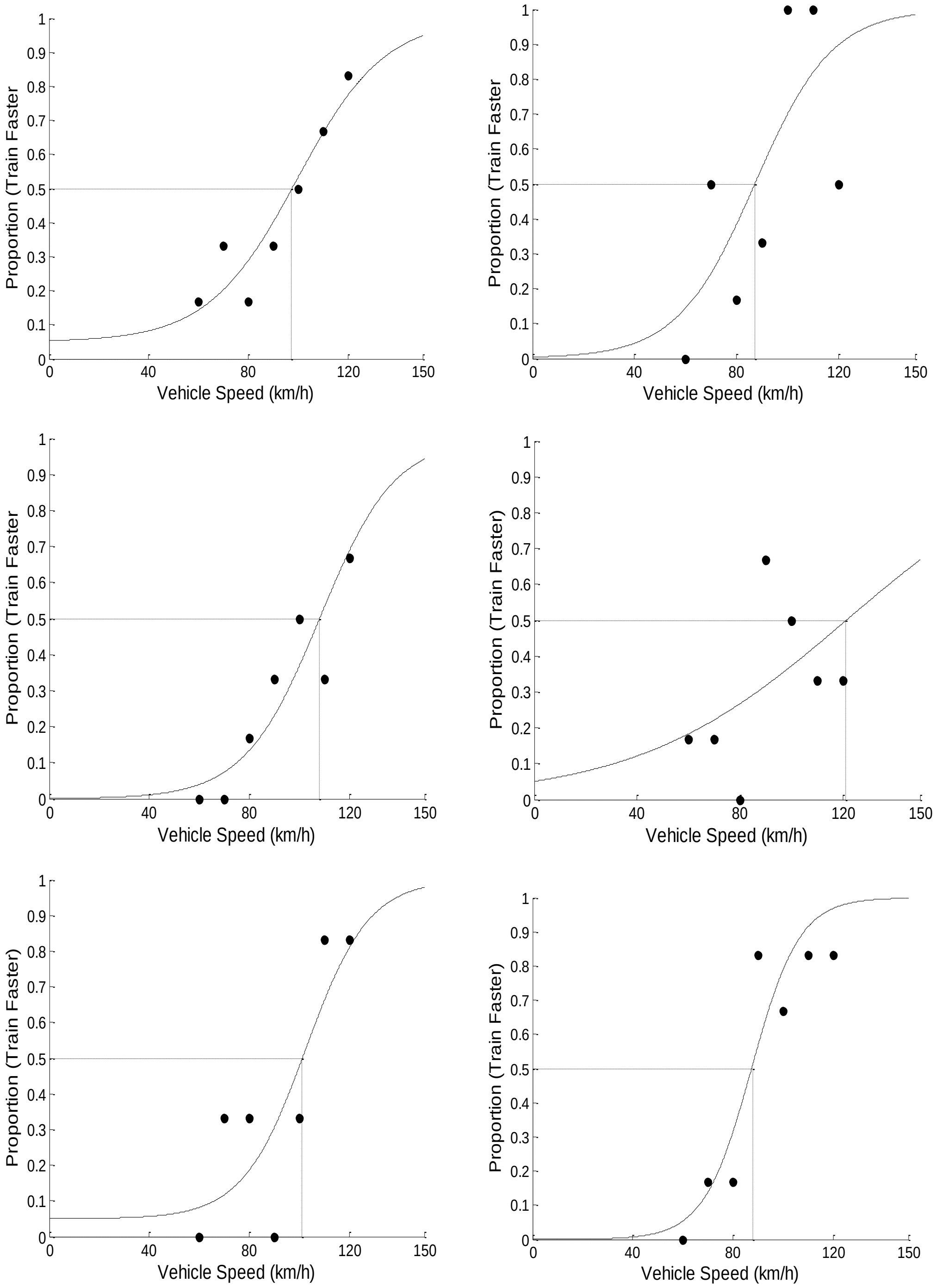
Appendix B.



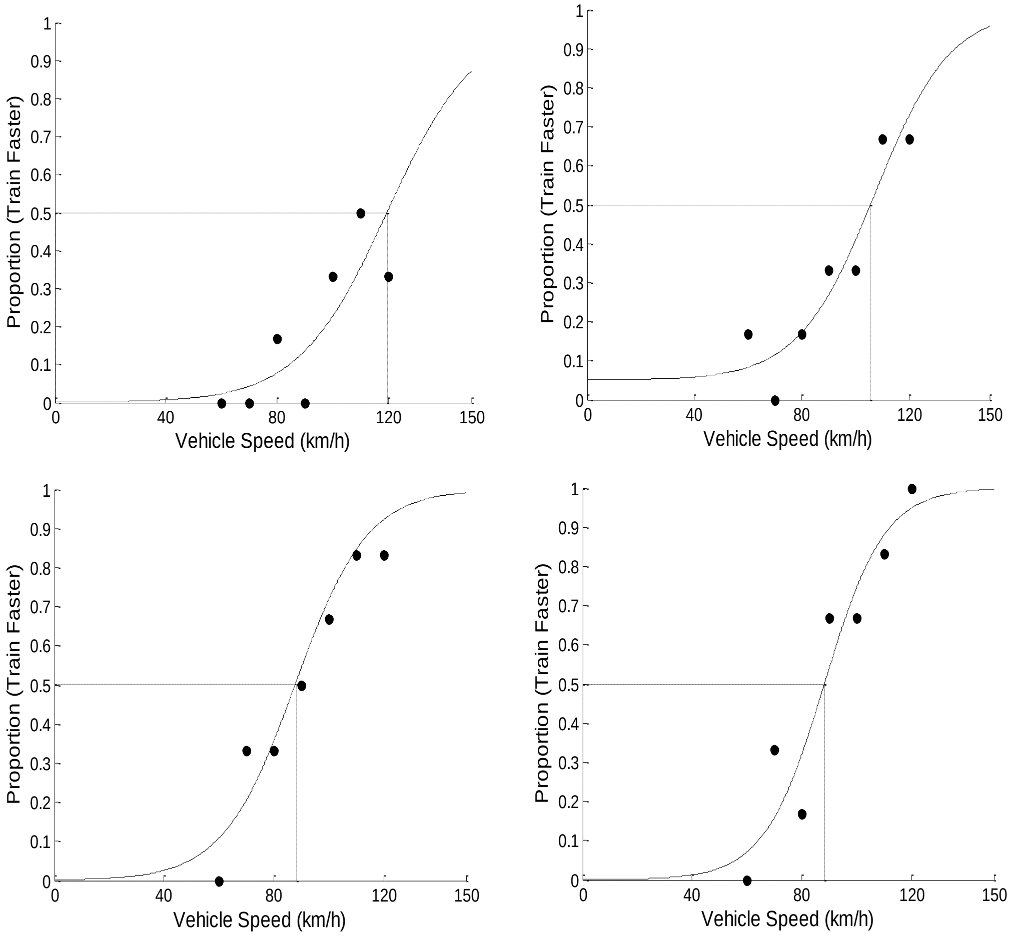
Individual participants' psychometric functions, for the 'far' distance condition.


Proportion (Train Faster)
Vehicle Speed (km/h)
0 40 80 120 150
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
Proportion (Train Faster)
Vehicle Speed (km/h)
0 40 80 120 150
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
Proportion (Train Faster
Vehicle Speed (km/h)
0 50 100 150
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
Proportion (Train Faster
Vehicle Speed (km/h)
0 50 100 150
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

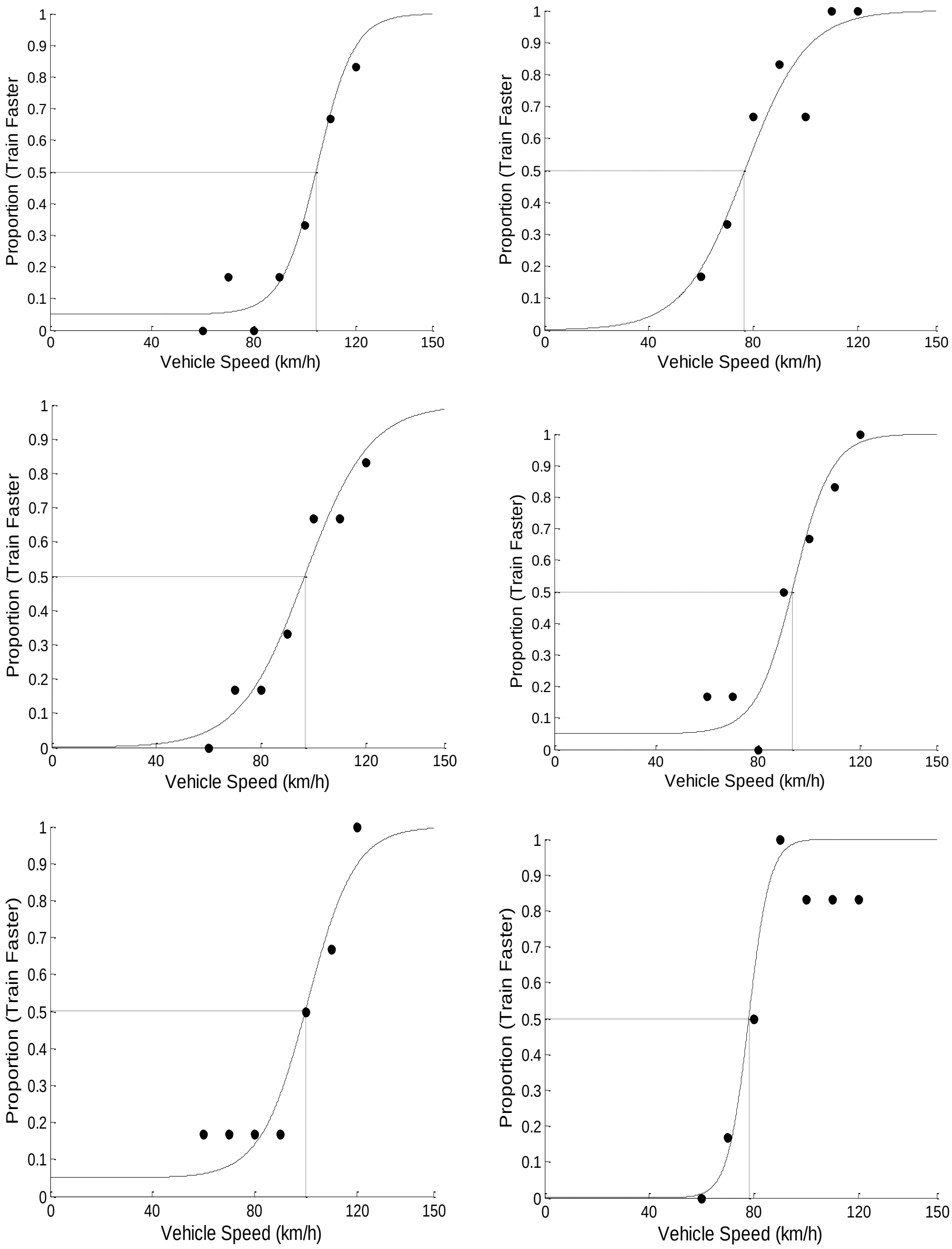
Appendix C.



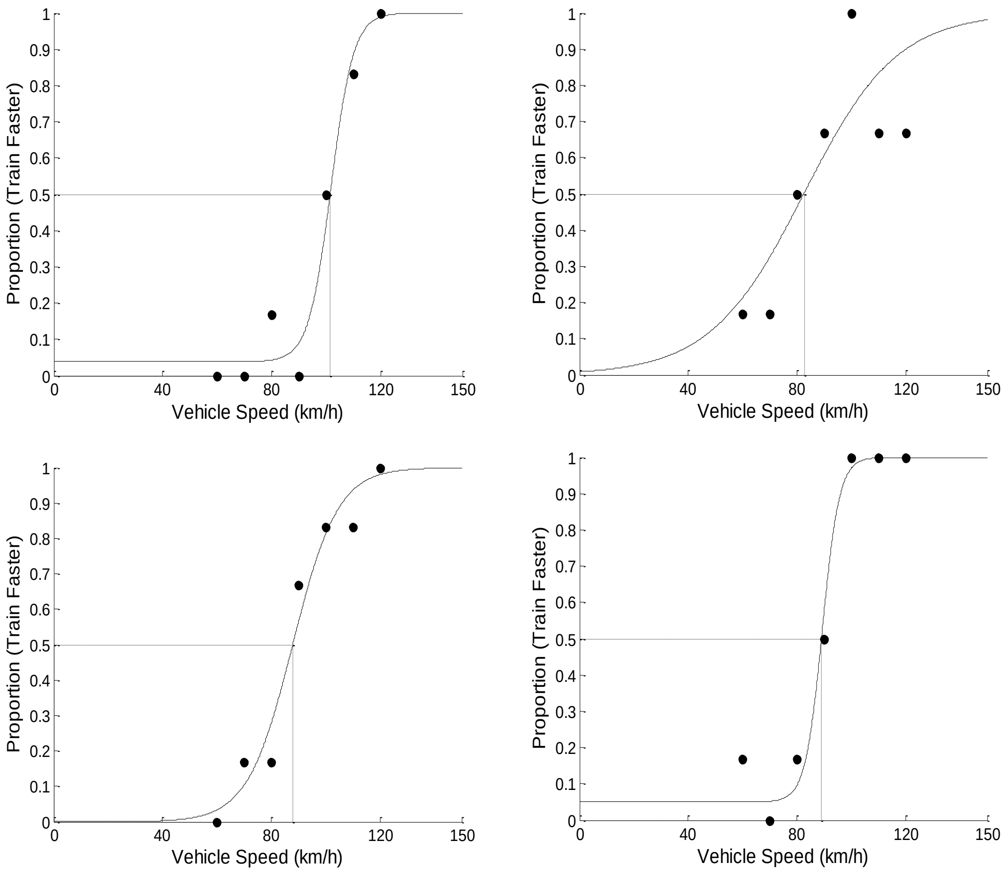
Individual participants' psychometric functions, for the 'middle' distance condition.


Proportion (Train Faster)
Vehicle Speed (km/h)
Proportion (Train Faster)
Vehicle Speed (km/h)
Proportion (Train Faster)
Vehicle Speed (km/h)
Proportion (Train Faster)
Vehicle Speed (km/h)

Appendix D.



Individual participants' psychometric functions, for the ‘near’ distance condition.


Proportion (Train Faster)
Vehicle Speed (km/h)
Proportion (Train Faster)
Vehicle Speed (km/h)
Proportion (Train Faster)
Vehicle Speed (km/h)
Proportion (Train Faster)
Vehicle Speed (km/h)

Appendix E.

Tables showing the 20% and 80% confidence intervals for the PSE estimate, for Experiment 2.

Table E.1.

20% and 80% confidence intervals for individual participants, for the 'far' condition.

Participant	20%	50%	80%
1	46.71	69.88	93.05
2	69.72	90.03	110.33
3	56.9	85.06	113.22
4	75.36	82.65	89.95
5	83.83	94.55	105.27
6	57.89	77.81	97.74
7	57.02	78.59	100.15
8	-11.02	43.69	98.4
9	74.75	95.22	115.68
*11	76.31	105.43	134.55

*Participant 10 excluded from final analysis as the psychometric function fitting procedure unable to provide a satisfactory fit, because of his extremely variable data.

Table E.2.

20% and 80% confidence intervals for individual participants, for the 'middle' condition.

Participant	20%	50%	80%
1	74.85	99.44	124.02
2	87.32	108.15	128.97
3	65.04	121.66	178.29
4	74.23	87.45	100.67
5	97.47	119.56	141.66
6	87.52	107.11	126.7
7	69.53	87.71	105.89
8	66.24	87.24	108.24
9	85.08	102.56	120.03
*11	73.07	88.24	103.41

*Participant 10 excluded from final analysis as the psychometric function fitting procedure unable to provide a satisfactory fit, because of his extremely variable data.

Table E.3.

20% and 80% confidence intervals for individual participants, for the 'near' condition.

Participant	20%	50%	80%
1	95.38	105.24	115.09
2	79.57	96.73	113.88
3	83.83	94.09	104.35
4	72.51	78.08	83.66
5	96.08	101.8	107.51
6	58.71	82.5	106.28
7	76.43	87.9	99.36
8	60.63	76.91	93.18
9	88.07	100.81	113.55
11	85.02	89.37	93.72

*Participant 10 excluded from final analysis as the psychometric function fitting procedure unable to provide a satisfactory fit, because of his extremely variable data.