Light Levels and Driver Perception of Speed:

A study examining egospeed under simulated day and night lighting conditions in a rural setting

A thesis

Submitted in fulfilment

of the requirements for the degree

of

Masters of Social Science

at

The University of Waikato

by

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THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

2015

Abstract

International studies show that globally, drivers are statistically more likely to be involved in collisions during the night than they are during the day. However, the exact mechanisms behind this have not been fully explored. The research carried out in the course of this thesis examined the possibility that the difference in light levels between day and night periods had an effect on drivers' perceptions of speed on a rural road. Three experiments were performed in order to test this hypothesised link between light levels and driving speed.

The first and second experiments were designed to examine whether light levels had an effect on egospeed discrimination ability at 60 km/h and 80 km/h (Experiment 1) and at 100 km/h (Experiment 2). The experiments used a psychophysical technique (method of constant stimuli) to measure the point at which two different egospeeds presented under day and night conditions appeared to be the same (the point of subjective equality, or PSE). The value of the PSE relative to the standard condition (60, 80, or 100 km/h) indicated whether egospeed was being underestimated or overestimate. The results of Experiment 1 indicated that participants were able to discriminate very small differences in egospeed (close to 6% in some cases) but that lighting level (day vs. night) did not have a strong effect on their perception of egospeed. Some participants perceived themselves to be moving faster during the night condition compared to the day condition at both 60 km/h and 80 km/h, but the difference was only statistically significant at 80 km/h. The results of Experiment 2 indicated that participants perceived themselves to be moving faster during the day condition compared to the night condition at 100 km/h, but that this was not to a significant degree. Large individual differences were found at all three speeds examined in Experiments 1 and 2.

The third experiment focussed on absolute estimates of egospeed rather than on differences, and was designed to examine whether light level had an effect on judgements of absolute speed at 60 km/h – 100 km/h, through the use of a magnitude estimation task. Participants were shown individual day and night scenarios, and were asked to estimate the exact speed at which they perceived themselves to be moving. The results showed that light levels did not have a statistically significant effect on the speed at which participants judged themselves to be moving, but that they were able to distinguish between the different speed conditions quite well. However, participants' absolute estimates of egospeed were greatly underestimated.

The overall findings from all of the experiments indicate that, in general, light levels do not affect drivers' egospeed perceptions, but that observers are quite sensitive to small differences in egospeed, and that their ability to judge these small changes is quite robust to the influence of light level.

Acknowledgements

I would firstly like to thank both of my supervisors, Associate Professor John Perrone and Associate Professor Robert Isler, for their invaluable guidance and support throughout the course of my thesis.

I would also like to thank the Psychology department technicians; Rob Bakker for helping me in the creation of the virtual environments used in this thesis, and for providing insight into 3D Studio, Andrew Malcolm for designing specialty software to make examination of the eye tracking information easier, and Alan Eaddy for helping me solve a number of different hardware and software issues that arose.

I would also like to thank my friends and family for the support and love they gave me throughout the course of this thesis, especially my fiancée Charlotte Wyatt.

Finally, I would like to thank all of my participants, without whom my research would not have been possible.

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1. Introduction

It is a fact of modern life for most adults that they will commute via vehicle at varied points of the day and night, and thus under varied environmental lighting conditions. Research has found that as environmental light levels decrease, the probability of any given individual crashing their vehicle increases (Opus, 2012). However, there is still a lack of understanding as to what processes are behind this increase in crash risk. Fatigue has been identified as an important factor in night crashes, as most drivers are likely to be more tired during night periods; however, research carried out by the European Transport Safety Council (2001) indicated that the fatigue is only a factor in approximately 20% of night crashes. It is likely that environmental light levels play a role in the increase in crashes during night hours, as changes in environmental lighting conditions are known to cause changes in perception of the environment and of objects within the environment (Boyce, 2014). In addition, it has been shown that reduced visibility conditions are known to affect estimations of egospeed (Pretto et al., 2012). Further, research has found that as light levels change, human perceptions of the speed at which other objects in the environment are moving also changes (Boyraz, 2007). While the effect of luminance contrast on absolute judgements of egospeed has been touched on in previous research (Fildes, Fletcher, and Corrigan, 1989; Triggs and Berenyi, 1982), it has not been examined in depth. Further, while the effect of luminance (Easa et al, 2010; Pritchard and Hammett, 2011; Reed and Easa, 2011) and of contrast (Dyre, Schauldt, & Lew, 2005; Horswill and Plooy, 2008; Owens, Wood, and Carberry, 2010; Pretto et al., 2012; Snowden et al., 1998) on egospeed discrimination ability, no known research has examined the effect of luminance contrast on egospeed discrimination ability.

In this thesis, I will focus on the manner in which environmental lighting levels inform human perceptions of vehicular self-motion in a rural setting. To do so, I aim to investigate egospeed discrimination ability and absolute judgements of egospeed in authentic pre-rendered virtual scenarios representing day and night conditions. A rural setting was chosen as it allows for the greatest difference in contrast between day and night conditions, and because many serious crashes happen on rural roads in New Zealand (New Zealand Transport Authority, 2014).

1.1 Vision and driver behaviour

In order to drive a car safely through dynamically changing environments, drivers have to be able to perceive relevant visual factors, such as road signs, other cars, and any pedestrians. To do so, drivers rely on both foveal and peripheral vision. Foveal vision is perceived with high visual acuity directly ahead of the observer in a narrow band (Millodot, 1965), while peripheral vision is that which is perceived in all other areas in a visual scene. In humans, foveal vision is more useful when observing brighter environments, such as may be experienced while driving during the day, but is relatively poor for observing darker environments, such as may be experienced while driving during the night, while the reverse is true for peripheral vision.

Visual perception of the environment under different lighting conditions utilises two separate sets of photoreceptors referred to as 'rods' and 'cones'. Rods are more sensitive to changes in light level, but are less sensitive to changes in colour, while the reverse is true for cones. (Barbur and Stockman, 2010). There are three visual 'ranges' of light level that activate rods and cones in different manners. These are photopic, scotopic, and mesopic vision. Photopic vision is used when observing high environmental light levels, is primarily informed by information from cone photoreceptors, and relies predominantly on foveal vision; scotopic vision is used when observing low environmental light levels, is entirely informed by information from rod photoreceptors, and relies predominantly on peripheral vision. Mesopic vision is used when observing 'intermediate' light levels, is equally informed by both rod and cone photoreceptors, and relies on both foveal and peripheral vision (Barbur and Stockman, 2010). Driving during day hours uses photopic vision, while driving during night hours is more likely to use mesopic vision than scotopic vision as the headlights of the vehicle being driven, as well as of other vehicles on the road and other light sources, provide enough light that foveal vision is able to be utilised (Halonen and Puolakka, 2010).

Although the field of view for humans is quite large, there is a set spatial range inside of the field of view in which an observer can accurately perform cognitive tasks such as detection, identification, or discrimination (Ball, Wadley, and Edwards, 2002). This requires use of both foveal and peripheral vision, and is referred to as the useful field of view (UFOV). The UFOV differs from person to person, and research has found that the risk of crashing while driving increases as the size of the UFOV decreases (Owsley et al., 1998; Rogé, Pébayle, Campagne, and Muzet, 2005).

The factor that has been identified as impacting on the size of the UFOV is foveal load, with increasing foveal load leading to a narrowing of the UFOV (Ikeda and Takeuchi, 1975). The factors that have been found to affect foveal load most strongly are visual acuity and contrast sensitivity (Matas, Nettelbeck, and Burns, 2014).

Visual acuity (VA) is a measure of the ability of an individual to distinguish the details and shapes of objects using foveal vision. VA is not a useful measure when using peripheral vision as it declines towards the periphery in a hyperbolic manner (Strasburger, Rentschler, and Jüttner, 2011). Cline, Hofstetter, and Griffin (1997) state that VA is dependent on the sharpness of the retinal focus within the eye, the health and functioning of the retina, and the sensitivity of the interpretative faculty in the brain. The most common cause of low VA is a refractive error in the eyeball. If the error is causing light to be refracted too much, this indicates that the individual is affected by nearsightedness, while if the error is causing light to not be refracted enough, this indicates that the individual is affected by farsightedness. Other causes of low VA are astigmatism (or other corneal irregularities) and neural factors such as detached retina, macular degeneration, or brain damage. For individuals who have a low VA due to optical factors (nearsightedness, farsightedness, astigmatism, or other corneal irregularity), VA can be normally be corrected through the use of prescription glasses or contact lenses. VA is essential to safe driving, as it allows for the correct identification of any hazards that a driver might come across, affects self-motion perception, and allows for road signs to be read correctly from a distance. Indeed, it is so important that in New Zealand a certain level of VA is required before an individual is eligible to get a driver’s licence (Land Transport Act, 1998; s. 1.4). If an individual does not have the required level of VA, they are required to always wear prescription glasses or contacts that correct their vision while driving. If the reason that their VA is lower than normal is not correctable, then the individual will not be able to get a driver’s licence.

Contrast sensitivity refers to the ability of an individual to distinguish very small differences between light levels. It is commonly linked with VA, as both a normal VA and a relatively high contrast sensitivity are required for safely driving in reduced contrast conditions, such as when vision is affected by low light, fog, or glare (Heiting, 2014). Low contrast sensitivity can cause issues for drivers such as not being able to identify objects including traffic lights, pedestrians, and other vehicles in low lighting conditions, making it harder to read road signs, and experiencing fatigue earlier. Some causes of low contrast sensitivity that have been identified are cataracts, glaucoma, diabetic retinopathy, eye surgery (predominantly LASIK or PRK surgery) (Heiting, 2014). However, it must be noted that in some cases, LASIK and cataract surgery can increase contrast sensitivity compared to pre-surgery levels.

1.2 Environmental light levels

Depending on the time of year, environmental light levels have been found to change by a factor of up to 10^{11} (Stockman and Sharpe, 2006). The illumination levels provided by headlights at night are approximate 200 times less powerful than daylight, and due to this, the majority of background information is completely absent as optic flow (discussed below) is highly sensitive to changes in environmental light levels (Fildes, 1979). There are two main methods by which the impact of environmental light levels on specific factors can be explored. These are through exploration of luminosity, and exploration of contrast.

1.2.1 Luminosity. Luminosity can be defined as the level of light energy visible to the human eye that is reflected or emitted from a specific object in a specific direction (DNP Denmark, 2014). While some researchers have examined the effect of luminance averaged across a scene on human perceptions of speed (Easa et al, 2010; Opus, 2012; Pritchard and Hammett, 2011; Reed and Easa, 2011), this is a highly contentious methodology. The National Aeronautics and Space Administration [NASA] (2014) holds that luminosity simply describes stimulus power and, as such, is not a useful measure. Further, Opus (2012) holds that even averaged across the visual scene, it is not a useful measure to use as it fluctuates very widely across relatively short distances. However, Opus does also state that the average luminance of a specific area is highly statistically significant for determining the number of vehicular collisions that occur during night hours, and that specifically “a higher value for average luminance… [is] related to fewer night time crashes” (p. 21).

1.2.2 Contrast. Contrast can be defined as the difference in the perceived lightness and/or hue between an object and its background (Hofstetter et al. 2000). Contrast is a very broad term, and has been manipulated in many different ways by different researchers, leading to a situation where it has become difficult to compare results across literature (Travnikova, 1985). When contrast is used to specifically examine the role of light levels, it is referred to as luminance contrast. NASA (2014) holds that luminance contrast is the best method to use for examining the effect of environmental light levels across a scene as it is able to be used to describe changes in the stimulus power.

When examining the role of contrast on a stimulus, the method of contrast reduction needs to be decided. There are three forms of contrast reduction; these are global reduction, linear reduction, and exponential reduction. A global reduction in contrast is when contrast is reduced equally regardless of distance from the observer, while a linear reduction in contrast is when contrast is reduced in a linear fashion based on distance from the observer, and an exponential reduction in contrast is when the contrast is reduced exponentially based on distance from the observer. Pretto et al. (2012) states that both linear and exponential reductions in contrast can be referred to as complex contrast reduction, as they function in a similar manner to each other but both function in a dissimilar manner to global reductions in contrast.

1.3 The role of egospeed

Egospeed can be defined as the internal estimation of self-motion. For the purposes of this thesis, egospeed will be discussed in relation to that observed while in a vehicle. This is because there is a fundamental difference in egospeed perception while driving as opposed to walking, as speed during walking is directly related to physical effort, which is not the case while driving (Pretto and Chatziastros, 2006). Egospeed has been found to be informed by three visual effects. These are global optical flow rate (GOFR), optical edge rate (OER), and motion parallax (MP) (Ballard, Roach, and Dyre, 1990; Dyre, 1997; Larish and Flach, 1990; McDevitt, Eggleston, and Dyre, 1999; Warren, 1982).

During self-motion, objects in the visual environment are observed to be moving due to the relative motion between the observer and the scene (Burton and Radford, 1978). This observed motion is referred to as optic flow. Movement is typically in the direction that the observer is looking, generating expanding optic flow (Cardin, Hemsworth, and Smith, 2012). Optic flow appears to emanate from a single source, referred to as the Focus of Expansion (FoE) (Gibson, 1950; Gibson, 1954). Research has found that heading estimation from optic flow is highly accurate, even if no landmark information is available (Bremmer and Lappe, 1999; Warren, 1982). GOFR is derived from optic flow across a visual scene, and holds that egospeed is “scaled in altitude units, such as eye-heights, where one eye-height is equal to the observer’s altitude over a plane” (McDevitt, Eggleston, and Dyre, 1999; p. 1). For example, if an individual was moving at ten meters a second and their eye height was set to two meters from the ground, the GOFR holds that they would perceive themselves to be moving at five meters a second.

OER can be defined as “the number of texture elements passing a fixed visual reference per unit of time” (Dyre, 1997; p. 1). An example in a rural environment would be the number fence posts along a fence line passing a set point on the windscreen. OER is sometimes referred to as discontinuity rate, although this is “a more general term… to describe the passage of any arbitrary texture element past a fixed optical reference” (Larish and Lach, 1990; p. 296).

MP is the apparent angular velocity at which objects moving in different parts of the visual field are observed to be moving depending on their distance from the observer, with the observed speed of the object being inversely proportional to the distance between the observer and the object, providing a reliable, consistant, and impression of both relative depth and of distance, even in the absence of all other cues to depth and distance (Helmhotz, 1925; Rogers and Graham, 1979; Williams, 2014). Gibson et al. (1959) state that MP is cued by differential displacement of parts of the retinal image over the retina.

An important factor in egospeed perception is Time To Passage (TTP). TTP can be defined as the speed, velocity, and distance of a specific object in the visual field (a) moving towards the observer, and/or (b) towards which the observer is moving, on a course that will result in the object and observer passing by each other. Beardsley et al. (2011) found that GOFR impacts upon TTP judgements, with an underestimation of egospeed due to GOFR leading to an overestimation in the TTP and vice versa. TTP is closely related to Time To Contact (TTC) (Regan, 2002), with the primary difference being that TTC measures the same factors for an object on a course which, if unchanged, will result in the object colliding with the observer (Lee, 1976).

Egospeed perception can be examined in a number of different ways. The three most common are to examine exact judgements of speed, to examine differences in perceived speed between pairs of conditions, and to examine the speed at which individuals drive under different conditions when asked to match a certain speed without the use of a speedometer. For ease of reference, in this thesis 'egospeed perception' will refer to the examination of differences in perceived speed between pairs of conditions, while 'judgements of egospeed' will refer to exact judgements of speed under different conditions. Unfortunately, due to resource constraints, the lack of a high-fidelity driving simulator meant that it was impossible during the course of this thesis to examine the speed at which individuals drive when asked to match a certain speed under varied conditions.

1.3.1 Egospeed perception. The primary method of examining egospeed perception is to use a psychophysical procedure, with the method of constant stimuli being considered the "standard psychophysical procedure to test how contrast affects perceived visual speed" (Pretto et al., 2012; p. 2). During an experiment that is designed using the method of constant stimuli, the experimenter chooses a range of stimulus values that are likely to encompass the entire threshold value. These stimuli are repeated in a random order, with all stimuli repeated the same number of times. Depending on whether the experiment was meant to examine an absolute threshold or a difference threshold, the observer then indicates whether or not the stimuli was detected (for absolute threshold) or whether the variable condition was stronger or weaker than the standard condition (for difference threshold). Experiments into the effect of contrast on egospeed perception tend to use the difference threshold approach, as it allows for direct comparisons between scenarios of varying contrast level.

When employing the method of constant stimuli for examining the role of a factor on egospeed perception, the number of times that the observer indicated that the variable condition was faster (or slower, if that is what is being examined) than the standard condition is plotted on a graph with the stimulus intensity along the x axis and the percentage of trials in which the variable condition was perceived to be faster along the y axis. This graph represents the psychometric function. The psychometric data is fit using a Cumulative Gaussian (*S* shaped) function that allows for the identification of the point of subjective equality and the point of just noticeable difference. If designed correctly, participants should always observe the standard condition to be moving faster than the variable condition when the variable condition is moving at the lowest stimulus value, and always observe the variable condition to be moving faster than the standard condition when the variable condition is moving at the highest stimulus value.

The point of subjective equality (PSE) is the most important output from the psychometric function, as it indicates the hypothetical speed at which participants would observe the variable condition to be moving at the exact same speed as the standard condition. If the PSE for any given participant is higher than the speed of the standard condition, this indicates that egospeed is being underestimated for the variable condition. However, if the PSE for any given participant is lower than the speed of the standard condition, this indicates that egospeed is being overestimated for the variable condition. As an example, if the standard scenario was moving at 10 km/h and the PSE was found to be equal to 11 km/h, this would indicate that egospeed is being underestimated for the variable condition, as the variable condition is required to move at 11 km/h to be perceived as moving at the same speed as the standard condition at 10 km/h. If there is no statistically significant difference between the PSE and the standard condition, this indicates that the factor being examined has no significant effect on egospeed perception. However, if the PSE is faster or slower than the standard condition, this indicates both that the factor being examined has a significant effect on egospeed perception, and the direction in which changes in the factor will affect egospeed perception.

The point of just noticeable difference (JND) indicates the point at which a participant is first able to perceive a difference between the standard and variable conditions, and provides an estimate for the variability (SD) of the Gaussian distribution underlying the cumulative Gaussian used for the psychometric fit function. A low JND indicates that the participant has a high level of discrimination sensitivity, while a high JND indicates a low level of discrimination sensitivity. JND has three uses when investigating how contrast affects egospeed perception. Firstly, it gives an accurate measure of how much faster or slower an individual could move before observing a difference in speed under varied contrast conditions, which has possible outcomes for road safety in naturalistic conditions; secondly it can be used to indicate whether certain contrast conditions affect discrimination sensitivity more or less than other conditions; and thirdly it can be used to calculate the Weber fraction (discussed below). Although the JND is meant to be calculated at the point where participants observed the variable condition to be faster than the standard condition 75% of the time, it is normally calculated at the point where participants observed the variable condition to be faster than the standard condition 84% of the time. Knoblich (2006) identifies two reasons for this; the first is that it is a more conservative estimate, and helps to eliminate errors caused by statistical noise. The second is that it is far easier to calculate, as the JND defined at the 84% level can be calculated through the equation JND = $\sqrt{2}$SD, where SD is the standard deviation derived from the best fitting psychometric function.

The strengths of using the method of constant stimuli are that it is a very precise tool, and can be used to determine very small differences in egospeed perception accurately; that the results provide a complete picture of sensitivity across all the variable stimuli levels; and that it is fast to administer experiments utilising the method.

The weaknesses of using the method of constant stimuli are that the thresholds for the variable condition has to be known, at least approximately, before the method can be used; that determining the threshold uses up a lot of time and creates data that isn't useable in the main analysis for the experiment; and that the results only indicate the difference in egospeed perception between the standard and variable conditions, and does not indicate the actual speed at which egospeed is perceived.

1.3.2 Judgements of egospeed. The primary method of examining judgements of egospeed is to use a magnitude estimation procedure (McDevitt, Eggleston, and Dyre, 1999; Larish and Flach, 1990), as it allows for the measurement of judgements of a sensory stimuli (Stevens, 1975). During an experiment that utilises a magnitude estimation procedure, the experimenter chooses a number of equally spaced stimulus values that cover the range of interest to the experiment. These stimuli are repeated in a random order, with all stimuli repeated the same number of times. The observer then estimates the magnitude of each stimuli by assigning a numerical value equal to the magnitude of the stimuli that they perceived. The results are then averaged across each stimulus value and, if the results indicate that it would be accurate to use, a graph showing the linear regression equation is created with the stimulus magnitude along the x axis and the mean magnitude estimation along the y axis. If the experiment is meant to examine the effect of a particular factor on the magnitude estimation of the stimuli, the results for each level of the factor are plotted using different lines on the graph, and an ANCOVA is used to compare the calculated mean magnitude estimation for each stimuli magnitude and each factor condition.

The strengths of using a magnitude estimation task are that it indicates the actual speed at which egospeed is judged to move; that the results provide a complete picture of judgements of egospeed across a wide range of magnitudes; and that it is fast to administer experiments utilising magnitude estimations.

The weaknesses of using a magnitude estimation task are that it is harder to implement and requires "more mathematical sophistication on the part of experiment participants" than forced choice tasks (Fukuda et al., 2012; p. 336), and some researchers have questioned whether certain assumptions, such as that participants will make ratio-based judgements (Sprouse, 2011), hold true.

1.4 Weber's law and Weber fractions

Human perception of changes in the magnitude of a stimuli is governed by Weber's law. This states that JND is proportional to the exact magnitude of the stimuli coupled with the sensitivity of the observer. This means that the observed JND will be lower when observing a smaller stimuli condition than when observing a larger stimuli condition, but that the JND as a proportion of the standard stimuli will remain constant. The level to which the JND for a participant at a particular stimulus magnitude is referred to as the Weber fraction (WF), and is calculated using the equation WF = JND/Ms, where Ms is the exact magnitude of the standard condition.

As Weber's law holds that changes in magnitude shouldn't lead to a change in WF, when a statistically significant difference is found for the WF at different levels of Ms, it is normally assumed that perception of the stimuli relies on different underlying perceptual mechanisms at different magnitudes (Ungan and Yagcioglu, 2014). Further, if the WF for a stimuli is found to lie outside the 'normal' WF for the broader category in which that stimuli exists, it is assumed that the exact stimuli is relying on a different underlying perceptual mechanism from that which is normally used for that category of stimuli. The exact size of a 'normal' WF depends on what it is being used to measure (Poynton, 1998).

McKee, Silverman, and Nakayama (1986) state that when used in relation to velocity discrimination, as it would be when using the method of constant stimuli to examine the effect of contrast on egospeed perception, the WF should be approximately 6%. However, these researchers used simple 2D stimuli, which are not as complex as 3D scenarios, so it is likely that WFs found when testing in 3D scenarios will be higher.

1.5 Previous research into the effect of luminance contrast on perceptions of speed

The effect of luminance contrast on egospeed has not historically been a widely researched subject. No consensus exists as to the effect of luminance contrast on absolute judgements of egospeed, and no known research has examined the effect of luminance contrast on egospeed discrimination ability. Previous research that has touched on the effect of luminance contrast on judgements of egospeed (Fildes, Fletcher, and Corrigan, 1989; Triggs and Berenyi, 1982) has focused on whether a difference existed, rather than on the nature of the difference.

Fildes, Fletcher, and Corrigan (1989), using a magnitude estimation task, found that participants watching video segments showing day and night driving conditions judged egospeed to be closer to actual speed during day periods than during night periods, but did not discuss the specifics of this finding. The reason for this is that the focus of the research was on the level of safety participants felt while driving under different luminance contrast conditions rather than on participants' judgements of egospeed. They concluded that participants felt less safe when driving at night than during the day. Interestingly, they found that for both day and night conditions that speeds fifteen percent above the posted speed limit were judged to be equal to the speed limit.

Triggs and Berenyi (1982), using a magnitude estimation task, found that participants watching video segments showing day and night driving conditions judged egospeed to be closer to actual speed during night periods than they did during day periods, although speed was underestimated in both cases. They attributed this to visual streaming patterns caused by reflective road delineators such as reflective posts and road signs, as these are highly visible features at night that are not available during the day. They also found that there was no significant difference found in judgements of egospeed between scenarios that showed a night scene with high-beam headlights, and scenarios that showed a night scene with low-beam headlights.

Although there is a lack of research into the effect of luminance contrast on perceptions of speed, research into the effects of contrast and luminance on perceptions of speed is useful to examine as it at least provides a basis from which to build hypotheses.

1.6 Previous research into the effect of contrast on perceptions of speed

As mentioned above, contrast is a broad term that has been applied in many different manners to different factors. The initial work on the effect of contrast on speed perception was carried out by Thompson (1982), but this was limited to 2D stimuli such as sinewave grating patterns. The largest body of research into contrast reduction in a 3D environment has been into the effect of fog on perceptions of speed (Dyre, Schauldt, & Lew, 2005; Horswill and Plooy, 2008; Owens, Wood, and Carberry, 2010; Pretto et al., 2012; Snowden et al., 1998). The focus on contrast reduced by fog has been so prevalent that some researchers have titled their research without reference to the manner in which contrast has been reduced (Owens, Wood, and Carberry, 2010; Pretto and Chatziastros, 2006). It might be assumed, therefore, that there is an unstated assumption that the effect of contrast in a 3D environment is relatively stable regardless of the exact manner in which contrast is being reduced. However, the research into the effect of fog on perceptions of speed has been split as to whether contrast should be decreased globally (Horswill and Plooy, 2008; Owens, Wood, and Carberry, 2010; Pretto et al., 2012; Snowdon et al., 1998) or in a complex manner (Dyre, Schauldt, and Lew, 2005; Pretto et al., 2012).

Horswill and Plooy (2008), using the method of constant stimuli, examined the effect of fog on egospeed perception using a global reduction in contrast. They found that participants watching video segments showing ‘clear’ and ‘foggy’ driving conditions judged vehicle speeds as slower for the ‘foggy’ scenarios, and that participants had a harder time with velocity discrimination for the ‘foggy’ scenes compared to the ‘clear’ scenes.

Owens, Wood, and Carberry (2010), using a naturalistic driving task, examined the effect of fog on perceptions of speed using a global reduction in contrast. They achieved global reductions of contrast in a naturalistic setting by diffusing filters on the windscreen and side windows. They examined three dependent measures, without participants viewing the speedometer, on separate laps around a closed course. These were verbal estimates of speed, adjustments of speed to instructed levels, and estimations of stopping distance. They found that "Reduced contrast had little or no effect on either verbal judgements of speed or estimates of minimum stopping distance" (p. 1199), but that drivers travelled significantly slower, and speed adjustments took significantly longer, under low-contrast compared to clear conditions. They state that this indicates that drivers perceive themselves to be travelling faster during low contrast conditions compared to clear conditions.

Snowden et al. (1998), using a driving simulator, examined the effect of fog on perceptions of speed using a global reduction in contrast. They found that as a scenario became foggier, participants increase their driving speed to compensate.

Pretto et al. (2012), using a driving simulator, examined the effect of fog on perceptions of speed in three ways. Firstly, they examined the effect of two different forms of global reductions of contrast. Secondly, they examined the effect of a linear reduction of contrast. Thirdly, they examined the effect of a linear increase in contrast. In relation to global reductions in contrast, they found that reductions in contrast were able to lead to an overestimation or underestimation of speed depending on the exact nature of the underlying visual contrast reduction. In relation to linear reductions and increases in contrast, they found that perceived speed is determined by the spatial distribution of contrast over the visual scene, and that specifically, "perceived speed is determined by the relative contrast between the central and peripheral areas of the visual field. When visibility is better in the peripheral than in the central visual field… speed is overestimated. Inverting the direction of the contrast gradient… inverts the perceptual bias such that speed is now underestimated" (p. 8). Further, they found that, across all of their experiments, when speed was overestimated drivers automatically reduced their speed, whereas when speed was underestimated drivers automatically increased their speed. They state that this demonstrates that driving speed is strongly affected by perceived visual speed.

Dyre, Schauldt, and Lew (2005), using the method of constant stimuli, examined the effect of fog on egospeed perception using an exponential reduction in contrast. They state that they chose this method as they felt that it modelled the effect of fog in a more realistic manner than a global reduction. They found that participants watching video segments showing ‘clear’ and ‘foggy’ driving conditions perceived egospeed as increasing linearly by approximately 5% as the exponential fog density increased by 67%. Further, they found that Weber fractions were unaffected by the increase in contrast.

1.7 Previous research into the effect of luminance on perceptions of speed

Easa et al (2010), using a driving simulator, examined the effect of luminance on the driving ability and confidence of older adults during night driving. They found that higher levels of luminance were associated with increases in driving ability and related tasks, such as sign recognition, it also increases driving confidence and leads to a situation where attention is reduced in some driving situations. They identified driving on curved road sections under higher luminance levels as being especially dangerous for older adults due to the reduction of attention being paid to the environment.

Pritchard and Hammett (2011), using a driving simulator, examined the role of ‘average luminance’ on perceptions of speed. This could be assumed to be equal to global levels of contrast. They found that “reducing luminance leads to a reduction in perceived speed, consistent with the notion that driving speed is determined by perceived speed” (p. 59).

Reed and Easa (2011), using a driving simulator, examined the effect of luminance on the driving ability of younger-older and older-older adults during night driving. They found that increasing luminance levels resulted in different effects on night driving performance depending on the age of the participant. Specifically, they found that when driving around a corner, ‘younger olds’ were more accurate in their lane positioning for the higher luminance condition than the lower luminance condition, while ‘older olds’ were more accurate in their lane positioning for the lower luminance condition than the higher luminance condition. However, it was found that the ‘younger olds’ were more precise in their lane positioning for both luminance conditions than the ‘older olds’.

1.8 Environmental considerations

The level to which an environment is urbanised has a strong effect on egospeed, altering GOFR, OER, and MP. Lenz et al. (2011) state that this is due to the road geometry of highways and rural roads being “rather clear compared to the arbitrary inner city streets… where distinctive features may be missing or misleading” (p. 1), and that urban traffic is more complex than highway or rural traffic due to “many different types of traffic participants… which must be distinguished while the surrounding scenery may differ arbitrarily” (p. 1). Urban and suburban environments also typically have more distractions than rural environments, such as attention-grabbing signs and fluorescent lighting.

Luminance contrast also varies quite widely based on urbanisation. In urban and suburban environments, streetlights, house lights, and business lights illuminate the scene for a long distance ahead of the driver, increasing the length of the visual field, while in rural environments without streetlights the visual field is much shorter as the main road is only lit by occasional house lights, the vehicles headlights, and the reflections from cat’s eyes, road signs, and reflective posts. These differences in luminance contrast reduction mean that contrast is likely to be reduced in a global fashion in urban and suburban environments, as the street, house, and business lighting acts to keep contrast at a relatively steady rate, while being reduced in an exponential fashion in rural environments due to the primary light source available for drivers being the headlights of their own vehicle.

Although the effect of environmental factors on perceptions of speed are meant to be mediated by speedometers, research (Recarte and Nunes, 1996; Recarte and Nunes, 2002) has found that there is a tendency for individuals to rely far more on external cues to indicate their speed rather than the speedometer, especially on stretches of road that the driver is familiar with.

1.9 Virtual environments

The examination of egospeed perception and judgements of egospeed normally involves the use of pre-rendered virtual environments representing naturalistic driving conditions. Advances in computer technology have meant that virtual environments have become more and more realistic, to the point where they are reliably able to be used for experimentation purposes and the results extrapolated to naturalistic conditions. Winter, van Leeuwen, and Happee (2012) state that the advantages of utilising virtual environments are that (1) it allows for controllability, reproducibility, and standardisation; (2) it allows for ease of data collection; (3) it allows for the possibility of encountering uncommon or even dangerous driving conditions without effort or physical harm to the participant; and (4) it allows for feedback and instruction in real time between the participant and researcher, while the disadvantages of utilising virtual environments are that (1) rendered scenarios have limited physical, perceptual, and behavioural fidelity; and (2) participants may become motion sick due to the lack of non-visual feedback (e.g. incompatible vestibular signals).

Controllability, reproducibility, and standardisation: There are many visual and environmental factors that can influence driving ability, and the using a virtual environment allows these factors to be controlled for. Winter, van Leeuwen, and Happee (2012) identify traffic behaviour, weather conditions, and road layout as prime examples of factors that can be controlled in a virtual environment but over which researchers have minimal or no control over in naturalistic driving experiments. This means that research into the effect of individual factors using a virtual environment can be performed with assurance that no factors that are not being purposefully manipulated will affect the results obtained, while the same cannot be said to be true for naturalistic conditions.

Ease of data collection: Experiments that utilise rendered scenarios can be set up to automatically output accurate data in a form that can be easily utilised by the researcher and, once the experiment has been successfully designed, does not require any maintenance. Comparatively, naturalistic conditions create a number of challenges for data collection. Exact measurements are harder to obtain, as the exact distances between the observer and objects in the environment, such as pedestrians, other cars, lane markings, etc. may be unknown (Godley, Triggs, and Fildes, 2002). Further, equipment used for experimentation in naturalistic conditions may need to be checked regularly in order to correct for any issues caused by the equipment moving while the vehicle is under motion.

Uncommon/dangerous driving conditions: There are a number of experiences that are either too rare or too dangerous to be examined naturalistically, such as driving on black ice at high speeds, or driving uncommon vehicles such as a giant earthmover, or driving in a specific type of traffic at different speeds. These situations can all be experienced safely and repeatedly utilising accurately rendered scenarios.

Feedback and instruction: Rendered scenarios offer the unique opportunity for feedback and instruction to a level not achievable under naturalistic conditions, such as utilising visual overlays to indicate objects of interest in the visual field (Winter, van Leeuwen, and Happee, 2012). Further, they allow the researcher to pause, reset, and/or replay individual scenarios if an issue or error arises.

Physical, perceptual, and behavioural fidelity: The level of realism present in a virtual environment is known to have an effect on the willingness to accept the virtual environment as reality, and on behaviour undertaken while observing the virtual environment. Winter, van Leeuwen, and Happee (2012) state that participants may become demotivated by virtual environments with low physical and perceptual fidelity, and may act in a manner not in keeping with how they would act in the same situation under naturalistic conditions. Further, as there is no connection between dangerous behaviour and long-term consequence in a virtual environment, participants may be more willing to undertake dangerous actions than they would be in the same situation under naturalistic conditions.

Motion sickness: As rendered scenarios normally offer relatively low physical fidelity, due to the difficulty in simulating the feeling of a car in motion, individuals are more likely to experience motion sickness in a virtual environment than they are under naturalistic conditions.

1.10 The New Zealand context

Road safety in New Zealand is the domain of the Ministry of Transport (MoT), which is tasked with governance of land, air, and marine transport. The MoT releases a Governmental policy statement once every three years. One of the goals of the Governmental Policy Statement is to achieve “a continued reduction in deaths and serious injuries that occur on the [road] network… [as a] short to medium term impact funding goal” (MoT, 2011; para 17), in order to address “the substantial burden road crashes place on the economy and health sector each year” (para 17). The MoT calculated that this burden was approximately 3.8 billion NZD for the year 2014.

In order to meet this goal in relation to night driving, the New Zealand government signed into law the AS-NZS 1158-1-1 (Council of Standards New

Zealand, 2005) and the AS-NZS 1158-1-2 (Council of Standards New Zealand, 2010). These specify the performance and design requirements of vehicular lighting schemes for both vehicular and pedestrian spaces, and lay out the requirements, guidelines, and other relevant information for the design, installation, operation, and maintenance of vehicular lighting schemes. Bridger and King (2012) raised concerns about the contents of the AS-NZS 1158-1-1 and AS-NZS 1158-1-2, stating that they do not use correct pavement reflectance values, ignore recommendations made by the International Commission on Illumination on the use of Scotopic and Photopic ratios to correct for reduced visual sensitivity to low intensity coloured lighting, and excluded LED road lighting as an option. They claim that these factors have led to a situation where New Zealand drivers face a crash risk of 5.8-1 for driving at night compared to day, compared to the international crash risk factor of 2-1.

In light of the above-global-average night time crash rate in New Zealand, and the findings of Opus (2012) on the role of reduced environmental lighting on crash risk, the legislation around rural roads is very interesting. Rural roads have the highest speed limits of any roads in New Zealand (between 60 km/h and 100 km/h in rural areas, depending on the road, compared to between 20 km/h and 70 km/h in urban areas), and yet there is a greatly reduced number of street lights on rural roads compared to urban and suburban roads, with a large number of rural roads having no street lights at all. This means that drivers on rural roads at night are not only subject to an increased crash risk from driving at night, but also from the reduced environmental lighting levels from those of urban and suburban roads. Further, as they are likely to be driving at a faster speed than if they were driving on urban and suburban roads, any crash they are involved in is more likely to be fatal.

The above factors indicate that not only is building an understanding of the effect of environmental lighting levels on egospeed perception especially important in the New Zealand context, but that examining this in the context of a rural environment would be both the most beneficial option for road safety in New Zealand. Further, they indicate that examination of the effect of light levels on egospeed in a rural environment would be the most beneficial angle to examine, as New Zealand rural roads are the least well-lit of any New Zealand road environment at night, yet have the highest legal speed limits imposed.

1.11 Overview of the current study

The purpose of the research undertaken in this thesis is to determine whether light levels have an effect on human perceptions of speed while driving on a rural road. Three potential areas for investigation were identified, but due to resource restraints only two were actionable in the course of this thesis. The two areas for investigation identified that will be examined are firstly whether light levels had an effect on egospeed perception, and secondly whether light levels had an effect on judgements of egospeed. Based on the reviewed literature, two hypotheses were formulated to guide the research. Hypothesis one is that egospeed will be overestimated for the night condition compared to the day condition. Hypothesis two is that differences in egospeed perception between speed conditions will abide by Weber's Law.

This study adds to research on egospeed, luminance contrast, and human visual perception. Depending on the results, the findings of this study have the possibility of having practical implications for road safety, the use of virtual environments in testing visual perception, and possibly the creation of rendered environments for filmography, simulator, and video game purposes.

For ease of discussion, the luminance contrast conditions will be referred to in the body of the thesis as being "day" and "night" conditions. Further, for the same reason the effect of differences in luminance contrast on egospeed will be referred to as the effect of lighting or as light levels.

2. Experiment 1

For the first experiment, the method of constant stimuli was used to test the hypotheses. The aim was to examine how day and night lighting conditions affected one's speed perception on a rural road. A two-alternative forced-choice design was used, with participants presented with pairs of driving scenarios mimicking self-motion from a car driver's perspective, and instructed to indicate under which scenario they perceived themselves to be moving faster. One of the scenarios (standard) moved at a set speed and presented either a day or night lighting condition, while the other (variable) presented the opposite lighting condition to the standard scenario, and displayed a variety of target speeds (described below). In keeping with the method of constant stimuli, the speed of the variable scenario was randomised between trials. This allowed for derivation of a psychometric curve, from which it was possible to extract the PSE, JND, and WF for each participant. These values are defined on pages 29 – 32.

2.1 Method

2.1.1 Participants. A total of 32 participants (16 female and 16 male) with normal or corrected to normal vision undertook this experiment. Participants were recruited via word of mouth and recruitment posters, and ranged in age from 17 to 44. The majority of the participants were first-year University of Waikato students, who were offered a 1% course credit in one psychology course as means of reimbursement. A copy of the recruitment poster can be found in Appendix A.

2.1.2 Apparatus. The experiment was run on a Dell OptiPlex 760MT Minitower PC, with a Windows XP Professional 32 bit SP2 operating system. The stimuli were displayed on a 57.15cm display (48.5cm width x 30.3cm height) ViewPixx 2001c LCD monitor, with a resolution of 1920 x 1200 and a screen refresh rate of 60Hz during the experimental phase. An EyeLink 1000 Desktop System (Eyelink 1000, SR Research Ltd., Ontario, Canada) was used in order to record eye movement data (the X and Y position at a rate of 1000Hz).

Participants undertaking these experiments did so in a dimly lit experimental chamber. During the experimental phase, all lights were turned off except for one small lamp (100 watt bulb, pointed away from the participant) and essential computer monitors. This was done in order to prevent light levels causing glare on the computer screens, while also preventing the participants from completely dark adapting.

Head posture and viewing distance were stabilised through the use of a chinrest, the position and height of which was set so that the participants' eyes were vertically and horizontally aligned to the centre of the monitor. Participants viewed the monitor from a distance of 57cm, and had a horizontal field of view of 39.6 cm and a vertical field of view of 25.4 cm. A free-standing mask was created that was placed between the headrest and the monitor to help create the illusion of 3D, and to cover the screen in a manner that corresponds to the view forwards out of a typical cars windscreen.

2.1.3 Stimuli. Both day and night rendered scenarios were created using 3D Studio Max (Autodesk, 2015). The virtual environment used to create these scenarios consisted of a modelled section (800 meters) of a real local rural road, including the geometry and course of the road. The geometric features modelled were the width of the road and each of the lanes, the width and composition of the road verge, and the placement of road markings, reflective posts, and cat's eyes (small raised reflectors measuring 8 cm (length) x 11.5 cm (width) x 2 cm (height)). The course of the road was straight, with a slight bend to the right visible at the end of the rendered section. The road had one lane for each driving direction, reflective posts were placed on each side of the road every 160 meters, and cat's eyes were placed on the dividing line between lanes every 65 meters. This was in keeping with their spacing on the real road. Other naturalistic objects such as buildings, other cars, and pedestrians were not included in the scenarios as they could draw cognitive attention away from the task. Fences and trees were placed on both sides of the road (see Figure 1 and Figure 2)

The scenarios were rendered as if they were filmed with a 50mm lens, a horizontal field of vision of 39.6 degrees, a vertical field of vision of 25.4 degrees, and an angle of 46 degrees. The virtual camera was set to a height of 1.13 meters. As there is no research into the average eye height of drivers within New Zealand, I determined this height by averaging the eye-heights of drivers across the UK (Hobbs, 1974), Australia (Lay, 1990), Bangladesh (Roads and Highways Department, 2000), the USA (American Association of State Highway and Transportation Officials, 2011), and Afghanistan (Ministry of Rural Rehabilitation and Development, 2013). This height is within the range of eye heights for a passenger in a typical car as identified by Bartlett (2014). A screenshot of a day time lighting scenario is shown in Figure 1, and a night time lighting scenario is shown in Figure 2. In order to best represent naturalistic lighting effects, lighting was kept within a certain level globally for the day scenarios and reduced in an exponential manner for the night scenarios.

Lighting for the day scenarios was based off the pre-set “daylight” settings of 3D studio max, combining an IES sun light and an IES sky light. This rendered the scenario as if it was midday on the summer solstice (June 21st for the northern hemisphere, December 22nd for the southern hemisphere). As such, the intensity of the rendered sunlight is approximately 90,000 lumen per square meter.

Lighting for the night scenarios was achieved by having the only source of lighting in the scenario being from the rendered headlights, which were attached to the camera. Extensive testing revealed that the manner of rendering the headlights that resulted in the most realistic effect in the scenario was to use a single standard target spotlight. This light source was modelled with inverse square decay, and was targeted at a point 1,399.599 meters away from the light source, with a hotspot region size of 5º and a falloff border of 40º. The intensity of light in the hotspot region was set with a multiplier value of 1,000,000. The inverse square decay started to affect the light level of area forwards of the light source at the 10 meter mark, and the area lit by the headlights extended to 400 meters away from the light source. The reflectance values for visual factors such as reflective posts, road markings, cat’s eyes, trees, and the fence line were modelled on their naturalistic reflectance values. Inverse square decay was chosen as the method of light decay as it is the form of light decay that occurs with naturalistic light sources (Autodesk, 2015).

Figure 1. Individual rendered frame showing an example of the day scenario. The brightness of this reproduced image may not reflect the actual brightness of the scenario on the screen.

Figure 2. Individual rendered frame showing an example of the night scenario. The brightness of this reproduced image may not reflect the actual brightness of the scenario on the screen.

2.1.4 Design. A repeated measures design was utilised for this experiment. Participants viewed pairs of scenarios. Each pair of scenarios was composed of one day and one night scenario. The ‘standard’ scenario ran at one of two standard speeds, and the ‘variable’ scenario ran at one of fourteen variable speeds (described in more detail below) with the trial running order randomised by the computer software. Except for two variable speed conditions that were shown five times each (described below), each possible standard/variable combination was shown ten times, with the trial running order randomised by the computer software, adding up to a total of 130 trials per session. Participants also ran five practice trials before starting the experiment (discussed below).

This experiment was run using Experiment Builder (SR Research, 2014). Counterbalancing was used in order to minimise order and/or adaptation effects. Each counterbalanced group was composed of eight participants, with four males and four females in each group. Table 1 shows the counterbalancing used.

Table 1.
Counterbalancing used in Experiment 1.

	Day Standard, Night Variable.	Night Standard, Day Variable.
60 km/h Standard followed by 80 km/h Standard	Group 1A	Group 2A
80 km/h Standard followed by 60 km/h Standard	Group 1B	Group 2B

Each trial consisted of firstly the standard scenario, composed of travelling at either 60 km/h or 80 km/h under a set lighting condition, followed after one second by the variable scenario, composed of travelling at one of the variable speeds (described below) and under a set lighting condition. In order to prevent participants from manually counting texture elements to estimate speed, the presentation time of each scenario was randomised to be 4, 4.5, 5, 5.5, or 6 seconds in length, with each scenario in a pair of scenarios being a different length, and no two pairs of scenario with the same presentation timing. Table 2 shows the variable speeds shown for each standard speed and lighting combination.

Table 2.

Variable speeds presented for each standard speed and lighting combination

	Standard Speed 60 km/h	Standard Speed 80 km/h
Day Standard, Night Variable	Variable Speeds: 40 km/h, 50 km/h, 55 km/h, 60 km/h, 65 km/h, and 70 km/h	Variable Speeds: 50 km/h, 60 km/h, 70 km/h, 75 km/h, 80 km/h, 85 km/h, 90 km/h, and 100 km/h
Night Standard, Day Variable	Variable Speeds: 50 km/h, 55 km/h, 60 km/h, 65 km/h, 70 km/h, and 80 km/h	Variable Speeds: 60 km/h, 70 km/h, 75 km/h, 80 km/h, 85 km/h, 90 km/h, 100 km/h, and 110 km/h

The two variable speed conditions that were only repeated five times were the 50 km/h and 100 km/h conditions for the 80 km/h day standard condition, and were 60 km/h and 110 km/h for the 80 km/h night standard condition. These conditions were included as a precaution in case participants had a harder time perceiving differences between the standard and variable scenarios for the standard 80 km/h conditions, as it was assumed that most participants would observe these speeds as being faster than the standard condition ~0% and ~100% of the time respectively.

During the experiment proper, participants undertook either 60 or 70 trials, then had a five minute break, and then undertook another 60 or 70 trials. If the participant undertook 60 trials in the first trial block, they undertook 70 trials in the second trial block, and vice versa.

As mentioned above, participants were given five practice trials before the start of the experiment. This was done in order for the participants to familiarize themselves with the experimental procedure. The light levels and presentation speeds of the standard and variable conditions were based on the standard condition that the participant was taking part in first in the experiment proper. For all four experimental groups the practice was composed of one trial in which the standard and variable conditions moved at the same speed, two trials in which the speed of the variable scenario was moving slower than the standard condition (40 km/h for Group 1A, 50 km/h for Group 1B and 2A, and 60 km/h for group 2B), and two trials in which the speed of the variable scenario was moving faster than the standard condition (70 km/h for Group 1A, 80 km/h for Group 2A, 100 km/h for Group 1B, and 110 km/h for Group 2B). These five trials were presented in a randomised order.

2.1.5 Procedure. The experiment and procedure was approved by the School of Psychology's Human Ethics committee of the University of Waikato. Each participant was provided with an instruction sheet outlining the experimental procedure prior to commencement. The scenarios were referred to as videos in both the instruction sheets and on-screen. This was done in order to minimise the amount of jargon used, to make the instructions easier for participants to understand. After reading the instruction sheet, participants were asked to complete a questionnaire about their driving history and habits. A copy of the instruction sheet can be found in Appendix B, while a copy of the questionnaire can be found in Appendix C.

During the experiment, participants were presented with pairs of driving scenarios. After each pair of scenarios had been viewed, a response screen with three text statements was shown. The first was centered at the top of the screen, and read "In which video were you moving faster?". The second was located to the left of the middle of the screen, and read "video one". The third was located to the right of the middle of the screen, and read "video two". Participants were then required to indicate which scenario they thought had been moving faster by clicking on either the words "video one" or on the words "video two". After doing so, the screen went black and, after a period of two seconds, the next trial began. The response screens shown can be found in Appendix D.

Participants' eye movements were measured in order to determine where they were focussing (the fixation point) for both day and night conditions.

2.2 Results

Custom software (MatLab (Version R2014b; Mathworks) was used to analyse the data from the experiment. The mean proportion (based on 5 and 10 trials) for judging the variable stimulus to be faster than the standard was found and a psychometric function (cumulative Gaussian) was fitted using the fminsearch function in Matlab. The software output the values of the PSE and SD for each curve, and the JND and WF values were derived using the equations provided above. For expediencies sake, during this experiment the day standard/night variable conditions are referred to as “day standard” when discussed as a unit, while the night standard/day variable conditions are referred to as “night standard” when discussed as a unit. Figure 3 shows an example of a psychometric function for one participant. Individual psychometric functions obtained in this experiment can be found in Appendix E. Table 3, Table 4, Table 5, and Table 6 show the calculated PSEs, JNDs, and WFs for each participant under each speed/lighting condition.

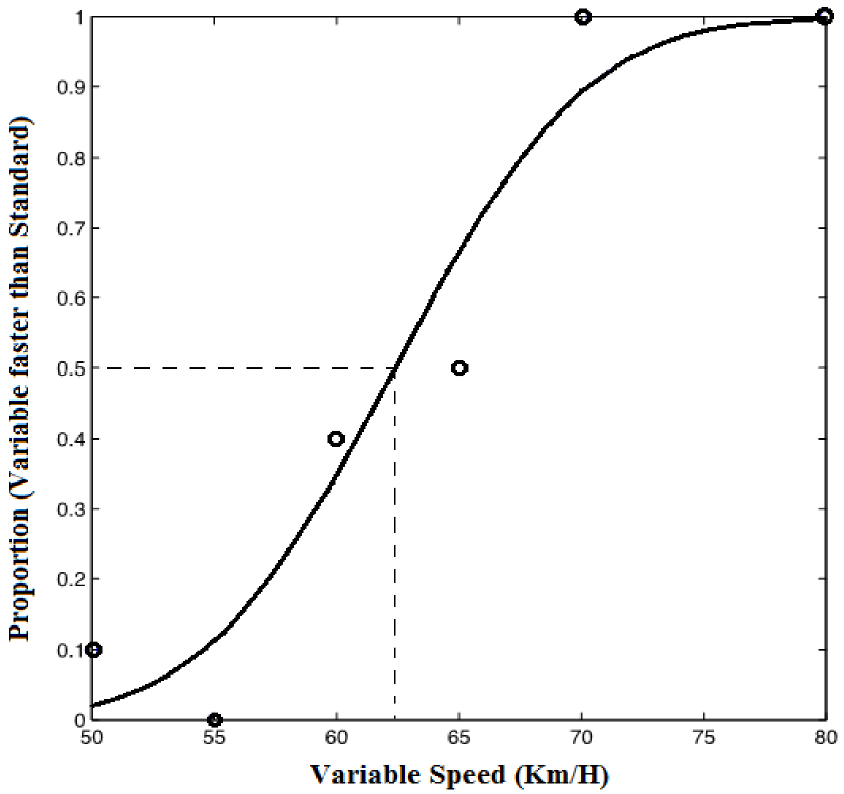

Figure 3: Psychometric function for a participant for the 60 km/h night standard condition. The small circles represent the fraction of the time that the participant indicated that the variable condition was moving faster than the standard condition. The dotted line represents the PSE.

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Table 3.

Individual Participant's PSE (and standard deviation (SD)), JND, and WF for the 60 km/h day standard condition.

Participant	PSE (km/h)	SD	JND	WF
6	62.33	11.42	4.779	0.08
7	61.48	10.15	4.506	0.075
8	57.83	6.43	3.586	0.059
9	62.09	5.14	3.206	0.053
10	56.29	8.73	4.179	0.07
11	53.55	11.95	4.889	0.081
12	59.62	6.01	3.467	0.058
13	59.46	9.88	4.445	0.074
24	51.93	5.89	3.432	0.057
25	61.55	10.18	4.512	0.075
26	56.38	5.16	3.212	0.054
29	60.09	6	3.464	0.058
30	59.11	7.6	3.899	0.065
31	55.11	10.28	4.534	0.076
32	60.96	4.19	2.895	0.048
33	60.16	9.76	4.418	0.074
Mean	**58.62**	**8.05**	**4.012**	**0.067**

Table 4.

Individual Participant's PSE (and standard deviation (SD)), JND, and WF for the 80 km/h day standard condition.

Participant	PSE (km/h)	SD	JND	WF
7 [a]	74.73	14.8	5.44	0.068
8	78.5	9.58	4.377	0.055
9	82.55	4.95	3.146	0.039
10	71.19	17.7	5.95	0.074
11	74.54	10.05	4.483	0.056
12	79.7	8.34	4.084	0.051
13	67.91	12.26	4.952	0.062
24	77.33	4.76	3.085	0.039
25	76.25	22.81	6.754	0.084
26	77.56	5.85	3.42	0.043
29	80.13	4.8	3.098	0.039
30	74.88	14.39	5.365	0.067
31	72.23	10.28	4.534	0.057
32	74.08	7.99	3.997	0.05
33	79.15	13.3	5.158	0.064
Mean	**76.05**	**10.79**	**4.645**	**0.058**

Note. [a] Participant 6 was excluded from the final analysis as the psychometric function fitting procedure was unable to provide a satisfactory fit due to extremely variable data.

Table 5.

Individual Participant's PSE (and standard deviation (SD)), JND, and WF for the 60 km/h night standard condition.

Participant	PSE (km/h)	SD	JND	WF
1	62.38	6.12	3.499	0.058
2	59.99	6.22	3.527	0.059
4 [a]	61.46	4.58	3.027	0.05
5	61.66	13.04	5.107	0.085
14	57.73	8.41	4.101	0.068
15	57.48	10.58	4.6	0.077
16	55.21	8.42	4.104	0.068
17	57.29	10.21	4.519	0.075
18	61.77	5.89	3.432	0.057
19	62.06	6.09	3.49	0.058
20	60.23	5.11	3.197	0.053
21	60.96	6.18	3.516	0.059
22	60.52	4.25	2.915	0.049
23	62.03	3.08	2.482	0.041
27	57.02	3.08	2.482	0.041
28	56.39	4.67	3.056	0.051
Mean	**59.64**	**6.62**	**3.639**	**0.061**

Note. [a] Participant 3 was excluded from the final analysis as the psychometric function fitting procedure was unable to provide a satisfactory fit due to extremely variable data.

Table 6.

Individual Participant's PSE (and standard deviation (SD)), JND, and WF for the 80 km/h night standard condition.

Participant	PSE (km/h)	SD	JND	WF
1	85.24	15.62	5.589	0.07
2	82.79	17.76	5.96	0.074
4 [a]	80.77	7.07	3.76	0.047
5	80.63	12.37	4.974	0.062
14	75.67	18.27	6.045	0.076
15	78.55	13.13	5.124	0.064
17 [a]	78.85	16.03	5.662	0.071
18	80.45	7.47	3.865	0.048
19	79.15	5.99	3.461	0.043
20	78.57	6.12	3.499	0.044
21	80.04	8.81	4.198	0.052
22	79.23	11.68	4.833	0.06
23	81.44	11.44	4.783	0.06
27	74.81	9.32	4.317	0.054
28	73.09	13.12	5.122	0.064
Mean	**79.29**	**11.61**	**4.819**	**0.06**

Note. [a] Participants 3 and 16 were excluded from the final analysis as the psychometric function fitting procedure was unable to provide a satisfactory fit due to extremely variable data.

The results indicated that participants seemed to be quite sensitive to small differences in the speeds depicted in the stimuli, regardless of the order in which the day and night scenarios were presented. This was indicated by a mean JND of approximately 4-5 km/hr and a Weber fraction of around 6%.

2.2.1 Effect of light level on egospeed perception. Four one-sample t-tests were conducted to compare the PSE obtained for the day standard and night standard conditions at both 60 km/h and 80 km/h standard speeds. One-sample t-tests were utilised instead of an ANOVA because it was more important to determine whether a difference existed between the PSE and the standard speed comparison for each speed/lighting condition than to determine the level of difference between the PSEs obtained for each speed/lighting condition. However, as utilising multiple t-tests can lead to an increase in type-1 error risk, it was decided that if the difference between the PSE and standard speed comparison was found to be statistically significant, that an ANOVA would be carried out to determine whether the PSE obtained for that standard speed/lighting condition was statistically significantly different from the PSE obtained for the other standard lighting condition at the same standard speed.

Figure 4 shows the mean PSEs obtained for the 60 km/h standard conditions for all participants, while Figure 5 shows the mean PSEs obtained for the 80 km/h standard conditions for all participants.

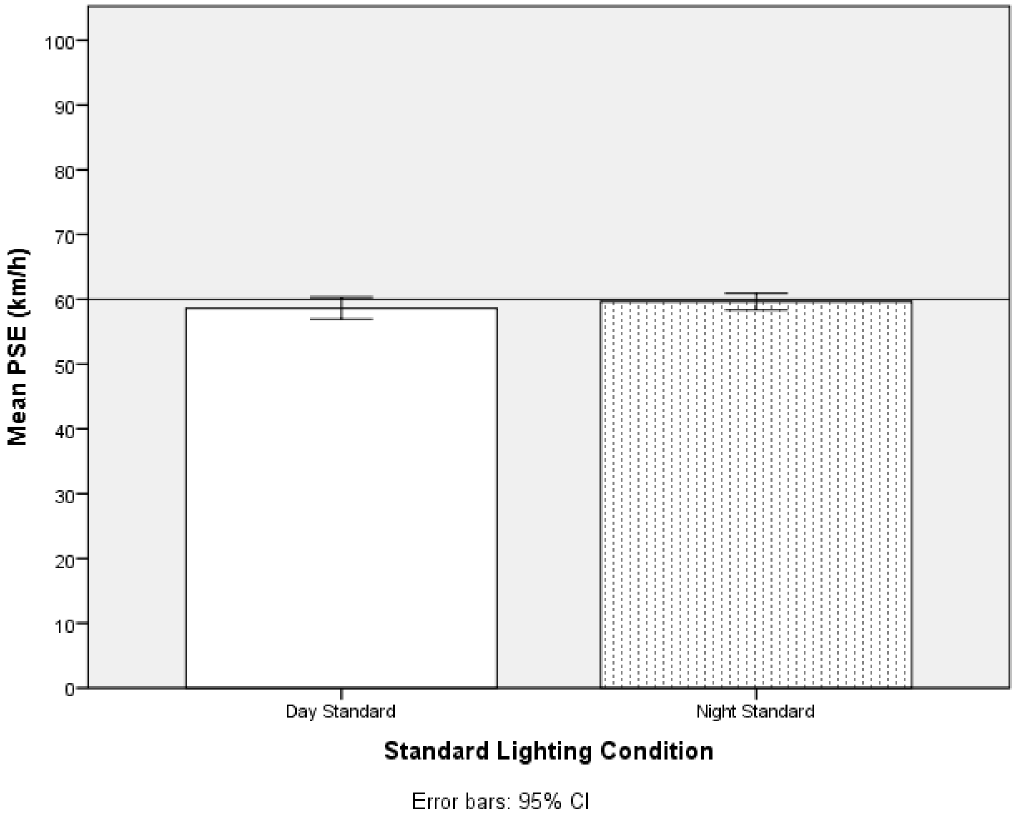

Figure 4. Bar graph showing the mean PSEs obtained for the 60 km/h standard day and night conditions for all participants. The dotted line represents the standard speed comparison (60 km/h). The error bars indicate the 95% confidence interval.

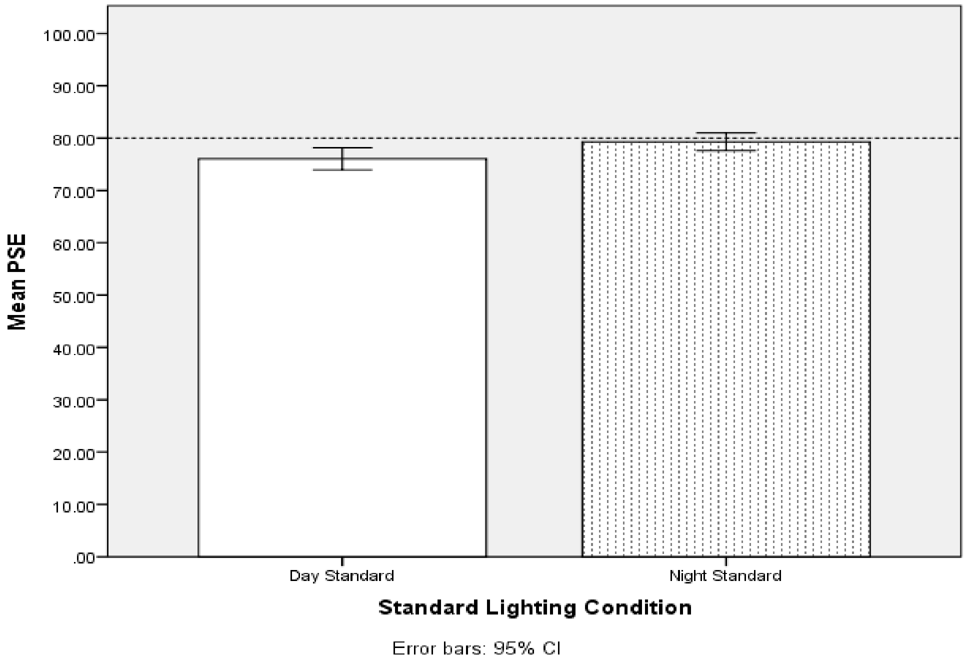

Figure 5. Bar graph showing the mean PSEs obtained for the 80 km/h standard day and night conditions for all participants. The dotted line represents the standard speed comparison (80 km/h). The error bars represented the 95% confidence interval.

The results indicate that there is no significant difference in egospeed perceived between the day standard and night variable conditions at 60 km/h (M = 58.52, SD = 3.23; t (14) = -1.78, p = 0.097), between the night standard and day variable conditions at 60 km/h (M = 59.64, SD = 2.38; t (15) = -0.61, p = 0.551), or between the night standard and day variable conditions at 80 km/h (M = 79.31, SD = 2.96; t (15) = -0.933, p = 0.366). However, the PSE for the night variable condition was statistically significantly slower than the day standard condition at 80 km/h (M = 75.65, SD = 3.80; t (14) = -4.439, p = 0.001). These results indicate that when averaged across all participants, egospeed is overestimated for the night variable condition compared to the day standard condition at 80 km/h, but that otherwise lighting has no effect on egospeed perception. This was an unexpected finding, as any effect of lighting on egospeed was expected to be mirrored between the day standard and night standard conditions. As such, in order to examine whether light levels were truly having an effect on egospeed perception, an independent samples t-test was utilised to compare the mean PSE obtained for the night variable condition (compared to the day standard condition) to the mean PSE found for the day variable condition (compared to the night standard condition).

The results of the independent samples t-test indicate that there was a significant difference in the mean PSE between the night variable condition (M = 75.86, SD = 3.71) and the day variable condition (M = 79.31, SD = 2.91); t (62) = -4.13, $p < 0.001$. This result indicates that light levels had a very strong effect on egospeed perception at 80 km/h, with participants perceiving egospeed to be faster during the night variable condition compared to the day variable condition.

Large differences in PSE were found between participants. Examination of the individual PSEs indicates that there are some participants for whom lighting has a significant effect on egospeed perception for all of the standard/variable combinations tested. Figure 6 shows the individual PSEs obtained for the 60 km/h standard condition, while Figure 7 shows the individual PSEs obtained for the 80 km/h standard condition.

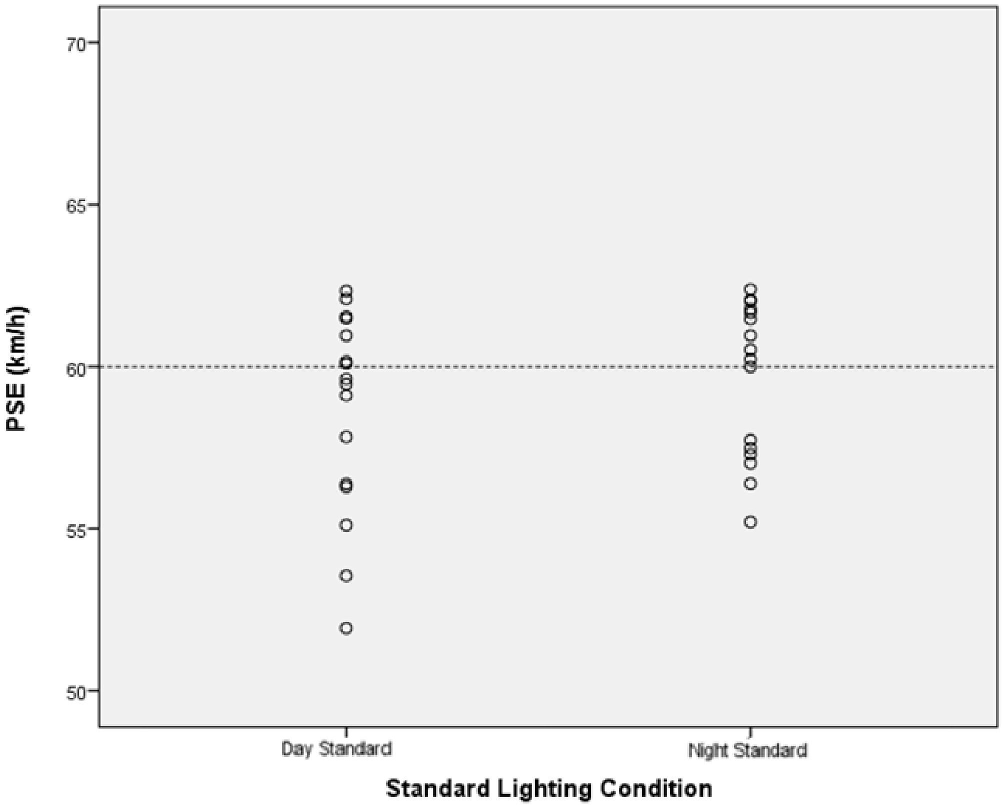

Figure 6. Scatter plot showing the PSEs obtained for the 60 km/h standard conditions for each participant. The dotted line represents the standard speed comparison (60 km/h).

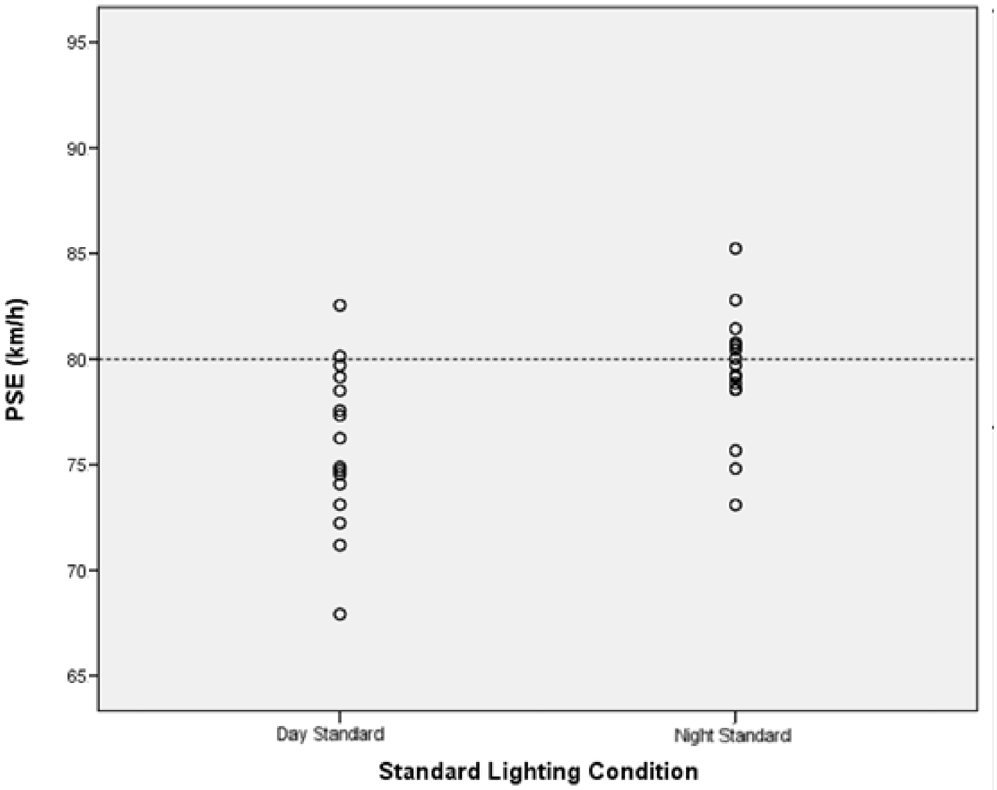

Figure 7. Scatter plot showing the PSEs obtained for the 60 km/h standard conditions for each participant. The dotted line represents the standard speed comparison (60 km/h).

Figure 6 and Figure 7 indicate two interesting things. Firstly, Figure 6 indicated that there was a wider spread of PSE values observed for the day standard condition (SD = 8.05) than the night standard condition (SD = 6.62) for both standard speed conditions. Secondly, both figures indicate that individual differences meant that some participants perceived egospeed to be faster during night conditions compared to day conditions and vice versa for all four standard conditions. Interestingly, all of the participants who underestimated egospeed for the variable condition compared to the standard condition had a JND larger than the difference between the PSE and the standard speed condition regardless of the nature of the standard condition, whereas there were participants who overestimated egospeed for the variable condition compared to the standard condition who had a JND smaller than the difference between the PSE and the standard speed condition for all four standard conditions. This suggests that participants may have adjusted to the speed of the standard condition, and as such underestimated it.

2.2.2 Adherence to Weber's law. A paired-samples t-test was performed looking at the WFs obtained for each lighting and speed standard/variable pairing in order to determine whether the mean WFs found for each group adhered to Weber's Law (i.e. were approximately the same across the two standard speed conditions (60 and 80 km/h) and across the two lighting conditions (day and night)). Figure 8 shows the distribution of WF values across all of the participants for each lighting/speed standard condition. The results of the paired-samples t-test are shown in table 7.

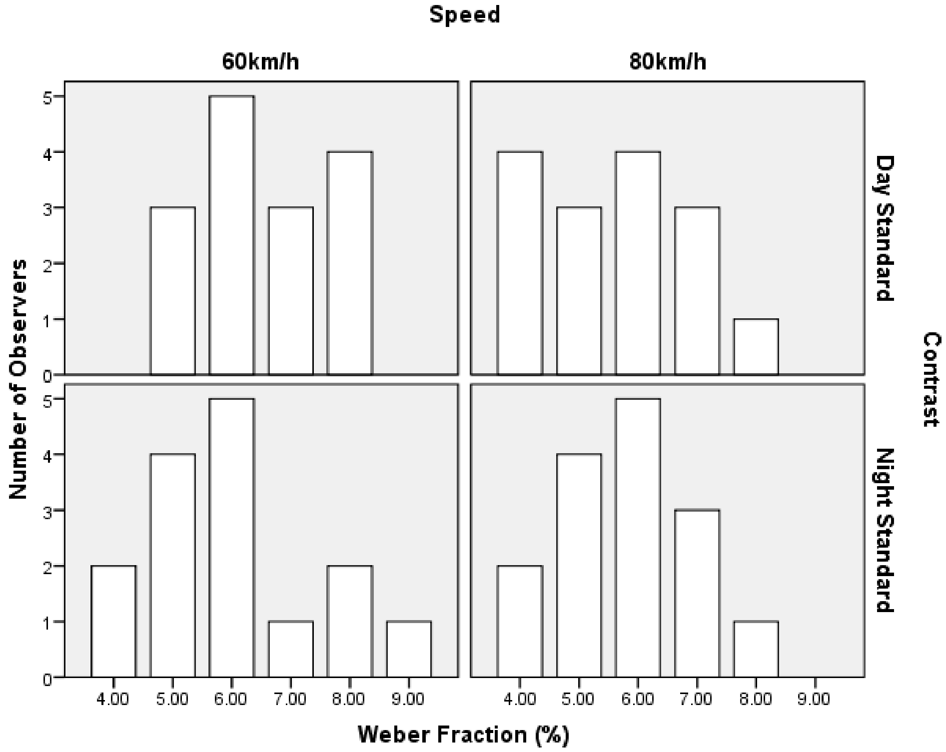

Figure 8. Bar graph indicating the distribution of WF values for all participants across all lighting and speed standard pairings.

Table 7.

Results of paired-samples t-test of weber fractions across all four speed/lighting conditions

Paired sample	T value	DF	Sig. (two-tailed)
Day Standard 60 km/h & Night Standard 60 km/h	1.746	15	0.101
Day Standard 60 km/h & Day Standard 80 km/h	1.749	14	0.102
Day Standard 60 km/h & Night Standard 80 km/h	1.705	14	0.110
Night Standard 60 km/h & Day Standard 80 km/h	0.743	14	0.470
Night Standard 60 km/h & Night Standard 80 km/h	0.157	14	0.878
Day Standard 80 km/h & Night Standard 80 km/h	-0.709	14	0.490

The results show that there was no statistically significant difference in the WFs found between any of the lighting and speed conditions. These results suggest that differences in speed and lighting do not significantly affect WF, and as such adhere to Weber's Law.

2.3 Discussion

Experiment 1 was designed to test the first two hypotheses. The first hypothesis was that egospeed would be overestimated during night conditions compared to day conditions, and the second hypothesis was that differences in egospeed perception between speed conditions would abide by Weber's Law. The results of Experiment 1 partially supported hypothesis one, and fully supported hypothesis two.

Analysis of the data found that lighting did not have a statistically significant effect on egospeed perception at 60 km/h. Further, participants overestimated egospeed for the night condition compared to the day condition at 80 km/h. It was also found that participants' velocity discrimination performance between 60 km/h and 80 km/h abided by Weber's Law.

As mentioned above, no known research has examined the effect of luminance contrast on egospeed discrimination ability. As such, the results of this experiment can only be compared to research in related fields.

The findings of Experiment 1 are somewhat contrary to previous research into the effect of complex contrast reductions on egospeed perception (Pretto et al., 2012; Dyre, Schauldt, and Lew, 2005). However, this earlier research was conducted on the effect of fog on egospeed perception, which reduces contrast in a much different way to luminance contrast. While luminance contrast reduction is a direct reduction in light level, fog reduces contrast through reflecting and diffusing light, which reduces the transparency of air, which in turn reduces both contrast and visibility distance (Green, 2013). This supports the idea that generalisations of effect are not useful between different types of contrast, and that as such it is important to define the exact form of contrast being examined in a study (Travikova, 1985).

The findings are contrary to the previous research into the effect of luminance on egospeed perception (Pritchard and Hammett, 2011), who found that reducing 'average luminance' led to a reduction in perceived speed. However, this can be explained by the fact that 'average luminance' is analogous to global contrast, and as luminance contrast was reduced in a complex manner, the results are not truly comparable.

The findings are in keeping with previous research into velocity discrimination and WFs (McKee, Silverman, and Nakayama, 1986). This is somewhat surprising as these researchers used simple 2D stimuli, which did not contain the complexity and non-linear image motion present in the road stimuli used in this thesis. The participants in the present experiment were able to perform at the same level of speed discrimination performance despite being presented with more complex stimuli. Further, as there was no significant difference in WF between any of the conditions, it is likely that participants are employing a single visual perception mechanism over all of the conditions tested (Ungan and Yagcioglu, 2014).

Previous research indicates that when egospeed is overestimated drivers automatically reduce their speed and vice versa (Pretto et al., 2012). As such, the finding that participants overestimated egospeed for the night condition compared to the day condition at 80 km/h indicates that it is likely that individuals who are attempting to drive at 80 km/h on a rural road but who are paying inadequate attention to their speedometers will be likely to drive at lower speeds while driving at night compared to day.

The mean PSEs (95% CI) for the night standard conditions for both 60 km/h and 80 km/h were centred on the standard speed comparison, while the mean PSEs (95% CI) for the day standard conditions for both 60 km/h and 80 km/h were centred slightly below the standard speed comparison. This indicates that, when participants are examined as a whole, the night variable condition was underestimated compared to the day standard condition at both 60 km/h (not to a statistically significant degree) and 80 km/h (to a statistically significant degree), but that the day variable condition was viewed as being equal to the night standard condition at both 60 km/h and 80 km/h. This suggests that the presentation order of the lighting conditions had an effect on egospeed perception. A possible reason for this could be that participants are choosing where in the scene to focus based on which scenario they see first. As the observed horizon line is closer to the participant during night conditions, visual elements chosen by participants as focal points during the night condition are always visible during the day condition, while visual elements chosen by participants as focal points during the day condition may not be visible during the night condition. In order to determine whether this is the case, the chapter that addresses eye movement behaviour will examine whether the presentation order of the lighting scenarios had an effect on eye movement behaviour.

An interesting finding was that, due to strong individual differences, some participants overestimated egospeed during day conditions compared to night conditions to a statistically significant level and vice versa. This indicates that, for these individuals, complex reductions in lighting have the same effect on egospeed perception as global reductions of contrast caused by fog (Horswill and Plooy, 2008; Owens et al., 2010; Snowden, Stimpson, and Ruddle, 1998). A possible explanation for this is that these participants could have been focussing on the reflective posts and/or cat's eyes as visual features that stand out strongly during night periods (Triggs and Berenyi, 1982) and that these posts, due to their reflective nature, did not comply with linear or exponential reductions in contrast.

Another interesting finding is that while the most common WF for both 60 km/h standard conditions and the 80 km/h night standard condition was 6%, the most common WF for the 80 km/h day standard condition was tied between 4% and 6%. This suggests that there may be something about the differences between the scenarios presented during this condition that makes it easier for individuals to discriminate. This is especially interesting as the same participants took part in the 60 km/h day standard condition as well and yet none of them demonstrated discrimination performance to the 4% level at 60 km/h.

Although there was no significant difference in WF between speed conditions, the standard deviation from the psychometric curve increased, indicating that participants found velocity discrimination to be a harder task at the higher speed level. While this did not cause any issues with this experiment, it could become an issue if higher standard speeds are examined. A solution to this would be to increase the step sizes between rendered speeds from 10 km/h to 20 km/h while maintaining the same number of variable conditions, as this would allow for higher levels of error to occur without affecting the results of the experiment.

In summary, it was found that lighting did not significantly affect egospeed perception at 60 km/h but did significantly affect egospeed perception at 80 km/h, as egospeed was overestimated for both the night variable condition compared to the day standard condition and for the night variable condition compared to the day variable condition. This suggests that the effect of lighting on egospeed perception may become more pronounced as the standard speed it is being tested at increases. It was also found that lighting had a significant effect on the egospeed perception of individual participants, with some overestimating the day condition compared to the night condition to a statistically significant level and vice versa at both 60 km/h and 80 km/h. Further, it was found that participants' velocity discrimination performance between 60 km/h and 80 km/h abided by Weber's Law. However, the speeds examined in Experiment 1 do not cover the entire range of speed limits enforced on rural roads in New Zealand, as the speed limit on some rural roads is 100 km/h. As this is the case, does the effect found at 80 km/h hold true at 100 km/h? If not what exactly changes? Further, as this experiment utilised the forced choice model, participants would have felt different levels of confidence in their answers; therefore, does the level of confidence felt by a participant while undertaking the experiment have an effect on PSE? Do more confident participants perform better or worse than less confident participants, or does confidence have no bearing?

In order to answer these questions, Experiment 2 was designed to examine the effect of differences in lighting on egospeed perception at 100 km/h on rural roads. As with the first experiment, Experiment 2 will involve participants watching pairs of scenarios and judging which they felt to be moving faster, employing the use of a two-alternative forced choice design. Experiment 2 will also utilise a magnitude estimation task to gather information on the level of confidence felt by participants. As Experiment 2 will be examining a higher speed than either examined in Experiment 1, step sizes will be increased from 10 km/h to 20 km/h pre-emptively in order prevent the curve fittings from straightening to the point of becoming unreliable for determining the correct PSE.

3. Experiment 2

The second experiment was designed to examine whether the findings of Experiment 1 held true at the highest speed at which drivers in New Zealand can legally drive on rural roads (100 km/h), and to explore the premise that the level of confidence felt by participants impacted on the PSE they observed. As with Experiment 1, this experiment used the method of constant stimuli in order to extend the testing the first two hypotheses. The aim was to examine how day and night time lighting conditions affects one's perceived visual speed on a rural road.

3.1 Methods

3.1.1 Participants. A total of 16 participants (8 female and 8 male) with normal or corrected to normal vision undertook this experiment. Participants were recruited in the same manner as for Experiment 1, and ranged in age from 18 - 43

3.1.2 Apparatus. The apparatus used for this experiment was the same as with Experiment 1.

3.1.3 Stimuli. The stimuli used in this experiment were created in the same manner as for Experiment 1.

3.1.4 Design. As with Experiment 1, a repeated measures design was utilised for this experiment. Participants viewed pairs of scenarios composed of one day and one night scenario, one standard speed, and seven variable speeds (described in more detail below) with the trial running order randomised by the computer software. Each possible contrast/speed combination was shown ten times, with the trial running order randomised by the computer software, adding up to a total of 70 trials. As with Experiment One, participants ran five practice trials before starting the experiment (described in more detail below).

This experiment was run using Experiment Builder. Counterbalancing was again used in order to minimise order effects and/or adaptation effects. Each counterbalanced group was composed of eight participants, with four males and four females in each group. Group 1 observed the day standard/night variable condition, while Group 2 observed the night standard/day variable condition.

Each trial consisted of firstly the standard scenario, composed of travelling at 100 km/h under a set lighting condition, followed by the variable scenario, composed of travelling at one of the variable speeds (described below) and under a set lighting condition. The presentation time of each scenario was again randomised to be 4, 4.5, 5, 5.5, or 6 seconds in length, with each scenario in a pair of scenarios being a different length, and no two pairs of scenario with the same presentation timing.

Each trial consisted of firstly the standard scenario, composed of travelling at 100 km/h under a set lighting condition, followed by the variable scenario, composed of travelling at either 40 km/h, 60 km/h, 80 km/h, 100 km/h, 120 km/h, 140 km/h, or 160 km/h under a set lighting condition.

As mentioned above, participants were given five practice trials before the start of the experiment. This practice was composed of one trial in which the standard and variable conditions moved at the same speed, two trials in which the speed of the variable scenario was moving slower than the standard condition (40 km/h), and two trials in which the speed of the variable scenario was moving faster than the standard condition (160 km/h). These five trials were presented in a randomised order, and the light levels of the standard and variable conditions were the same as the participant was presented with during the experiment proper.

3.1.5 Procedure. The experiment and procedure were approved by the University of Waikato School of Psychology's Human Ethics committee. The procedure was the same as that of Experiment One, with the addition that after indicating which scenario they had observed as being faster, another response screen appeared with two text statements. The first was centered at the top of the screen, and read "On a scale of one to ten, with 1 being completely unconfident and 10 being completely confident, how confident are you in your answer?". The second was centered in the middle of the screen, and was a scale line from zero to ten in increments of one, with the words "completely unconfident" below the number zero, and the words "completely confident" under the number ten. Participants were then required to indicate how confident they were in their answer by clicking the corresponding number on the scale. After doing so, the screen went black and, after a period of two seconds, the next trial began. A copy of the instruction sheet for Experiment 2 can be found in Appendix F, while the response screens shown can be found in Appendix G.

As with Experiment One, participants' eye movements were measured in order to determine where they were focussing for both day and night contrast conditions.

3.2 Results

As with Experiment one, the day standard and night standard responses were structured into separate databases and analysed using MatLab (Version R2007b; Mathworks, 2007). As with Experiment 1, during this experiment the day standard/night variable conditions are referred to as “day standard” when discussed as a unit, while the night standard/day variable conditions are referred to as “night standard” when discussed as a unit. Individual psychometric functions obtained during this experiment can be found in Appendix H. The psychometric curves were examined in order to calculate the mean PSEs, JNDs, and WFs for each condition and across all participants. Table 8 and Table 9 show the calculated PSEs, JNDs, and WFs for each participant.

Table 8.

Individual Participant’s PSE (and standard deviation (SD)), JND, and WF for the day 100 km/h standard condition.

Participant	PSE (km/h)	SD	JND	WF
1	108.54	42.18	9.185	0.092
2	110.94	49.49	9.949	0.099
5[a]	95.43	26.35	7.259	0.073
10	91.84	14.78	5.437	0.054
12	101.8	35.25	8.396	0.084
13	110.4	36.31	8.522	0.085
14	120.69	32.5	8.062	0.081
15	117.28	47.35	9.731	0.097
Mean	**107.12**	**35.53**	**8.430**	**0.084**

Note. [a] Participant 3 and Participant 4 were excluded from the final analysis as the psychometric function fitting procedure was unable to provide a satisfactory fit due to extremely variable data.

Table 9.

Individual Participant's PSE (and standard deviation (SD)), JND, and WF for the night 100 km/h standard condition.

Participant	PSE (km/h)	SD	JND	WF
6	101.75	14.79	5.439	0.054
7	91.38	28.07	7.493	0.075
8	95.07	19.99	6.323	0.063
9	96.28	20.5	6.403	0.064
11	111.33	29.37	7.664	0.077
16	90.11	8.42	4.104	0.041
17	100.87	14.75	5.431	0.054
18	114.39	16.31	5.711	0.057
19	96.47	14.59	5.402	0.054
Mean	**99.47**	**18.53**	**6.088**	**0.061**

The results indicated that participants seemed to be quite sensitive to small differences in the speeds depicted in the stimuli for the night standard condition. This was indicated by a mean JND of approximately 6 km/h and a Weber fraction of around 6%. The results also indicated that participants were relatively sensitive to differences in speeds depicted in the stimuli for the day standard condition. This was indicated by a mean JND of approximately 8 km/h and a Weber fraction of around 8%.

3.2.1 Effect of light level on egospeed perception. Two one-sample t-tests were conducted to compare the PSE obtained for the day standard and night standard conditions at 100 km/h.

Figure 9 shows the mean PSEs obtained for the 100 km/h standard conditions for all participants.

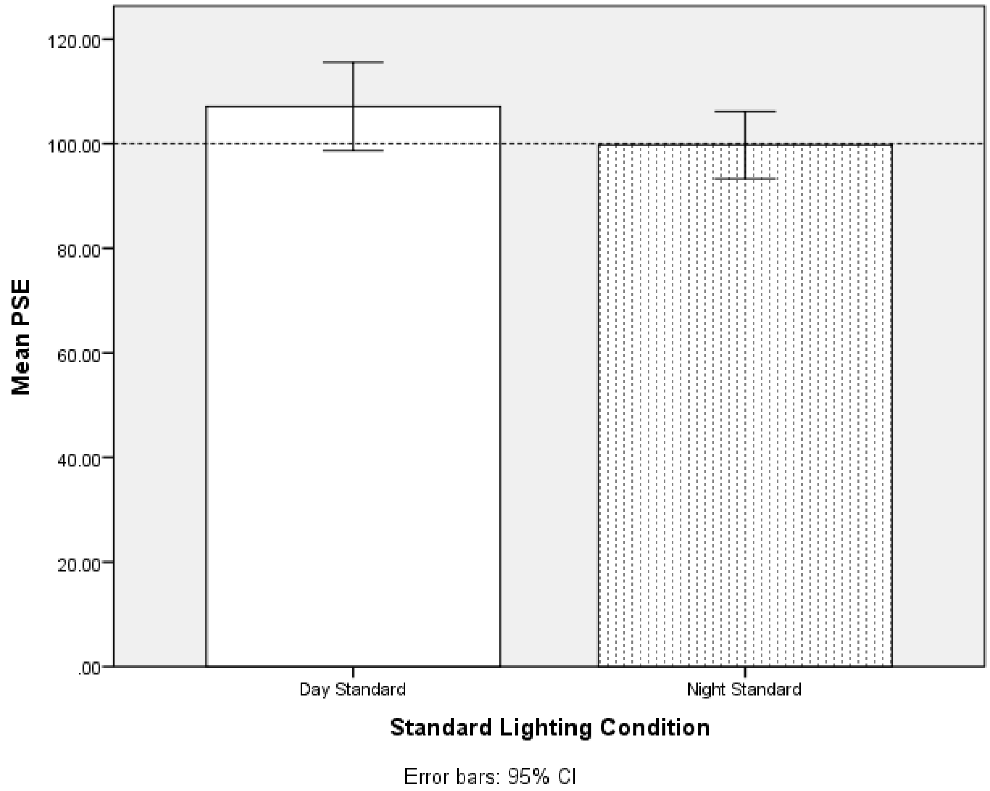

Figure 9. Bar graph showing the mean PSEs obtained for the 100 km/h standard conditions for all participants. The bars represent the mean PSEs obtained for the day standard condition and the night standard condition. The dotted line represents the standard speed comparison (100 km/h). The error bars represented the 95% confidence interval.

The results indicate that although egospeed for the night variable condition was overestimated compared to the day standard condition, it was not to a statistically significant degree (*M* = 107.11, *SD* = 10.09; *t* (7) = 1.994, *p* = 0.086), and that further, there was no significant difference in egospeed perception between the night standard and day variable conditions (*M* = 99.74, *SD* = 8.38; *t* = -0.92, *p* = 0.929). These results indicate that when averaged across all participants, lighting has no effect on egospeed perception.

As with Experiment 1, large differences in PSE were found between participants. Examination of the individual PSEs indicates that there are some participants for whom lighting has a significant effect on egospeed perception for both day standard and night standard conditions. Figure 10 shows the individual PSEs obtained for the 100 km/h standard condition.

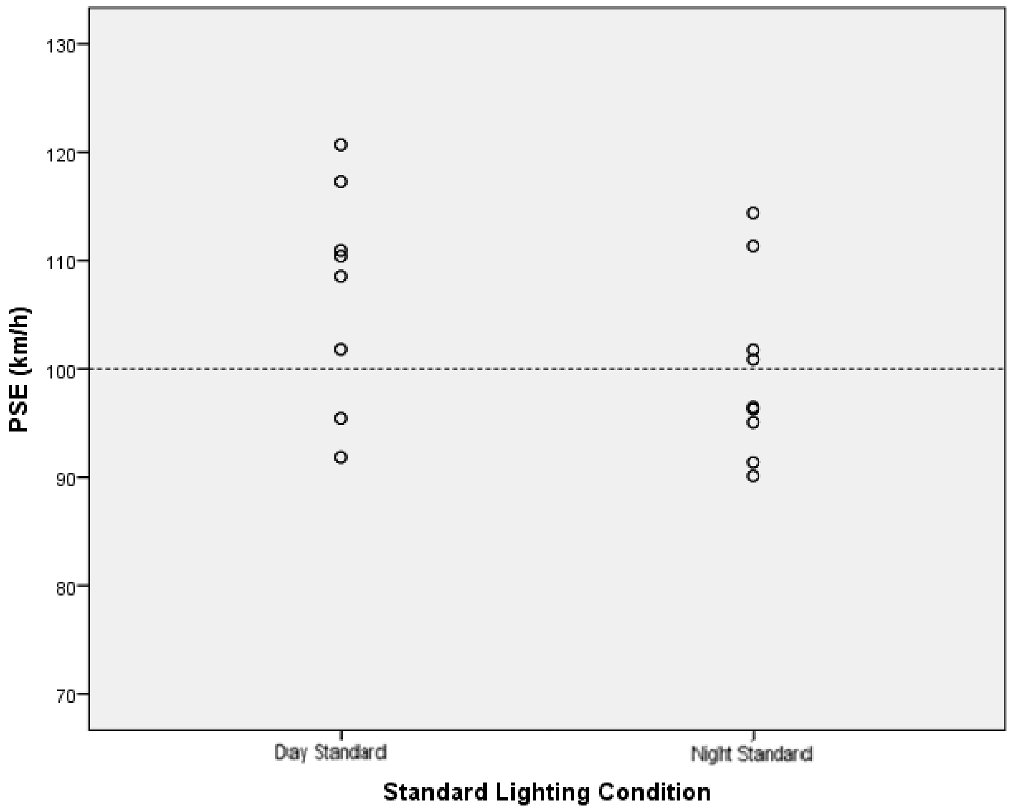

Figure 10. Scatter plot showing the PSEs obtained for the 100 km/h standard conditions for each participant. The dotted line represents the standard speed comparison (100- km/h).

3.2.2 Effect of confidence on egospeed perception. In order to examine whether the level of confidence an individual felt was related to the effect of lighting on egospeed perception, a univariate ANCOVA was conducted comparing the PSE obtained for the day standard and night standard conditions at 100 km/h, with mean confidence tested as a covariate. Figure 11 shows the mean confidence felt by participants at each variable speed compared to the standard speed for both day standard and night standard conditions.

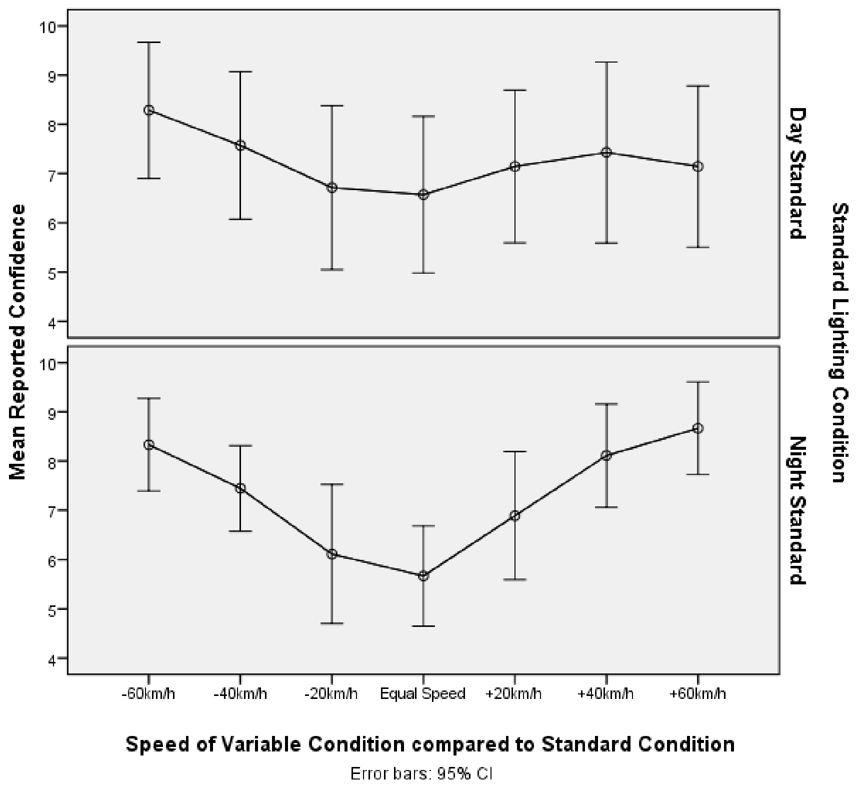

Figure 11. Line graph showing the mean reported confidence level for each variable speed condition compared to the standard condition for both standard lighting conditions.

The mean level of confidence felt by participants during the experiment was found to not have a statistically significant impact on observed PSE (F (1, 13) = 1.137, p = 0.306). Further, including it as a covariate did not change the finding that lighting does not have a statistically significant effect on egospeed at 100 km/h (F (1, 13) = 2.399, p = 0.145).

Figure 11 indicates that participants became more confident as the difference between the standard and variable conditions increased, which was expected. However, it also indicates that participants were more confident when the day scenario was faster than the night scenario with the same speed differential regardless of which lighting condition was used as the standard condition. Interestingly, although it was expected that confidence would increase in a relatively linear fashion as the difference between the standard and variable conditions increased, this is not supported at the +60 point for either contrast condition, where the rate of confidence increase is reduced. For the night standard condition this amounted to a reduction in the level to which confidence was increasing, but for the day standard condition this amounted to a reduction in the mean reported confidence. It is also interesting to note that there was less variation in reported confidence levels for participants who observed the night standard condition than for those who observed the day standard condition.

3.2.3 Adherence to Weber's Law. A paired-samples t-test was performed looking at the WFs obtained for each lighting and speed standard/variable pairing from Experiment One compared to the WFs obtained for both lighting standard/variable pairings examined in this experiment. Figure 12 shows the distribution of WF values across all of the participants for each contrast/speed standard condition.

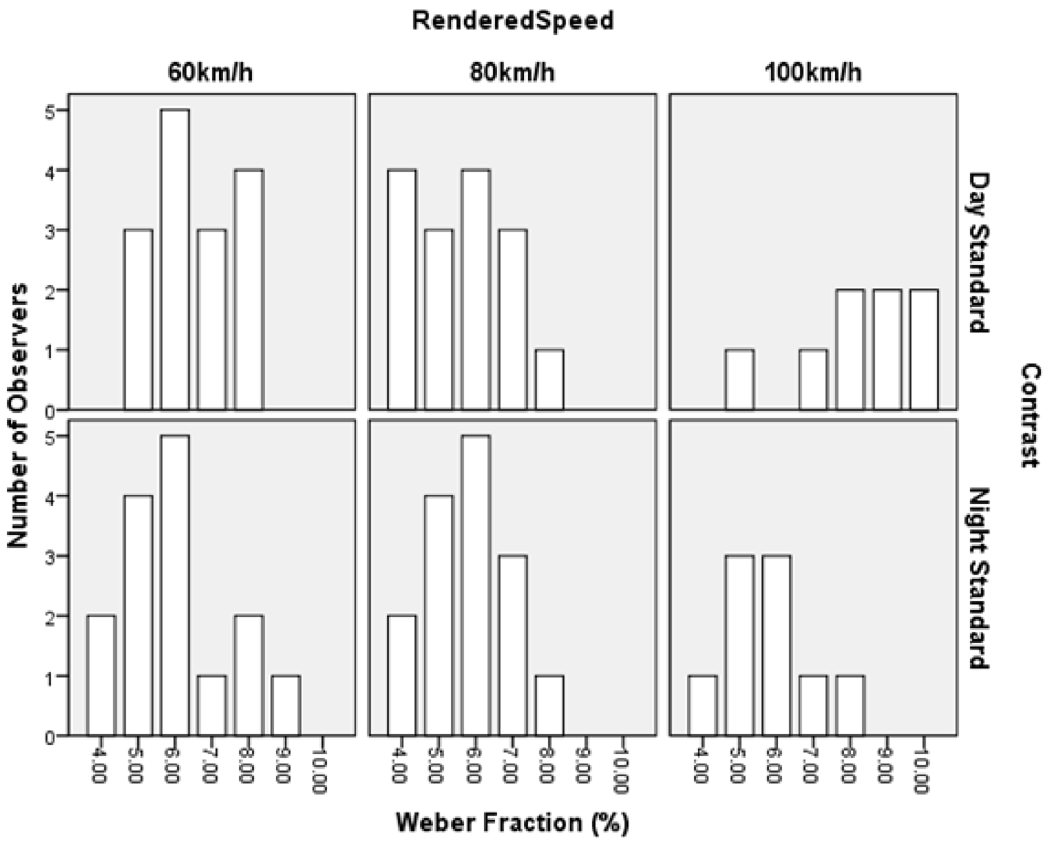

Figure 12. Distribution of WF values for all participants of Experiment 1 and Experiment 2 across all lighting and speed standard pairings. Note that there were 16 participants per group for 60 km/h and 80 km/h under both contrast conditions but only 8 participants per group for the 100 km/h condition.

The results of the paired-samples t-test are shown in table 10.

Table 10.

Results of paired-samples t-test of weber fractions across all four speed/lighting conditions from Experiment 1 compared to Weber fractions from both lighting conditions for this experiment, as well as between lighting conditions for this experiment

Paired sample	T value	DF	Sig. (two-tailed)
Day Standard 60 km/h & Day Standard 100 km/h	-4.656	7	0.002
Day Standard 80 km/h & Day Standard 100 km/h	-3.432	7	0.011
Night Standard 60 km/h & Day Standard 100km/h	-2.046	7	0.08
Night Standard 80 km/h & Day Standard 100 km/h	-3.259	7	0.014
Day Standard 60 km/h & Night Standard 100 km/h	1.348	8	0.215
Day Standard 80 km/h & Night Standard 100 km/h	-0.187	8	0.857
Night Standard 60 km/h & Night Standard 100 km/h	1.113	8	0.298
Night Standard 80 km/h & Night Standard 100 km/h	0.388	8	0.708
Day Standard 100 km/h & Night Standard 100 km/h	3.378	7	0.012

The results show that there was no statistically significant difference in the WFs found between the night standard 100 km/h condition and any of the speed/lighting standard conditions examined in experiment one. However, they also show that the WFs found for the day standard 100km/h was statistically significantly different to those obtained for the night standard 100km/h condition and all of the speed/lighting standard conditions examined in experiment one. Figure 12 indicates that this difference in WF is due to participants being worse on average at the velocity discrimination task required of them when undertaking the 100 km/h day standard condition than when undertaking any of the other lighting/speed standard conditions. These results indicate that the 100 km/h night standard condition adhere to Weber's law, but that the 100 km/h day standard condition does not.

3.3 Discussion

Experiment 2 was designed to extend the testing of the first two hypotheses. The first hypothesis was that egospeed would be overestimated during night conditions compared to day conditions, and the second hypothesis was that differences in egospeed perception between speed conditions would abide by Weber's Law. The results of Experiment 2 did not support hypothesis one, and only partially supported hypothesis two.

Experiment 2 also explored the premise that the effect of lighting on egospeed perception found at 80 km/h would hold true at 100 km/h. The results of Experiment 2 did not support this premise.

Experiment 2 also explored the premise of whether the level of confidence felt by participants had an effect on PSE. The results of Experiment 2 did not support this premise.

Analysis of the data found that lighting did not have a statistically significant effect on egospeed perception at 100 km/h. It was also found that the WFs participants obtained for the 100 km/h day standard condition were statistically significantly different from those obtained for all other speed/contrast conditions. However, the WFs obtained for the100 km/h night standard condition was found to not be significantly different from those obtained for any of the speed/lighting conditions examined in Experiment 1.

The findings of Experiment 2 are contrary to previous research into the effect of complex contrast reductions on egospeed perception (Pretto et al., 2012; Dyre, Schauldt, and Lew, 2005). As mentioned in the discussion for Experiment 1, this is most likely due to the exact manner in which contrast is reduced, and as such supports the idea that generalisations of effect are not useful between different types of contrast, and that as such it is important to define the exact form of contrast being examined in a study (Travnikova, 1985).

Although it was not to a significant degree, the night variable condition was underestimated compared to the day standard condition. This is the opposite of what was found in Experiment 1, where the night variable condition was overestimated compared to the day standard condition at both 80 km/h (to a statistically significant degree) and at 60 km/h (not to a statistically significant degree). This finding supports the idea that participants are likely to have employed a different visual perception mechanism for the 100 km/h day standard condition compared to any of the other speed/lighting conditions. Further, this is not in keeping with research into the effect of contrast on egospeed perception in a 3D environment (Horswill and Plooy, 2008; Dyre, Schauldt, and Lew, 2005) as the effect, although only significant at 80 km/h, reverses at 100 km/h while the results of both Horswill and Plooy (2008) and Dyre, Schauldt, and Lew (2005) were steady across all the speed conditions they tested. A possible reason for this could be that, as mentioned above, this research has focussed on a different medium through which contrast has been reduced. Interestingly, research into the effect of contrast on peed perception using a 2D grating stimuli (Thompson, 1982) did find that the effect became reversed at high speeds.

The mean PSE for the night standard condition was centred on the standard speed comparison, while the mean PSE was centred above the standard speed comparison. This is in keeping with the findings of Experiment 1, with the proviso that it is the deviation from the standard speed condition that is important when observing the day standard conditions across all three speed conditions rather than the direction of the deviation, and supports the idea that the presentation order of the lighting conditions had an effect on egospeed perception. As mentioned in Experiment 1, this will be examined in the chapter that addresses eye movement behaviour.

An interesting finding was that participants had a statistically significantly higher WF for the day standard 100 km/h condition than for any of the other conditions, but that there was no significant difference in WF between any of the other conditions. This finding is partially in keeping with McKee, Silverman, and Nakayama (1986), who found that WFs obtained from velocity discrimination tasks performed a U-shaped function, with both fast speeds and low speeds having a higher WF than speeds in the middle. Interestingly, as mentioned in the discussion for Experiment 1, they were examining velocity discrimination in a 2D environment, which does not contain the complexity and non-linear image motion present in the road stimuli used in this thesis. This suggests that WF may act in this manner regardless of the method by which velocity discrimination is being examined. Further, finding a significant difference in WF is unusual in a single perception mechanism (Ungan and Yagcioglu, 2014), indicating that participants are likely to have employed a different visual perception mechanism for the 100 km/h day standard condition compared to any of the other speed/lighting conditions.

As with Experiment 1 it was found that, due to strong individual differences, some participants overestimated egospeed during day conditions compared to night conditions to a statistically significant level and vice versa. As this was found at all of the speed conditions examined in this thesis, this indicates that the role of lighting on egospeed perception is likely to be highly individualised regardless of speed. It is interesting that such strong individual differences were found and yet any effect was washed out over all participants at both 60 km/h and 80 km/h speed conditions.

In summary, it was found that although participants underestimated egospeed for the night variable condition compared to the day variable condition, lighting did not significantly affect egospeed perception at 100 km/h. This suggests that the effect of lighting on egospeed perception reverses at high speeds, although this is not to a significant degree at 100 km/h. Further, it was found that participants' velocity discrimination performance did not abide by Weber's Law between the 100 km/h day standard condition and all other speed/lighting conditions, but that it did between the 100 km/h night standard condition and the speed/lighting conditions tested in Experiment 1. However, examining the effect of lighting on egospeed perception only allows for the identification of the degree of difference in egospeed perception between the two lighting conditions, and does not allow the identification of the exact speed at which individuals perceived themselves to be moving under different lighting conditions. Previous research (Fildes, Fletcher, and Corrigan, 1989; Triggs and Berenyi, 1982) has found that lighting has a significant impact on judgements of egospeed, but there is no consensus as to whether day conditions are judged to be faster or slower than night conditions. What effect, if any, does lighting have on judgements of egospeed? Experiments 1 and 2 have examined speed discrimination performance to look at the effects of lighting, while examining judgements of egospeed would involve using absolute estimates of speed to determine whether lighting has an effect; do the effects found in Experiment 1 and Experiment 2 hold true when examining judgements of egospeed rather than egospeed perception? How fast do participants judge themselves to be moving under different speed/lighting conditions?

In order to answer these questions, Experiment 3 was designed to examine the effect of differences in lighting on judgements of egospeed between 60 km/h and 100 km/h on rural roads. Experiment 3 will involve participants watching individual scenarios and indicating the speed at which they judged themselves to be moving, employing the use of a magnitude estimation task. As with Experiment 2, Experiment 3 will also utilise a second magnitude estimation task to gather information on the level of confidence felt by participants.

4. Experiment 3

For the third experiment, a magnitude estimation task was used to test the first hypothesis, determine the speed at which participants judged themselves to be moving under different speed/lighting conditions, and explore the premises that (1) the findings of Experiment 1 and Experiment 2 will hold true for judgements of egospeed, and that (2) confidence will have an effect on judgements of egospeed. The aim was to examine how day and night lighting conditions affected one's speed judgements on a rural road. Participants were presented with individual driving scenarios mimicking self-motion from a car driver's perspective, and instructed to indicate the speed at which they perceived themselves to be moving. The scenario displayed a variety of target speeds (described below) and displayed both day and night lighting conditions.

4.1 Methods section

4.1.1 Participants. A total of 16 participants (8 female and 8 male) with normal or corrected to normal vision undertook this experiment. Participants were recruited in the same manner as for Experiments One and Two, and ranged in age from 18 – 44.

4.1.2 Apparatus. The apparatus used for this experiment was the same as with Experiment One, except that the EyeLink 1000 Desktop System (Eyelink 1000, SR Research Ltd., Ontario, Canada) was not utilised.

4.1.3 Stimuli. The stimuli used in this experiment were created in the same manner as for Experiment One.

4.1.4 Design. A magnitude estimation task was utilised to test for participants perceptions of speed during different lighting conditions. Participants viewed individual scenarios, each depicting either the day or the night lighting condition and moving at one of five predetermined speeds (described in more detail below). Speed and lighting level were randomised between trials. As with Experiment One and Experiment Two, participants ran five practice trials before the start of the experiment (described in more detail below).

This experiment was run using Experiment Builder. Each possible contrast/speed combination was shown six times, with the trial running order randomised by the computer programme, adding up to a total of 60 trials.

Each trial consisted of either a day or night scenario travelling at 60km/h, 70km/h, 80km/h, 90km/h, or 100km/h. The contrast level and scenario speed were randomly selected by the computer software. In order to prevent participants from manually counting texture elements to estimate speed, the presentation time of each scenario was randomised to be 4, 4.5, 5, 5.5, or 6 seconds in length.

As mentioned above, participants were given five practice trials before the start of the experiment. The practice trial was composed of one trial showing the day lighting condition at 100km/h, one trial showing the night lighting condition at 100km/h, one trial showing the day lighting condition at 60km/h, one trial showing the night lighting condition at 60km/h, and one trial showing the day lighting condition at 80km/h. These five trials were presented in a randomised order.

4.1.5 Procedure. The experiment and procedure were approved by the University of Waikato School of Psychology's Human Ethics committee. Each participant was provided with an instruction sheet outlining the experimental procedure prior to commencement. A copy of the instruction sheet for Experiment 3 can be found in Appendix F.

During the experiment, participants were presented with individual driving scenarios. After each scenario had been viewed, a response screen with two text statements was shown. The first was centered at the top of the screen, and read "In km/h, at what speed were you moving?". The second was centered in the middle of the screen, and was a scale line from zero to one hundred and fifty in increments of ten. Participants were then required to indicate the speed at which they thought the scenario had been moving by clicking on the scale line. After doing so, another response screen with two text statements was shown. The first was centered at the top of the screen, and read "On a scale of one to ten, with 1 being completely unconfident and 10 being completely confident, how confident are you in your answer?". The second was centered in the middle of the screen, and was a scale line from zero to ten in increments of one, with the words "completely unconfident" below the number zero, and the words "completely confident" under the number ten. Participants were then required to indicate how confident they were in their answer by clicking the corresponding number on the scale line. After doing so, the screen then went black and, after a period of two seconds, the next trial began. The response screens shown in this experiment can be found in Appendix J.

4.2 Results

While there were individual differences in magnitude, speed was underestimated by all participants for both day and night conditions, and across all rendered speeds. Individual's estimates of egospeed during this experiment can be found in Appendix H. Table 11 shows the mean perceived speeds, standard deviations, and mean confidence across all participants for all rendered speeds and contrast conditions.

Table 11.

Rendered speeds, mean perceived speeds for day, mean perceived speeds for night, standard deviations, and mean confidence.

Rendered Speed	Mean Perceived Speed Day	Standard Deviation	Mean Confidence
60km/h	33.29km/h	11.183	5.47
70km/h	40.97km/h	13.358	5.28
80km/h	45.69km/h	13.648	5.l7
90km/h	52.35km/h	14.785	5.29
100km/h	60.36km/h	15.844	5.41
Rendered Speed	Mean Perceived Speed Night	Standard Deviation	Mean Confidence
60km/h	32.88km/h	10.989	5.43
70km/h	39.46km/h	12.976	5.17
80km/h	44.42km/h	11.625	5.24
90km/h	53.07km/h	15.438	5.31
100km/h	57.20km/h	13.717	5.38

4.2.1 Effect of lighting on judgements of egospeed. In order to determine whether lighting had an effect on judgements of egospeed, a repeated measures ANOVA was used to compare the calculated mean perceived speed for all participants across all five rendered speeds (60km/h, 70km/h, 80km/h, 90km/h, and 100km/h) for both contrast conditions (day and night). Mauchley's test indicated that the assumption of sphericity was violated for both rendered speed ($x^2(9) = 21.494$, $p = 0.011$, $\varepsilon = 0.624$ (Greenhouse-Geisser) or 0.733 (Huynh-Feldt) and the interaction between the level of contrast and rendered speed ($x^2(9) = 17.508$, $p = 0.042$, $\varepsilon = 0.63$ (Greenhouse-Geisser) or 0.741 (Huynh-Feldt)). As ε

< 0.75 for both rendered speed and for the interaction between the level of contrast and rendered speed, Greenhouse-Geisser correction was used. Figure 13 shows the effect of lighting on mean perceived speed obtained for each rendered speed.

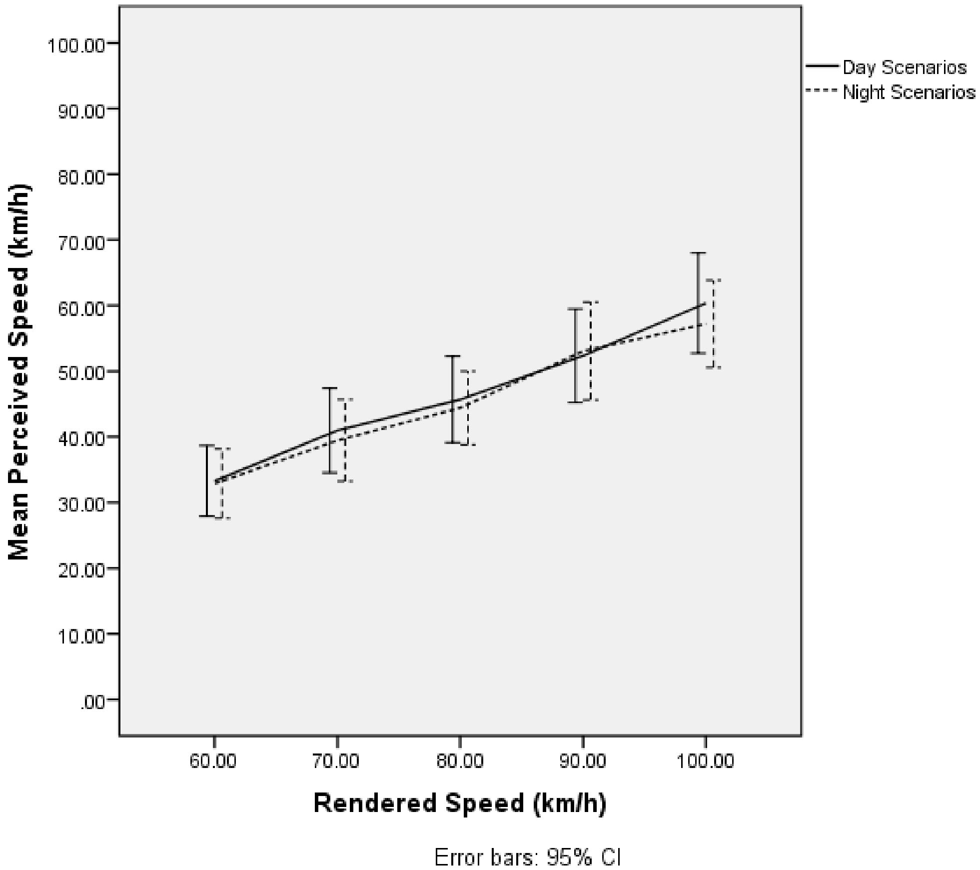

Figure 13. Line graph showing the mean perceived speed for day and night light levels level at each rendered speed averaged across all participants. The error bars represent a 95% confidence interval.

The results show that while there was a significant effect of rendered speed on judgements of speed (F (4, 72) = 111.453, $p < 0.001$), there was no significant interaction between rendered speed and contrast level (F (4, 72) = 1.113, $p = 0.357$). This suggests that while participants could reliably determine visual differences between the rendered speeds, the visual changes caused by changes in the level of lighting alone were not enough to significantly impact upon egospeed perception.

Pairwise comparisons found that all five rendered speeds were judged to be statistically significantly different from each other (Bonferotti = $p < 0.001$ for all comparisons except for between 60km/h and 70km/h, where $p = 0.001$). These results indicate that all of the rendered speeds were different enough from each other for participants to reliably differentiate.

Regression analysis was carried out to find the slope and intercept of the fitted function. Figure 14 shows the regression line for judgements of speed.

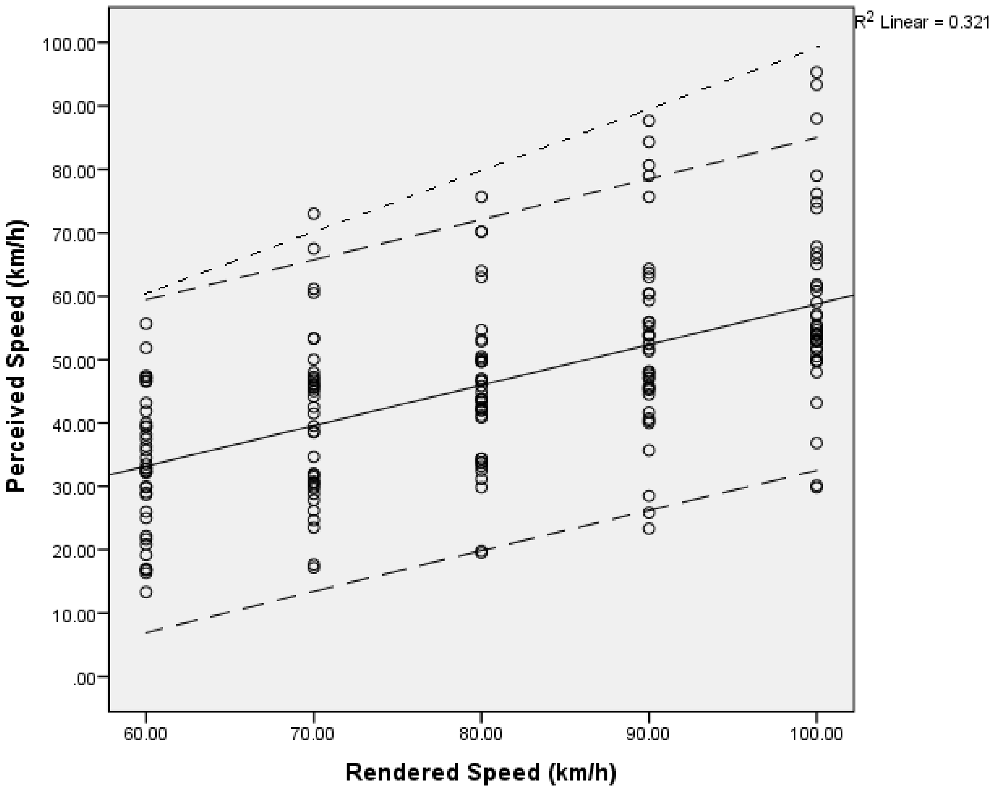

Figure 14. Scatter plot showing the regression line obtained for participants' judgements of egospeed. The dotted line represents the rendered speed comparison. The dashed lines show the 95% confidence interval.

The results of the linear regression analysis indicate that the slope of the regression line is 0.639, 95 % CI (F = 88.97, p < 0.001, R^2 = 0.321), with a y intercept value of -5.14, 95% CI. These results indicate that judgements of egospeed can be modelled by the equation 'judgement of egospeed = -5.14 + 0.64(rendered speed), R^2 = 0.321'. These results indicate a significant slope (p < 0.05), and as such support the idea that egospeed judgements increase linearly with an increase in actual speed.

Figure 14 indicates that there were large individual differences in judgements of egospeed. While this is the case, the difference lay in individual participant's judgements of egospeed across both lighting conditions, as lighting was not found to have a statistically significant effect on judgements of egospeed for any of the participants individually. Individual graphs for each participants' judgements of egospeed can be found in Appendix 12.

4.2.2 Effect of confidence on judgements of egospeed. In order to examine whether the level of confidence an individual felt was related to the effect of lighting on judgements of egospeed, a univariate ANCOVA was conducted comparing the judgements of speed obtained for each lighting/speed condition, with mean confidence tested as a covariate. Figure 15 shows the mean confidence felt by participants at each speed condition under both day and night lighting conditions.

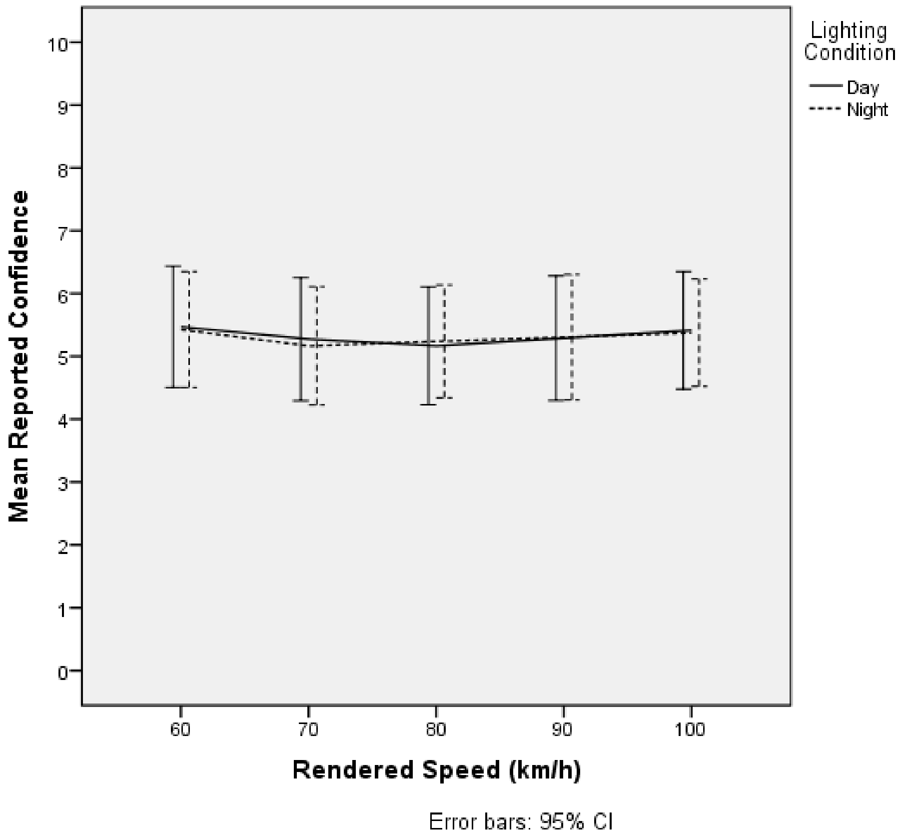

Figure 15. Line graph showing the mean reported confidence level for each speed condition for both lighting conditions

The mean level of confidence felt by participants during the experiment was found to not have a statistically significant impact on judgements of egospeed (F (1, 177) = 0.0436, p = 0.51).

4.3 Discussion

Experiment 3 was designed to test the hypothesis that egospeed would be overestimated during night conditions compared to day conditions. The results of Experiment 3 do not support hypothesis one.

Experiment 3 also examined the speed at which participants judged themselves to be moving under different speed/lighting conditions. The results of Experiment 3 indicate that this can be determined through the use of the equation 'judgement of egospeed = -5.14 + 0.64(rendered speed), $R^2 = 0.321$'. This slope represents a large underestimation of speed, as participants are only observing an increase of 0.64 km/h for each 1 km/h increase in speed.

Experiment 3 also explored the premise of whether the effects found in Experiment 1 and Experiment 2 for egospeed perception would hold true for judgements of egospeed. The results of Experiment 3 did not support this premise.

Experiment 3 also explored the premise that the level of confidence felt by participants would have an effect on judgements of egospeed. The results of Experiment 3 do not support this premise.

Analysis of the data found that participants judged each of the speed conditions to be statistically significantly different from all other speed conditions examined in this experiment, indicating that differences between speed conditions were large enough for participants to be able to reliably determine different speed conditions, which meant that judgements of egospeed could be examined for each speed condition separately. However, it was found that lighting levels did not significantly affect participants judgements of egospeed at any of the speed conditions examined in this experiment. Further, unlike the results of Experiment 1 and Experiment 2 on egospeed perception, no individuals were found for whom lighting had a significant effect on judgements of egospeed. A possible reason for this is that magnitude estimation is a far less precise tool than the method of constant stimuli, so any significant differences in judgements of egospeed caused by lighting levels are lost in the noise.

The findings of Experiment 3 are contrary to previous research (Fildes, Fletcher, and Corrigan, 1989; Triggs and Berenyi, 1982). Fildes, Fletcher, and Corrigan (1989) found that participants judged egospeed to be closer to actual speed during day periods than during night periods, while Triggs and Berenyi (1982) found that participants judged egospeed to be closer to actual speed during night periods than they did during day periods. A possible reason for the differences in the results between studies could be the exact layout of the visual scene and the inclusion and/or exclusion of certain elements within the environment. Both Fildes, Fletcher, and Corrigan (1989) and Triggs and Berenyi (1982) used film footage of actual roads in their studies, meaning that they could not control visual elements in the environments they presented their participants, while Experiment 3 utilised rendered scenarios of a naturalistic road, meaning that visual elements in the environment were controlled when the scenarios were created. The outcome of this is that the visual elements for Experiment 3 were identical between lighting conditions except for the effect of lighting on how they appeared to the participant, while the film footage used by Fildes, Fletcher, and Corrigan (1989) and Triggs and Berenyi (1982) was filmed at different times of day on the same public roads, meaning that factors such as other vehicles, pedestrians, etc. could not be controlled for.

An issue that arises with the results are that participants judged egospeed as being slightly more than half of the rendered speed they were presented with, which can be seen as judgements of egospeed can be modelled with the equation 'judgement of egospeed = -5.14 + 0.64(rendered speed), $R^2 = 0.321$'. However, both Fildes, Fletcher, and Corrigan (1989) and Triggs and Berenyi (1982) state that their participants underestimated their speed regardless of lighting level, which suggests that individuals generally perform poorly at judging their actual speed. At first it was suspected that the large amount of underestimation may have arisen from a programming error and that participants were being shown slower speed. However, some individual participants performed quite at the task, with some individuals' judgements of egospeed not being statistically significantly different from the rendered speed, indicating that the underestimations of egospeed are not likely to have been caused by an error with the display software.

In summary, it was found that lighting did not significantly impact upon participants judgements of egospeed at any of the speeds examined in this study. This suggests that a magnitude estimation task may not be precise enough to pick up any small effects caused by lighting on perceptions of speed, indicating that examining egospeed perception through the use of a forced choice design is more useful for examining the role of lighting on egospeed perception, as it is able to reliably determine far smaller effects.

5. Eye movement behaviour

The relationship between eye movement and egospeed perception is not currently well understood. It is possible that the large individual differences found during Experiments 1 and 2 were due to eye movement behaviour influencing egospeed discrimination ability. Further, it is possible that eye movement behaviour was influenced by differences in light levels between the day and night scenarios. As eye movement data was obtained during the experimentation process, it was decided that it would be useful to examine whether there were some clear trends in the eye movements typically made by participants under the different lighting conditions, and whether eye movement behaviour was correlated with egospeed perception.

There are many different measures that can be used when analysing eye movements, such as examining the length and frequency of saccades and blinks, examination of fixation points, and examining the level of visual spread. For this preliminary analysis, however, only four measures of eye movement behaviour were examined. These were the mean X and Y fixation locations (Xmean and Ymean) and the level of visual spread on the X axis (Xspread) and Y axis (Yspread). These measures were chosen as they allowed for the identification of the point in the scenario upon which participants focussed, as well as the level to which they looked around the scenario, under day and night lighting conditions. These measures were chosen as they allowed for the examination of whether individuals' fixated on different points and looked over a wider or narrower range under the day and light conditions. In order to determine the level of Xspread and Yspread, the standard deviation of the X and Y values (Xsd and Ysd) were calculated, but were not examined as a separate measure of eye movement behaviour. A comprehensive exploratory analysis of the eye movement data was carried out, including an attempt to answer questions raised about eye movement behaviour in Experiments 1 and 2, the details of which, including a discussion, can be found in Appendix M.

The results of the eye movement analysis were quite complex, with some relationships showing up between light level, presentation order, and standard speed (discussed in Appendix M), but did not seem to provide evidence that light level affected any of the measures examined at any of the standard speeds (60 km/h, 80 km/h, and 100 km/h). This finding is contrary to previous research

(Konstantopoulos, Chapman, and Crundall, 2010), which found that drivers adopted different eye movement strategies during day and night conditions. A possible reason that light levels were not found to have an effect on eye movement behaviour in this study could be that the effect of presentation order may have been too strong and washed out any effect that light level by itself may have had on eye movement behaviour.

The results also indicated that eye movement behaviour was significantly related to the PSEs obtained by participants at both 60 km/h and 100 km/h, but not at 80 km/h. A possible reason for this finding is that participants may have found it easier to differentiate between scenarios when they observed a significant difference in egospeed between the day and night conditions, and as such did not focus as hard on the task as they were less reliant on accurate perception of the visual information obtained through eye movements than when they did not observe a significant difference. However, different eye movement measures were found to be correlated with PSEs at 60 km/h (Xmean and Yspread) and 100 km/h (Ymean). This finding seems to support the idea postulated in the discussion section for Experiment 2 that a different visual perception mechanism was used at 100 km/h than was used at lower speeds.

While this analysis provided some useful findings on the relationship between eye movement and egospeed in relation to differences in light level, further research is still needed. For example, it is possible that some of the eye movement measures not examined in the course of this analysis were significantly affected by differences between the day and night lighting conditions, and that some of the eye movement measures not examined were also significantly related to egospeed perception. Further, these results indicate that future research with the aim of exploring of the relationship between eye movement behaviour and egospeed perception, such as examining differences in individuals' egospeed discrimination ability and eye movement behaviour between pairs of identical scenarios moving at different speeds, may provide useful insight into human egospeed perception.

6. General discussion

The purpose of this study was to determine whether different light levels had an effect on human perceptions of speed while driving on a rural road. Two potential areas for investigation were identified. The first was whether light levels had an effect on egospeed discrimination ability, while the second was whether light levels had an effect on absolute judgements of egospeed. This was examined through the use of three experiments. Experiments 1 and 2 examined the effect of lighting on egospeed discrimination performance at different base speeds, while Experiment 3 examined the effect of lighting on absolute judgements of egospeed across a number of speeds. Two hypotheses were created in order to guide the research. The first hypothesis was that egospeed would be judged to be faster during night conditions compared to day conditions, while the second hypothesis was that differences in egospeed discrimination between speed conditions would abide by Weber's Law.

The outcomes of Experiments 1 and 2 showed that lighting affected egospeed perception to a statistically significant level at 80 km/h, but did not do so at either 60 km/h or 100 km/h. They also showed that while the night variable condition was overestimated compared to the day standard condition at both 60 km/h (not to a significant degree) and 80 km/h (to a statistically significant degree), but that the night variable condition was underestimated compared to the day standard condition at 100 km/h (not to a significant degree). The outcome of Experiment 3 showed that lighting did not have a significant effect on judgements of egospeed at any of the speeds examined (60 km/h, 70 km/h, 80 km/h, 90 km/h, and 100 km/h).

Experiment 1 tested hypotheses one and two through testing the effect of lighting on egospeed discrimination performance at 60 km/h and 80 km/h. The results showed that lighting did not have a significant effect on egospeed discrimination performance at 60 km/h, but that egospeed during the night condition was overestimated to a statistically significant degree compared to the day condition at 80 km/h. This was found for both the night variable condition compared to the day standard condition and for the difference between PSE and standard speed found for the day standard condition compared to the difference between PSE and standard speed found for the night standard condition. The results also showed that egospeed perception between 60 km/h and 80 km/h abided by Weber’s Law. It was also found that strong individual differences meant that there were participants for whom lighting had a significant effect on egospeed perception at both 60 km/h and 80 km/h, with some participants observing egospeed during the day scenarios as being faster than during the night scenarios, some participants observing the opposite effect, and some participants for whom lighting did not have a significant effect on egospeed perception.

Experiment 2 tested hypotheses one and two through testing the effect of lighting on egospeed discrimination performance at 100 km/h, and comparing the results of the findings on WF against those obtained during Experiment 1. The results showed that lighting did not have a significant effect on egospeed discrimination performance at 100 km/h, and that while the 100 km/h night standard/day variable condition abided by Weber’s Law in relation to the speed/lighting pairings examined in Experiment 1, the 100 km/h day standard/night variable condition did not abide by Weber’s Law in relation to either the 100 km/h night standard/day variable condition nor any of the speed/lighting pairings examined in Experiment 1. This outcome suggested that a different visual perception mechanism was being used for the 100 km/h day standard/night variable condition than was used for any of the other lighting/speed conditions examined in Experiments 1 and 2. It was also found that, as with Experiment 1, strong individual differences meant that there were participants for whom lighting had a significant effect on egospeed perception at 100 km/h, with some participants observing egospeed during the day scenarios as being faster than during the night scenarios, some participants observing the opposite effect, and some participants for whom light did not have a significant effect on egospeed perception. Experiment 2 also explored the premises that the effect of lighting on egospeed perception found at 80 km/h would hold true at 100 km/h, and that the level of confidence felt by participants would have an effect on egospeed perception. Neither of these premises were supported.

Experiment 3 used magnitude estimation and tested hypothesis one through testing the effect of light on absolute judgements of egospeed at 60 km/h, 70 km/h, 80 km/h, 90 km/h, and 100 km/h. The results showed that lighting had no significant effect on judgements of egospeed regardless of speed. While strong individual differences were found, these were in the speed at which participants judged the scenes to be moving, as no participants were found for whom light levels had a statistically significant effect on judgements of egospeed. Experiment

3 also explored the premise that the level of confidence felt by participants would have an effect on judgements of egospeed. This was found to not be the case.

Exploratory analysis was carried out on the eye movement data obtained from Experiments 1 and 2 in order to examine whether the large individual differences found during Experiments 1 and 2 were due to eye movement behaviour influencing egospeed discrimination ability. This analysis focussed on whether light level affected eye movement behaviour, and whether eye movement behaviour was significantly related to the PSEs obtained by participants at 60 km/h, 80 km/h, and 100 km/h. The results of this analysis did not support the idea that light level affected eye movement behaviour, but did indicate that eye movement behaviour was significantly related to the PSEs obtained by participants at both 60 km/h and 100 km/h, but not at 80 km/h.

6.1 Theoretical implications

The findings from Experiments 1 and 2 are contrary to previous research into the effect of contrast on egospeed perception in a 3D environment (Dyre, Schauldt, & Lew, 2005; Horswill and Plooy, 2008; Owens, Wood, and Carberry, 2010; Pretto et al., 2012; Snowden et al., 1998), which found that participants either viewed self-motion during high contrast conditions to be significantly faster (Horswill and Plooy, 2008; Owens, Wood, and Carberry, 2010; Pretto et al., 2012; Snowdon et al., 1998) or slower (Dyre, Schauldt, and Lew, 2005; Pretto et al., 2012) than during low contrast conditions, without any reversal of effect at high speeds being observed. This may have been due to differences in the exact manner in which contrast is being reduced, as the previous research mentioned has focussed on fog as the medium through which to reduce contrast, which operates in a different manner to reductions in contrast due to reductions in light level. Further, although a crossover in effect has not been found in research into the effect of contrast on egospeed perception in a 3D environment, previous research into the effect of contrast on perceived rate of movement in a 2D environment (Thompson, 1982) did find that the effect of contrast, although steady at low speeds, reversed at higher speeds, indicating that the finding is not completely unprecedented.

The finding from Experiment 3 is contrary to previous research (Fildes, Fletcher, and Corrigan, 1989; Triggs and Berenyi, 1982), who found that light levels did have an effect on judgements of speed, although they disagreed as to the nature of the effect (Fildes, Fletcher, and Corrigan (1989) found that participants judged egospeed to be closer to actual speed during day periods as opposed to night periods, while Triggs and Berenyi (1982) found the opposite effect). This may have been due to differences in the layout and nature of the scenarios presented to participants, as well as the inclusion and/or exclusion of certain elements within the environment. Both Fildes, Fletcher, and Corrigan (1989) and Triggs and Berenyi (1982) used film footage of actual roads at different times of day in their studies, and as such could not control certain visual elements in the environments presented to their participants. The outcome of this is that the experiment carried out in the course of this thesis is likely to have more visual elements repeated perfectly between the two lighting conditions, but the videos used by Fildes, Fletcher, and Corrigan (1989) and Triggs and Berenyi (1982) are likely to have been accepted as 'reality' easier than those used in this experiment.

Another finding of Experiment 3 was that participants consistently underestimated egospeed regardless of lighting levels. This finding is in keeping with previous research (Fildes, Fletcher, and Corrigan, 1989; Triggs and Berenyi, 1982), and as such adds to the results demonstrating a large underestimation of speed in this type of study. It is unclear whether this is the result of showing 3D virtual environments using 2D displays, or whether some other general factor is causing speed to be misperceived.

Examination of the eye movement data indicated that light levels were not significantly related to eye movement behaviour. This finding is contrary to previous research (Konstantopoulos, Chapman, and Crundall, 2010), who found that drivers adopted different eye movement strategies during day and night conditions. A possible reason that light levels were not found to have a significant effect on eye movement behaviour is that the effect of presentation order may have been too strong, washing out any effect that light by itself may have had.

The results of Experiments 1 and 2 indicated that the 100 km/h day standard condition did not abide by Weber's Law in relation to all other speed/lighting standard conditions, but that all other speed/lighting standard conditions did abide by Weber's law in relation to each other. Ungan and Yagcioglu (2014) state that if a condition is not found to abide by Weber's Law in relation to other conditions, then it is very likely that a different perception mechanism is being used for that condition compared to the others. The eye movement data supported Ungan and Yagcioglu's statement, as it was found that the PSE obtained by participants at 60 km/h and 100 km/h, while statistically significantly related to eye movement behaviour, was related to different eye movement variables (mean fixation position on the X axis and level of visual spread on the Y axis at 60 km/h, mean fixation position on the Y axis at 100 km/h), that the mean fixation position on the X axis and the level of visual spread on the Y axis followed the effect of lighting on egospeed perception (significant or non-significant) at 60 km/h, 80 km/h, and 100 km/h, and that the mean fixation position on the X axis and the level of visual spread on the Y axis changed by a relatively equal amount for the night standard condition that it did for the day standard condition between 80 km/h and 100 km/h. These results suggest that perception of both the day and night standard conditions at 100 km/h utilised different visual perception mechanisms from at 60 km/h and 80 km/h, but that the 100 km/h night standard condition utilised enough of the same visual perception mechanisms used at 60 km/h and 80 km/h that it was not found to break Weber's Law.

Interestingly, the findings of Experiments 1 and 2 were mostly in keeping with the findings of McKee, Silverman, and Nakayama (1986) into velocity discrimination and Weber's Law. McKee, Silverman, and Nakayama found that velocity discrimination tasks using 2D stimuli should produce a Weber fraction of approximately 6%, which was found to be the case in this thesis, with the exception of the 100 km/h day standard condition. McKee et al. also found that the Weber fractions increased for higher test speeds (in a U shaped function). This is interesting, as the 2D stimuli tested by McKee, Silverman, and Nakayama did not contain the complexity and non-linear image motion present in the conditions used in this thesis.

6.2 Methodological issues

An issue with this study is with the population pool that was able to be drawn upon for each experiment. Although there was a relatively wide spread in the age range of those who took part (17 – 44), and the same number of males and females were recruited to take part in each experiment, the majority of the participants were students at Waikato University (predominantly first year students, although there were second and third year students and some post-graduate students who also took part). Further, the majority of the students who took part were those in the School of Psychology. Although all of the participants fulfilled the requirements to take part, there is still an issue in that they may not be completely representative of the New Zealand driving population as a whole, especially as no older drivers (65+) were examined during this study.

Another issue with this study was that Experiment 1 used different step sizes between variable speed conditions than Experiment 2. Although the change was made in order to stop individuals' psychometric curves from straightening out to the point where they were unusable when examining the effect of lighting on egospeed perception at 100 km/h, it is possible that the change in step size had an effect on the point of subjective equality between the day and night lighting conditions.

6.3 Future directions for research

A possible future direction would be to employ a driving simulator task to examine whether there was any difference in the speed at which individuals drove under different lighting conditions. Unfortunately, it was impossible during the course of this thesis to use a driving simulator task due to a lack of resources. The inclusion of a driving simulator study would have provided the perfect balance, as it would have allowed for examination of the speed at which participants actually drive under different lighting conditions, the speed at which they judge themselves to be moving under different lighting conditions, and the difference in speed that they perceive between lighting conditions. Further, driving simulator studies are commonly used when examining the role of contrast or luminance on egospeed (Easa et al., 2010; Pretto et al., 2012; Pritchard and Hammett, 2011; Reed and Easa, 2011; Snowden et al., 1998), so it would be keeping with research techniques used when examining the general topic area.

In a similar vein, the driving task could also be carried out in a naturalistic driving situation. This would require the use of a private road space, and participants who would be willing to undergo the experiment at least twice, in order to have a measure of any within-subjects effect that light level had, but would have the benefit of providing exact measures of different speeds at which individuals naturalistically drive under different lighting conditions.

Another possible future direction would be to examine the effect of light on egospeed perception at higher speeds. An issue arises in that no one in New Zealand should legally have first-hand experience with driving at faster than 100 km/h, and so may not be able to complete the tasks required of them with a high level of accuracy. Two possible avenues for exploration present themselves on this point; firstly, it may be fruitful to carry out this research in a country with a higher speed limit on some roads, for example testing drivers who commonly drive at high speeds on the Autobahn in Germany; and secondly, it could be fruitful to test individuals who are willing to admit, off the record, that they regularly drive substantially above the speed limit, and as such are able to undertake the experiment without impacting on the results.

Although this research did not indicate that lighting had a significant effect at all of the speeds tested, the large individual differences indicated that light level had a significant effect on some participants' egospeed perceptions. Therefore, a possible future avenue for study would be to research whether light levels had an effect on the egospeed perception of individuals who had been at fault in crashes that occurred at night, and further, whether these individuals had a lower contrast sensitivity than the average.

Future research into this area might also benefit from a restructuring of experimental order, in that it may be useful to use an experiment into the effect of lighting on judgements of speed to also identify whether speeds are being accurately represented by the rendered scenarios. While some individuals were able to correctly identify presented speeds to a statistically significant level during this experiment, indicating that the scenarios rendered for this experiment were rendered appropriately, doing so would allow for increased confidence in the exact level to which any effect, significant or otherwise, is found.

6.4 Conclusion

The overall findings indicate that individuals were found to be sensitive to small differences in speed when presented with the virtual worlds used in the experiments, but that lighting (day versus night) generally had no strong effect on the detection of these small speed differences. This suggests that egospeed perception is not a significant factor in the heightened rate of night-time crashes across the general population, as whatever techniques observers used to assess egospeed while observing these scenarios must be fairly robust to lighting levels and to large differences in the scene content. This indicates that many of the accidents that occur at night cannot be simply ascribed to a misperception of speed caused by lack of light. Other more complex factors must be involved, such as the loss of other critical visual information. Individual differences were found for the egospeed discrimination tasks in Experiments 1 and 2, but these differences may be indicative of other factors impacting on specific individuals' egospeed discrimination ability, such as low contrast sensitivity.

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Appendix A: Research participant sign-up sheet

Ψ **School of Psychology**

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

Participants Wanted

I am looking for participants to take part in my Masters level research into drivers' perceptions of speed. The title of my project is Light Levels and Driver Perceptions of Speed.

Participation involves watching short rendered videos that represent driving down a local road. Participants must have a learner driver's licence at the very least, but there are no other eligibility requirements. Participants who are enrolled in (x) will receive 1% course credit. Participation time varies, but will not exceed 45 minutes.

This study has received approval from the School of Psychology Research and Ethics committee at the University of Waikato, and is supervised by Associate Professor John Perrone and Associate Professor Robert Isler.

Please contact the researcher for any further information:

Jonathan Kim – Email: Jdk3@students.waikato.ac.nz

– Cellphone: 021 251 5764

Appendix B: Instruction sheet for Experiment 1

Ψ **School of Psychology**

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

Participant Information Sheet

Project Title: Perception of Vehicular Speed under Varied Light Levels

Approval Statement: *This research project has been approved by the School of Psychology Research and Ethics Committee of the Faculty of Arts and Social Sciences, University of Waikato. Any questions about the ethical conduct of this research may be sent to Associate Professor Linda Nikora, member of the Research and Ethics Committee (phone: 838 4466 ext. 8200, e-mail psyc2046@waikato.ac.nz).*

Purpose: This research project is being conducted as a partial requirement for a Masters in Social Science. This project requires the researcher to perform experiments into how individuals perceive vehicular speed under varied light conditions.

What is this research project about? This research project is about watching rendered videos and determining which video moved at a faster pace. There will also be a short questionnaire about your background and driving habits. This project should take no longer than 45 minutes. You will be asked to give consent prior to the start of the research project.

Outcome of this research: The main outcome of this research will be determining whether and to what extent light levels have an effect on visual perceptions of speed, and, in doing so, either support or challenge the current understanding of the effect of light level on visual perceptions of speed. The results will be published in the form of a Master's Thesis, and there is a possibility that they may be published in a psychological journal.

Instructions: If you are required to wear glasses or contacts while driving, you will need to do so while undertaking this experiment. Firstly, you will answer a simple questionnaire about your driving history. After that, you will be asked to watch videos of day and night scenes. There are two videos in each set. One video will be of a day-time driving scene, and the other video will be of a night-time driving scene. After both videos have been shown, a screen will appear with the words 'video one' and 'video two' on it, and you will be required to indicate which video you believe was faster by clicking on the appropriate word. After you have clicked on the appropriate word, the screen will go black for a short period and then the next set of videos will be shown. After the final set of scenes, you will see a screen that says you have completed the experiment. At this point, alert the researcher that you have finished. Eye movement will be measured during this experiment. For this purpose, you are required to place your head in the bracket in front of the screen at the start of the video section of the experiment, and keep it there until the experiment is concluded.

What will happen to the information collected? The information collected will be used by the researcher to write a thesis. It is possible that articles and presentations may be the outcomes of the research. Only the researcher will be privy to any notes and/or documents. Afterwards, notes and documents will be kept in a safe location for five years and then will be safely destroyed. No participants will be named in the thesis or any publications arising from the thesis, and every effort will be made to disguise participants' identities.

Declaration to participants: If you take part in the study, you have the right to:

- Refuse to answer any particular question;
- Withdraw from the study at any stage without bias or penalty;
- Ask any further questions about the study that occur to you during your participation; and
- Be given access to a summary of the findings from the study when it is concluded.

Who's responsible? If you have any questions or concerns about the project, either now or in the future, please feel free to contact either:

Researcher: Jonathan Kim, email jdk3@students.waikato.ac.nz

Supervisors: Associate Professor John Perrone, email jpnz@waikato.ac.nz

Associate Professor Robert Isler, email psyc2255@waikato.ac.nz

Appendix C: Demographic and driving questionnaire

Ψ **School of Psychology**

THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

Light Levels and Driver Perception of Speed Questionnaire

Participant No: _______

Age *(years):* _____________

Gender *(please circle):* Male Female Other: ________

Level of Drivers Licence Held *(please circle):* Learners Restricted Full

Have you heard anything about this research before?

____
____
____
____

Have you been involved in any previous driving studies with the University of Waikato?

____
____
____
____

How long has it been since you first got your learners licence?

____
____
____
____

On average, how long would you spend driving in a week?

____
____
____
____

Do you wish to be informed of the results of this research? *(Please circle):*

Yes No

If yes, how do you wish to be informed? *(Please circle):*

Email Phone Mail

If yes, what is your Email, Phone number, or Mail address: ___________________

____

____

Appendix D: Response screens from Experiment 1

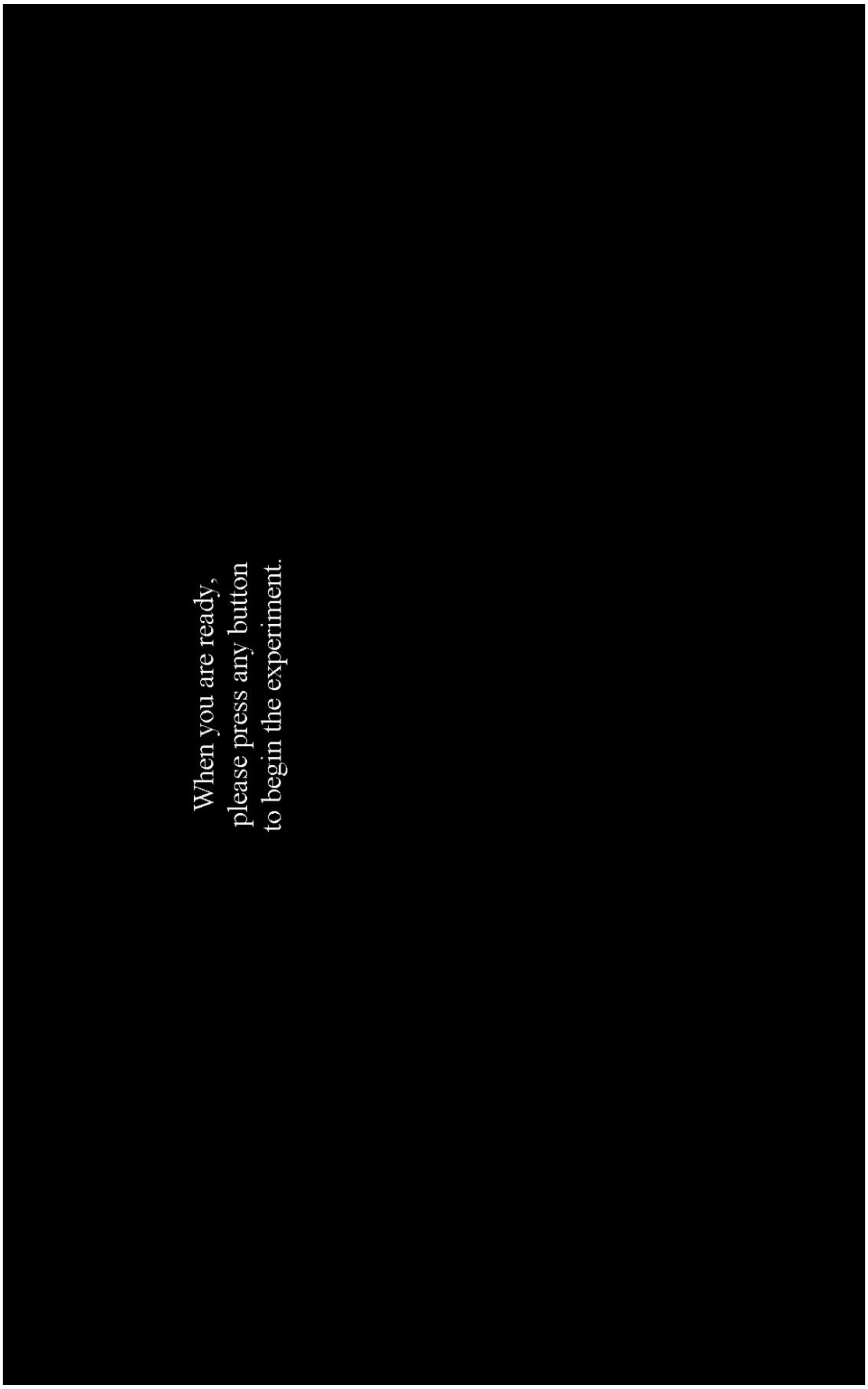


Figure D1: Experimental start screen

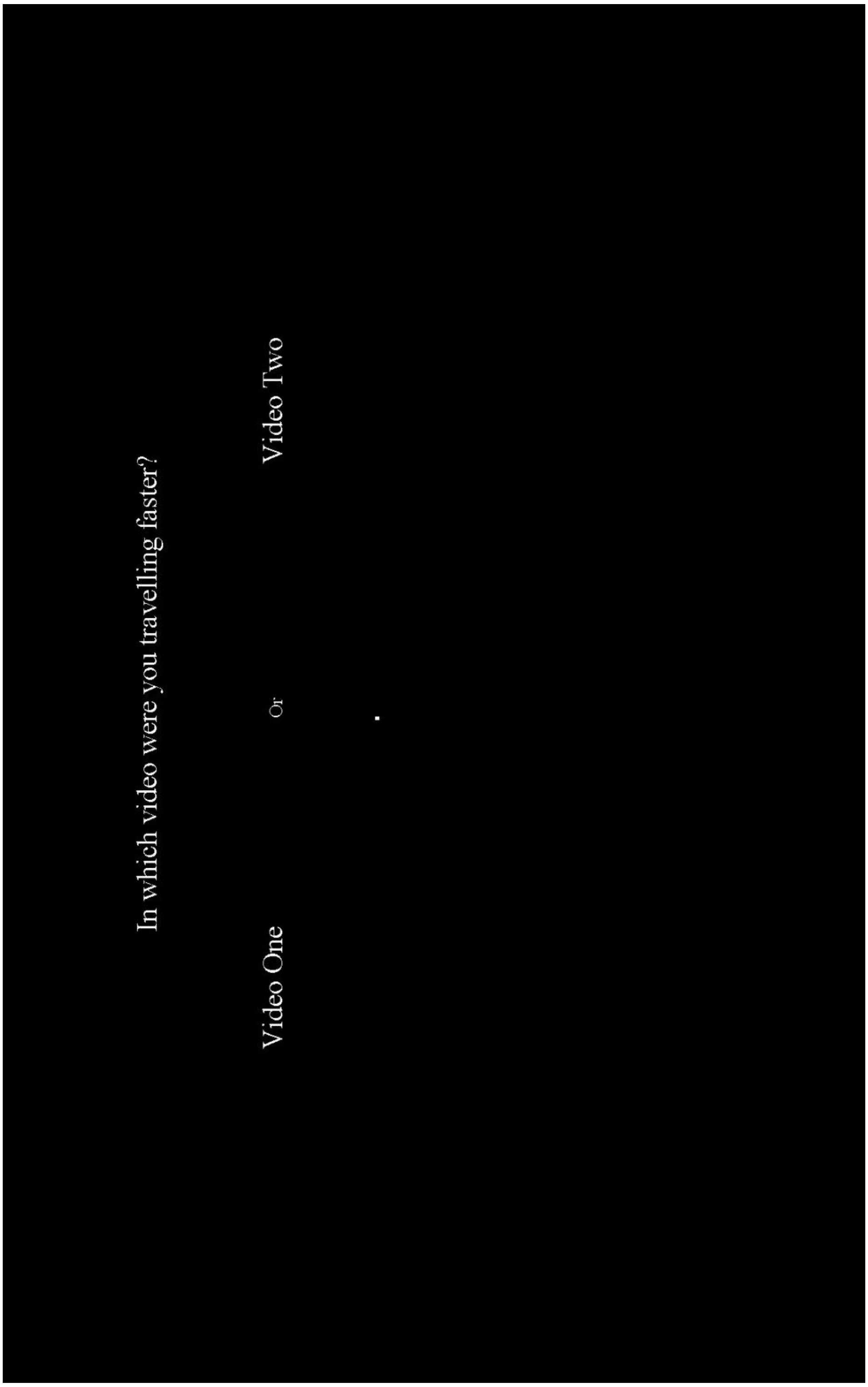
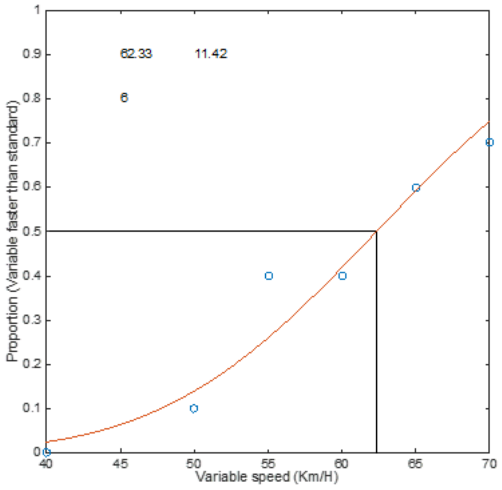


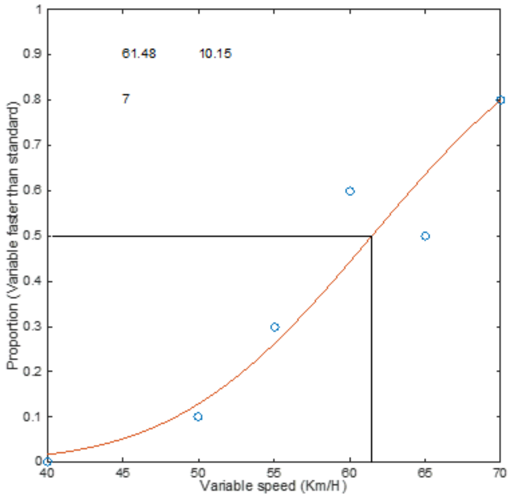
Figure D2: Forced choice response screen. The white dot is the mouse cursor.

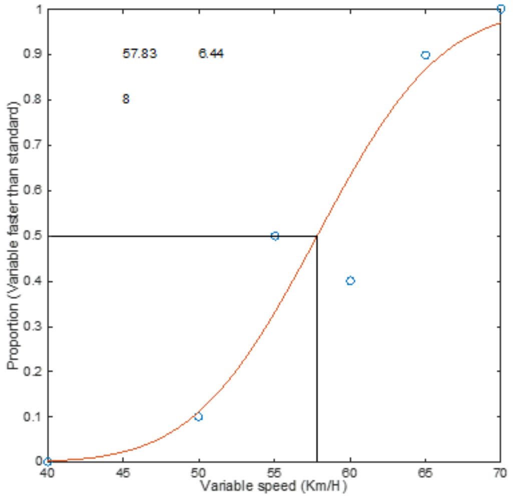
Figure D3: Final experimental screen

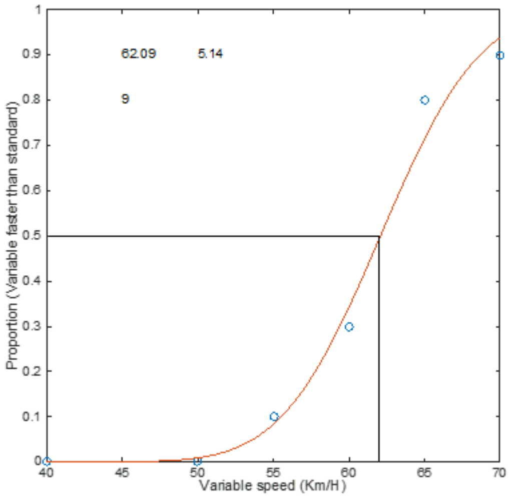
Appendix E: Psychometric curves obtained during Experiment 1

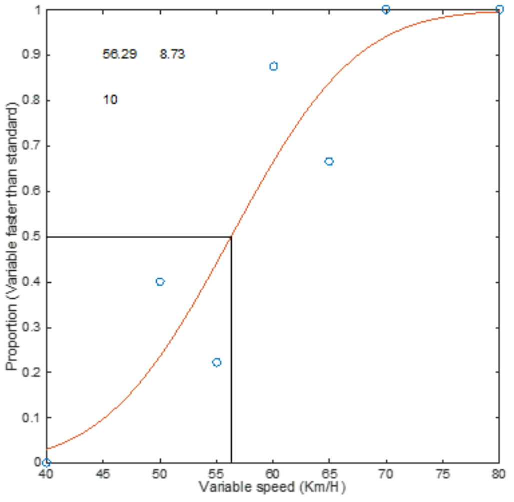
Individual participants' psychometric functions for the 60 km/h day standard condition

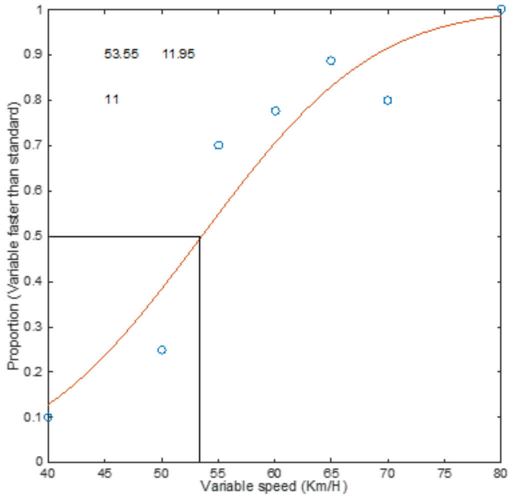


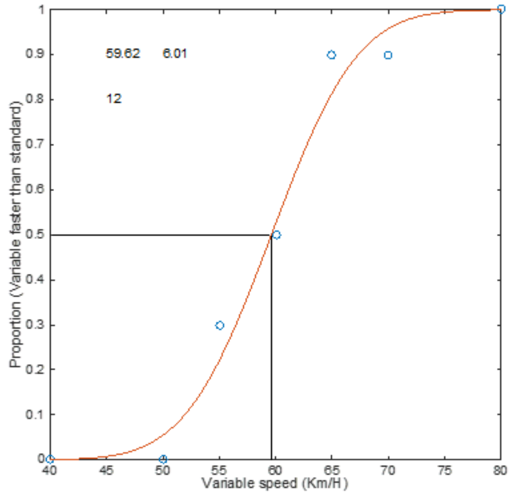


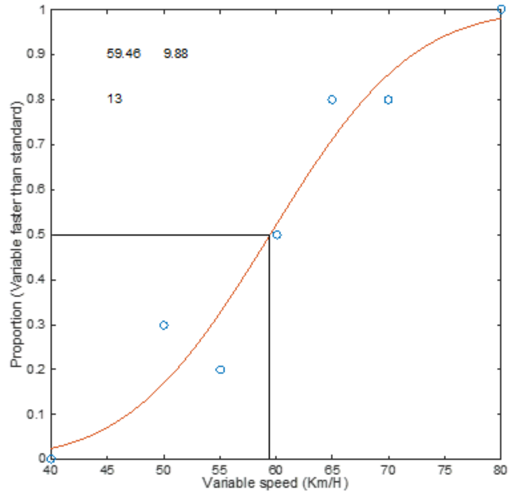


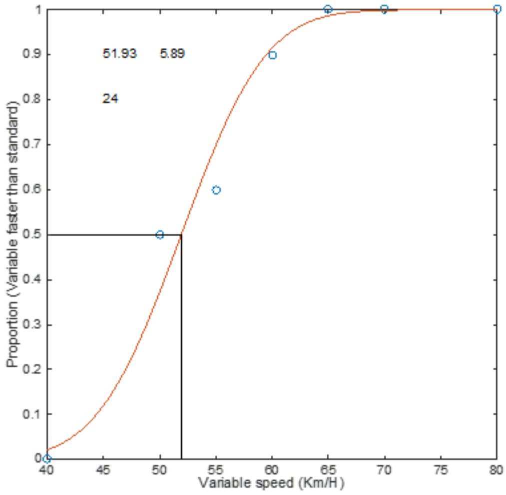


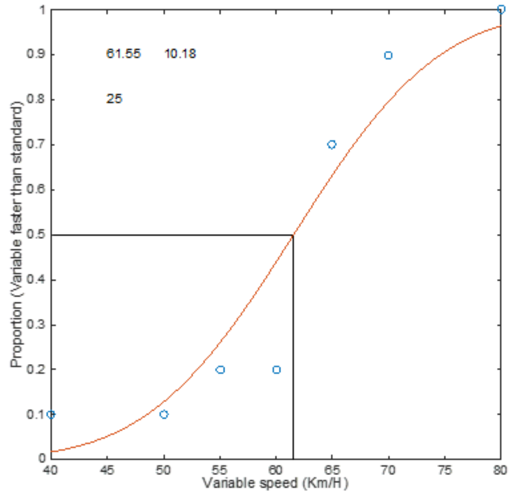


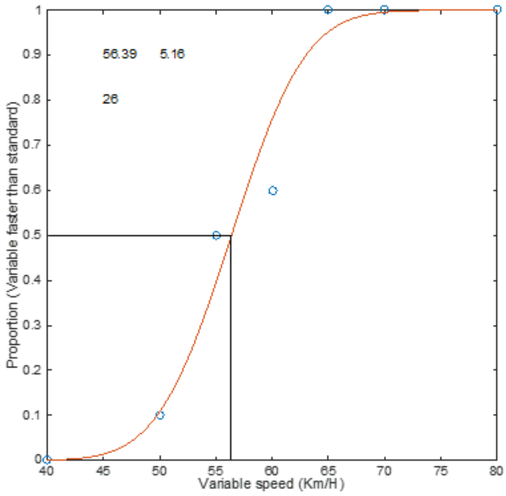


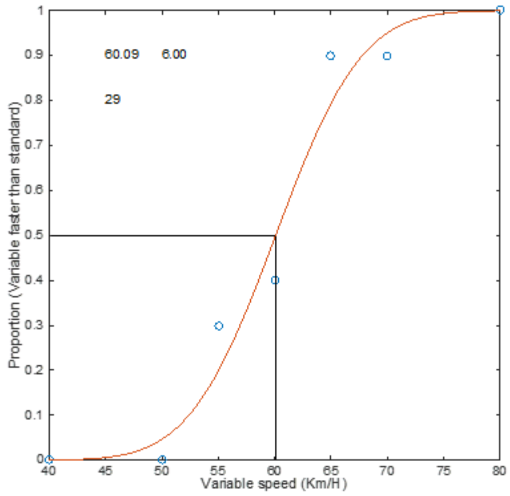

59.62 6.01
12
Proportion (Variable faster than standard)
Variable speed (Km/H)

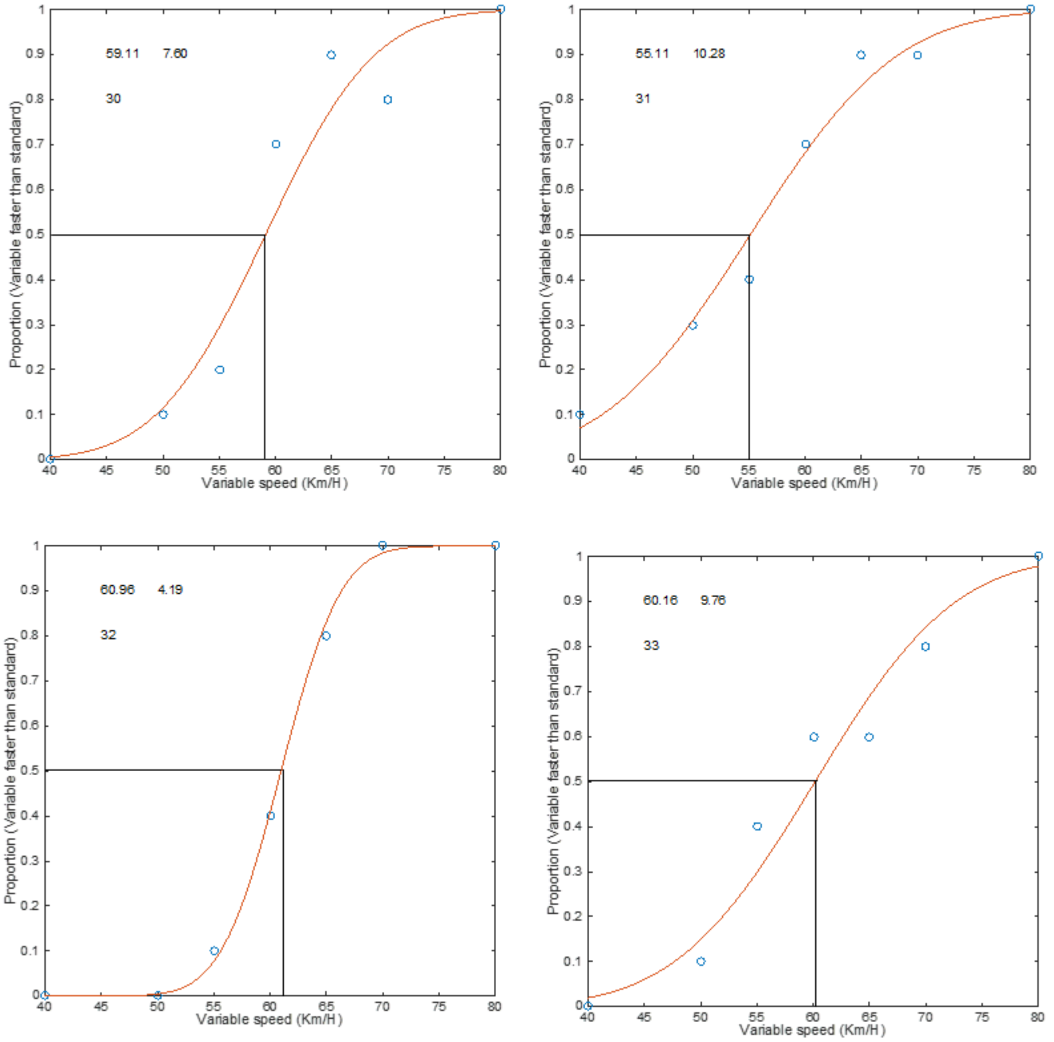

59.46 9.88
13
Proportion (Variable faster than standard)
Variable speed (Km/H)


51.93 5.89
24
Proportion (Variable faster than standard)
Variable speed (Km/H)

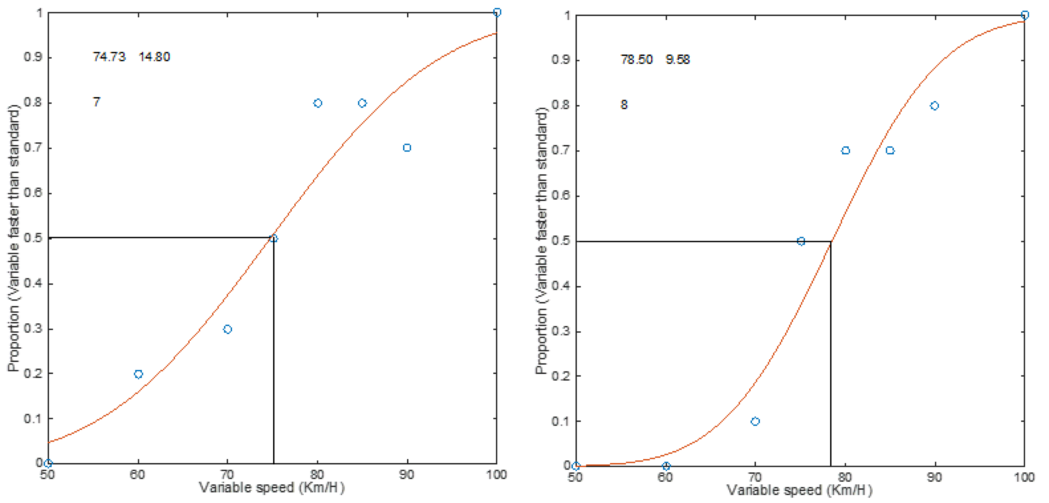

61.55 10.18
25
Proportion (Variable faster than standard)
Variable speed (Km/H)

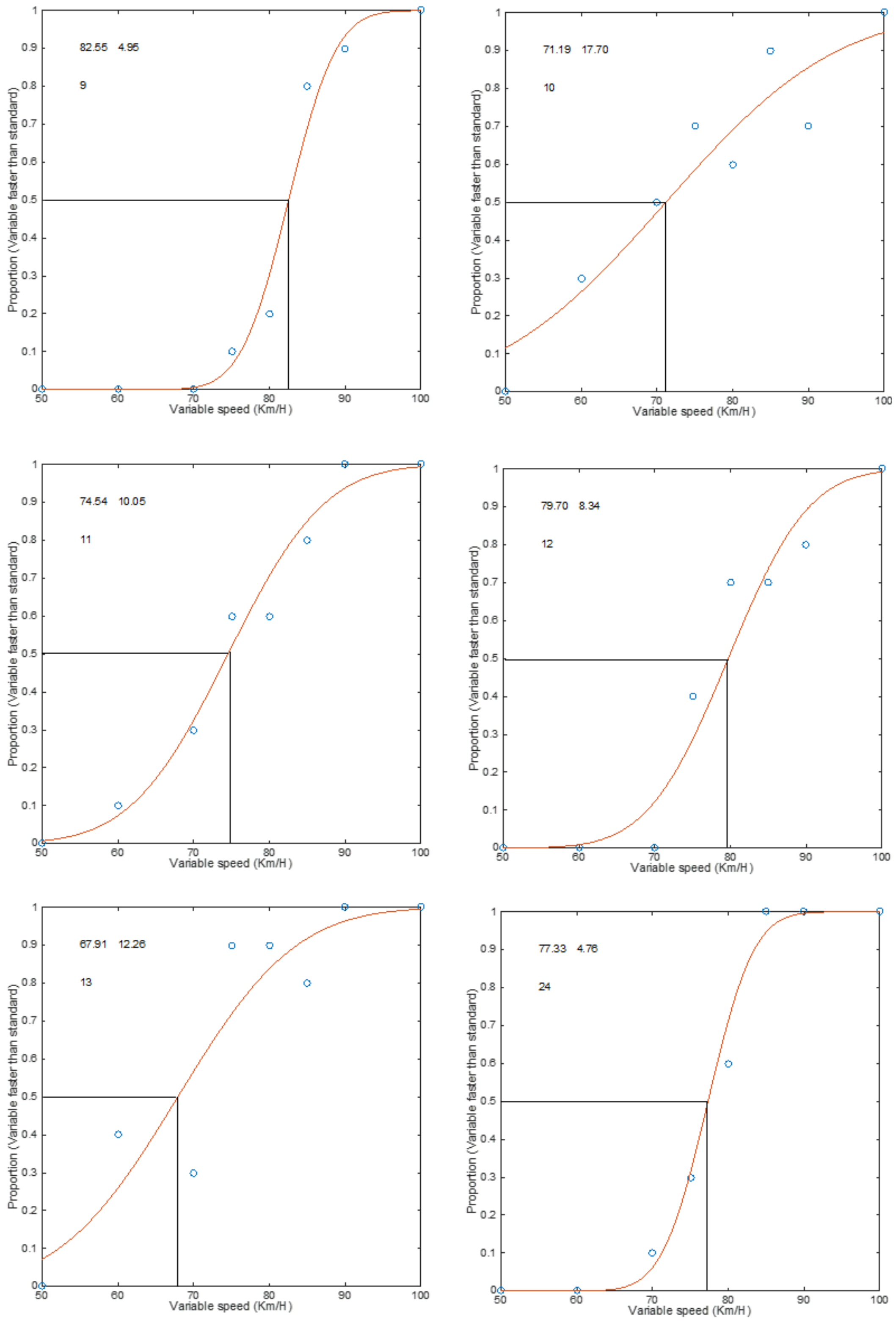

56.39 5.16
26
Proportion (Variable faster than standard)
Variable speed (Km/H)

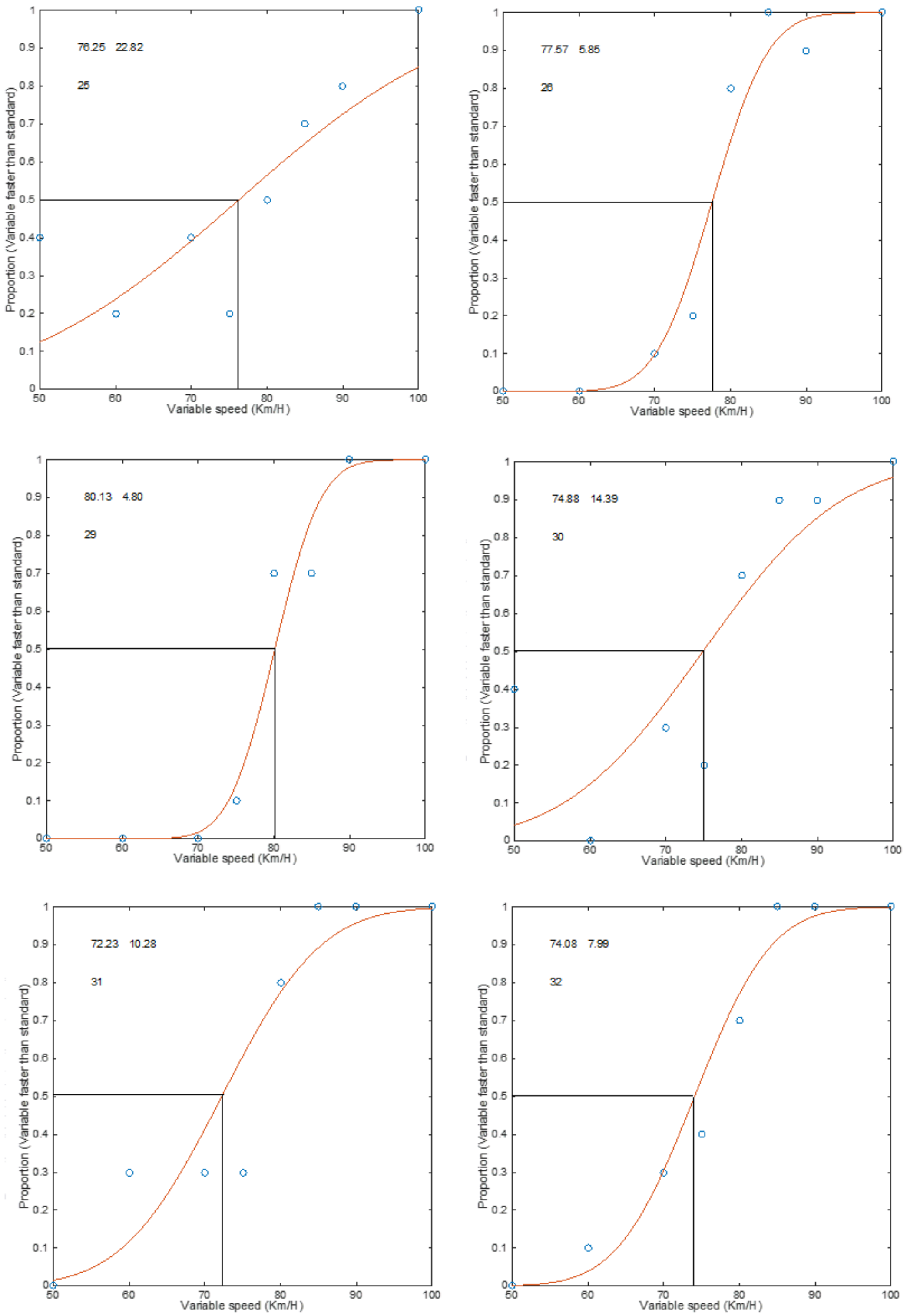

60.09 6.00
29
Proportion (Variable faster than standard)
Variable speed (Km/H)

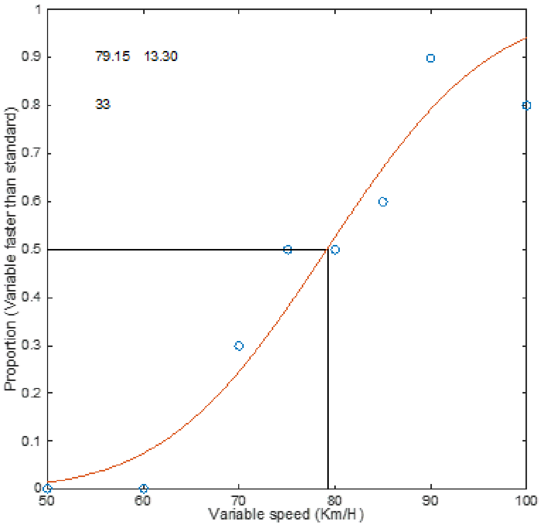


Individual participants' psychometric functions for the 80 km/h day standard condition

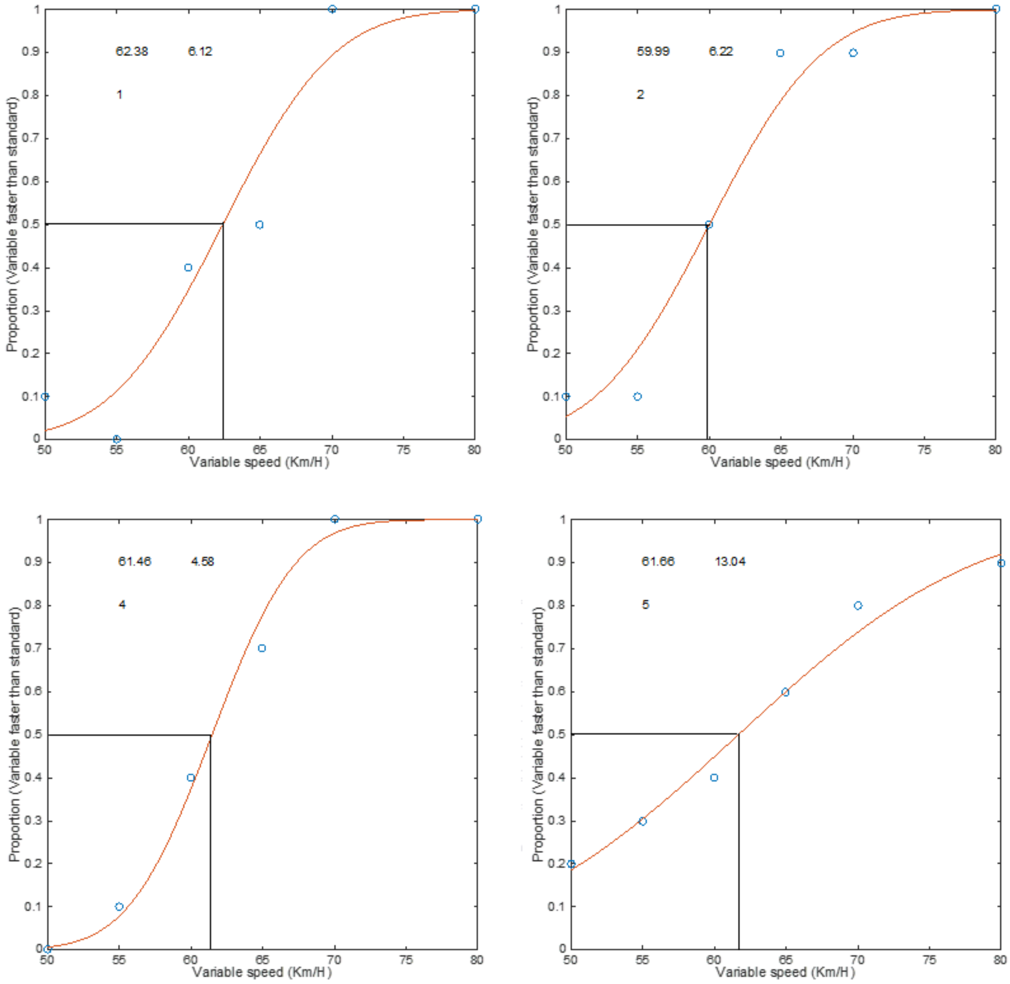


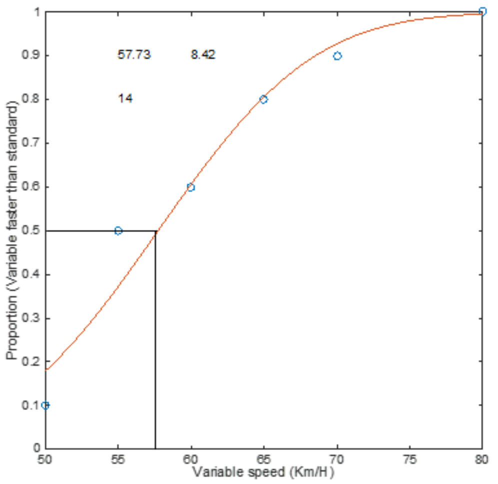

82.55 4.95
9
71.19 17.70
10
74.54 10.05
11
79.70 8.34
12
67.91 12.26
13
77.33 4.76
24
Proportion (Variable faster than standard)
Variable speed (Km/H)

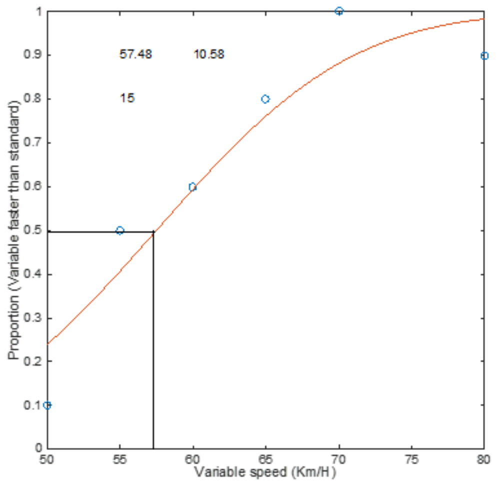

76.25 22.82
25
Proportion (Variable faster than standard)
Variable speed (Km/H)
77.57 5.85
28
Proportion (Variable faster than standard)
Variable speed (Km/H)
80.13 4.80
29
Proportion (Variable faster than standard)
Variable speed (Km/H)
74.88 14.39
30
Proportion (Variable faster than standard)
Variable speed (Km/H)
72.23 10.28
31
Proportion (Variable faster than standard)
Variable speed (Km/H)
74.08 7.99
32
Proportion (Variable faster than standard)
Variable speed (Km/H)

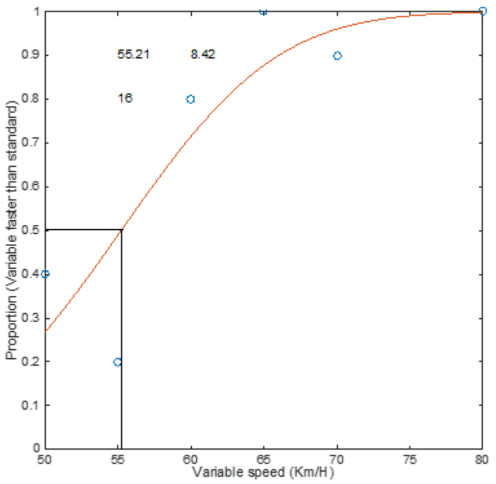


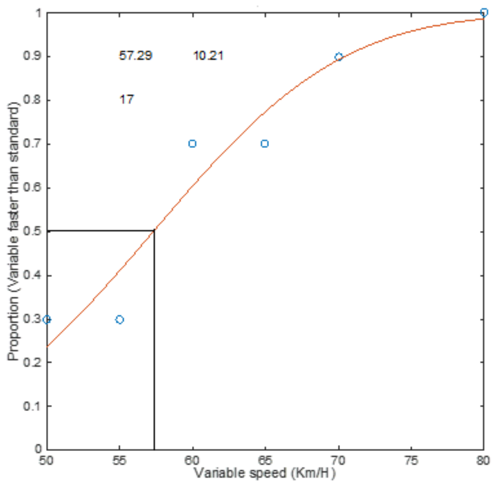
Individual participants' psychometric functions for the 60 km/h day standard condition

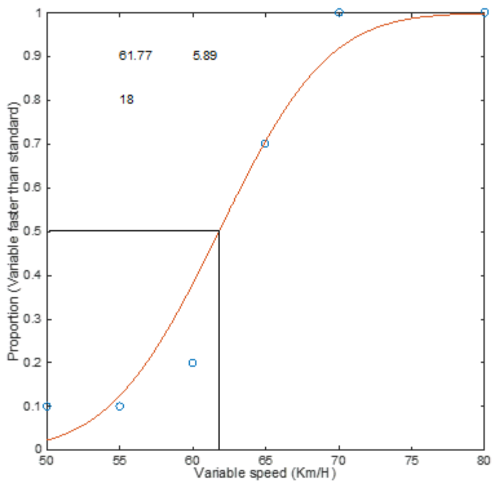


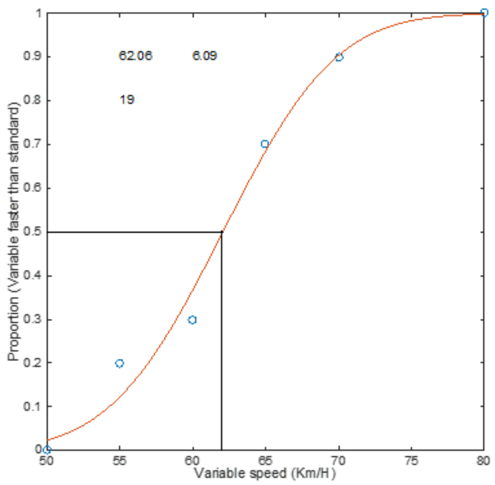

57.73
8.42
14
Proportion (Variable faster than standard)
Variable speed (Km/H)

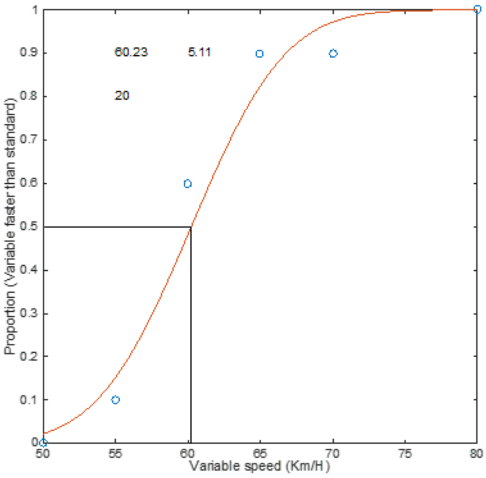

57.48
10.58
15
Proportion (Variable faster than standard)
Variable speed (Km/H)

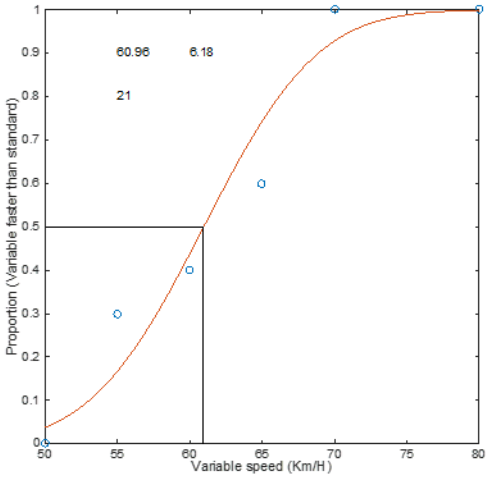

55.21
8.42
16
Proportion (Variable faster than standard)
Variable speed (Km/H)

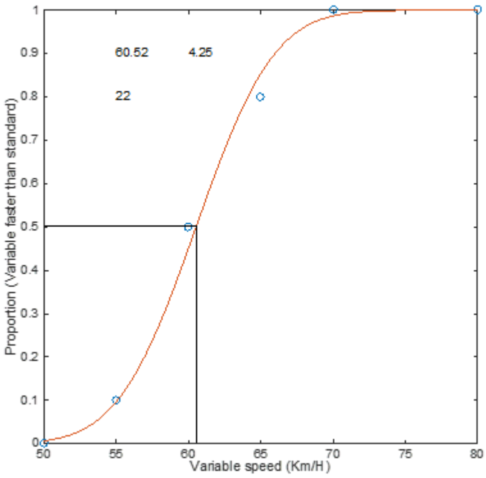

57.29
10.21
17
Proportion (Variable faster than standard)
Variable speed (Km/H)

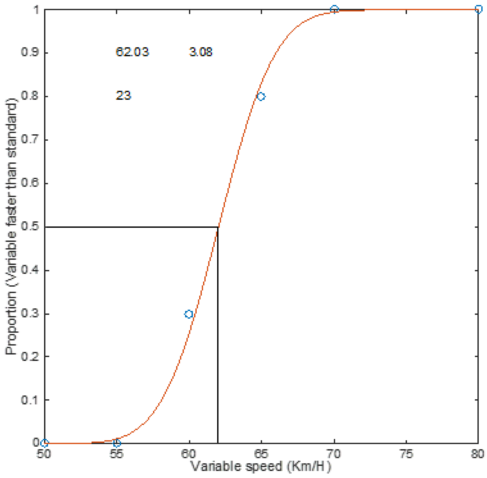

61.77
5.89
18
Proportion (Variable faster than standard)
Variable speed (Km/H)

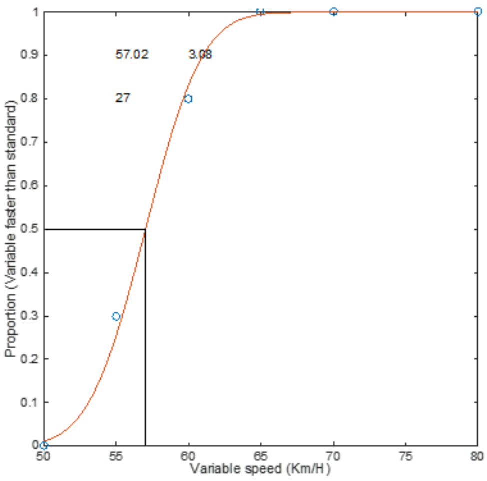

62.06
6.09
19
Proportion (Variable faster than standard)
Variable speed (Km/H)

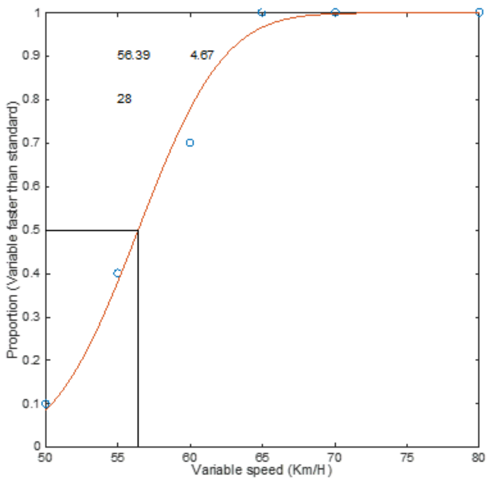

60.23
5.11
20
Proportion (Variable faster than standard)
Variable speed (Km/H)


60.96
6.18
21
Proportion (Variable faster than standard)
Variable speed (Km/H)

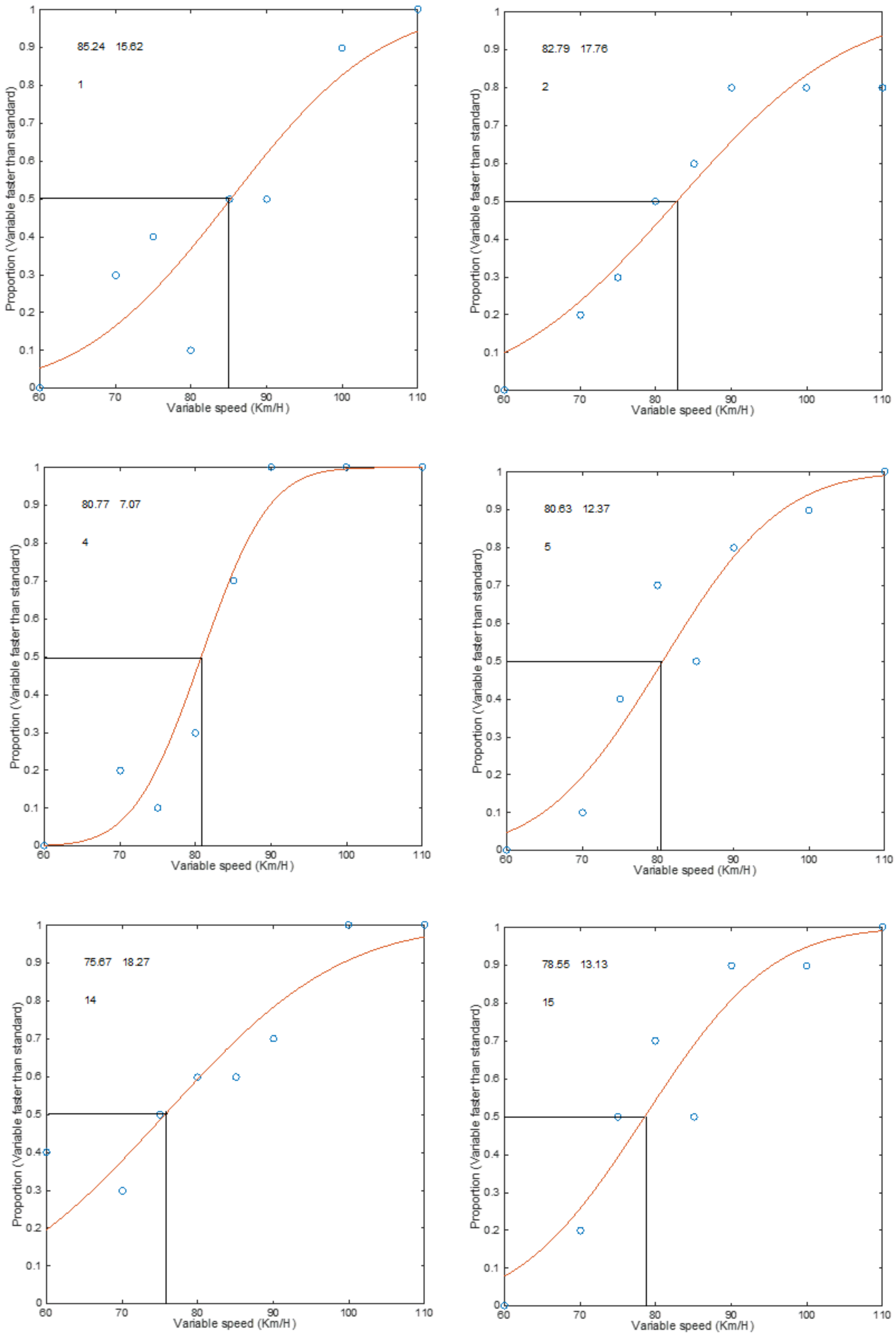

60.52
4.25
22
Proportion (Variable faster than standard)
Variable speed (Km/H)

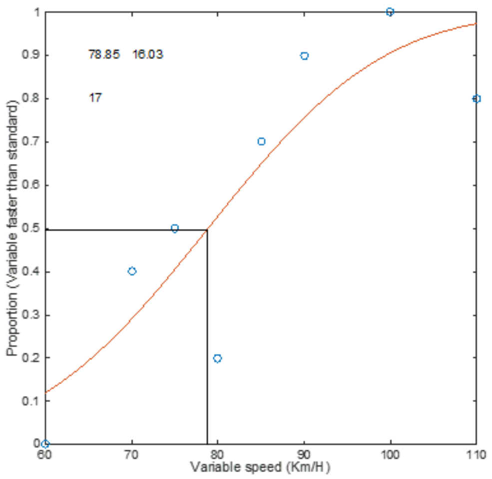

62.03
3.08
23
Proportion (Variable faster than standard)
Variable speed (Km/H)

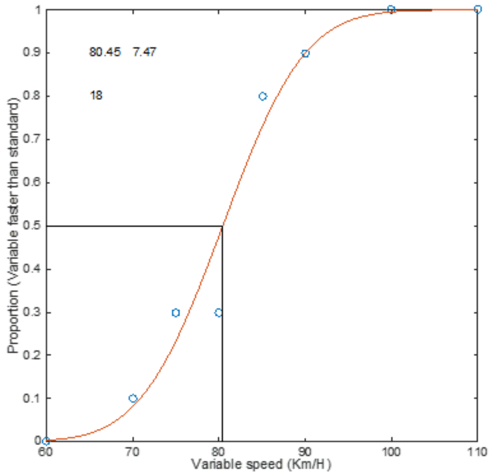

57.02
3.08
27
Proportion (Variable faster than standard)
Variable speed (Km/H)

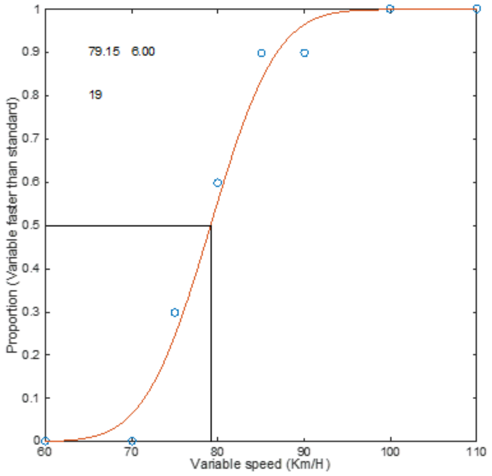

56.39
4.67
28
Proportion (Variable faster than standard)
Variable speed (Km/H)

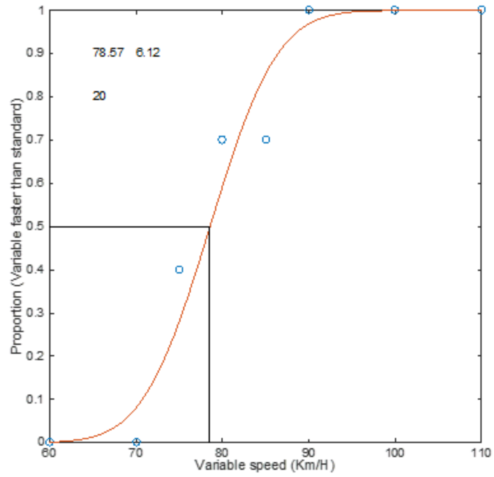
Individual participants' psychometric functions for the 80 km/h night standard condition

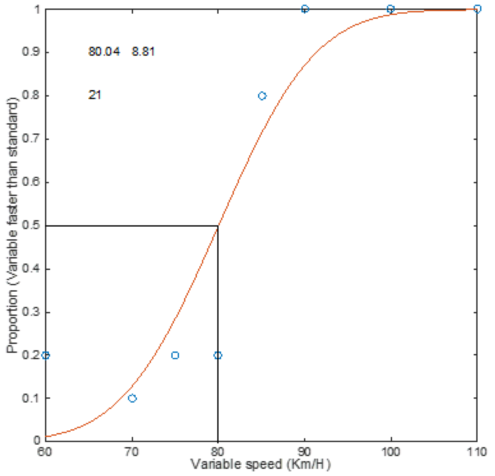


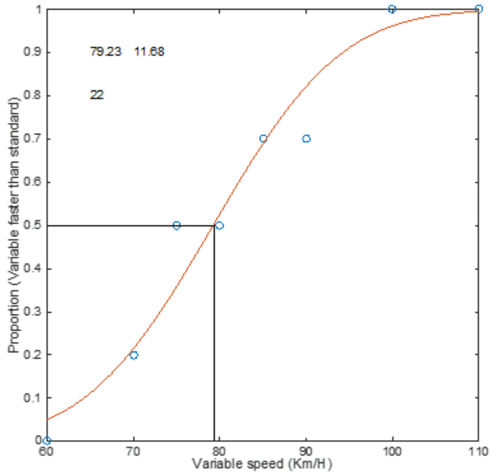

78.85 16.03
17
Proportion (Variable faster than standard)
Variable speed (Km/H)

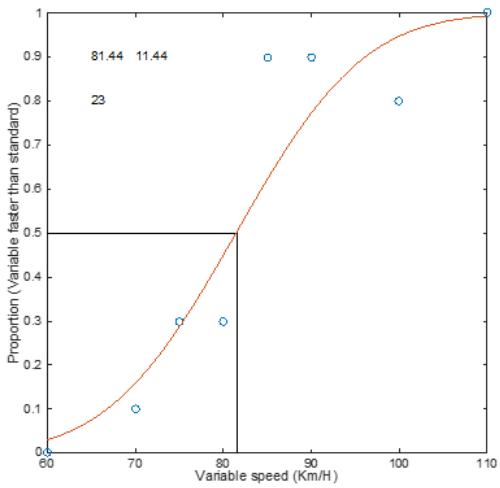

80.45 7.47
18
Proportion (Variable faster than standard)
Variable speed (Km/H)

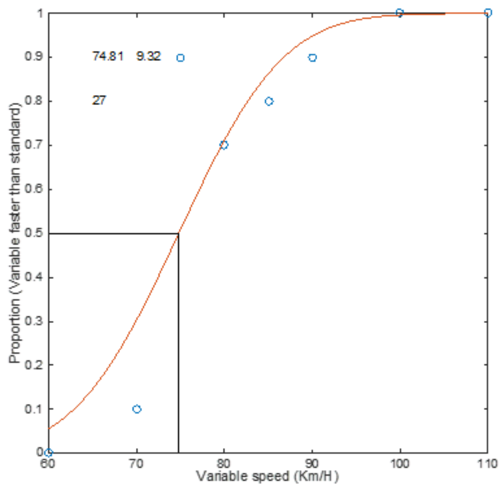

79.15 6.00
19
Proportion (Variable faster than standard)
Variable speed (Km/H)

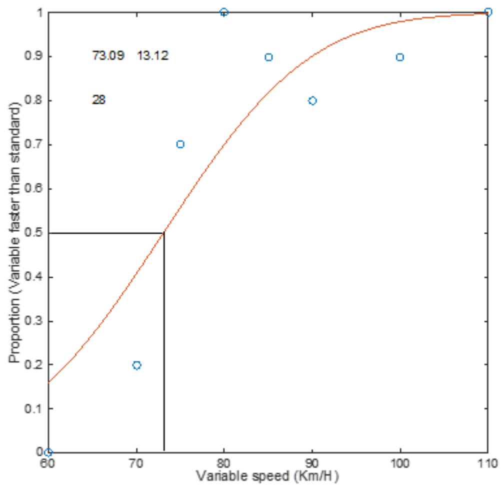

78.57 6.12
20
Proportion (Variable faster than standard)
Variable speed (Km/H)


80.04 8.81
21
Proportion (Variable faster than standard)
Variable speed (Km/H)


79.23 11.68
22
Proportion (Variable faster than standard)
Variable speed (Km/H)


81.44 11.44
23
Proportion (Variable faster than standard)
Variable speed (Km/H)


74.81 9.32
27
Proportion (Variable faster than standard)
Variable speed (Km/H)


73.09 13.12
28
Proportion (Variable faster than standard)
Variable speed (Km/H)

Appendix F: Instruction sheet for Experiment 2

School of Psychology

Participant Information Sheet

Project Title: Perception of Vehicular Speed under Varied Light Levels

Approval Statement: *This research project has been approved by the School of Psychology Research and Ethics Committee of the Faculty of Arts and Social Sciences, University of Waikato. Any questions about the ethical conduct of this research may be sent to Associate Professor Linda Nikora, member of the Research and Ethics Committee (phone: 838 4466 ext. 8200, e-mail psyc2046@waikato.ac.nz).*

Purpose: This research project is being conducted as a partial requirement for a Masters in Social Science. This project requires the researcher to perform experiments into how individuals perceive vehicular speed under varied light conditions.

What is this research project about? This research project is about watching rendered videos and determining which video moved at a faster pace. There will also be a short questionnaire about your background and driving habits. This project should take no longer than 45 minutes. You will be asked to give consent prior to the start of the research project.

Outcome of this research: The main outcome of this research will be determining whether and to what extent light levels have an effect on visual perceptions of speed, and, in doing so, either support or challenge the current understanding of the effect of light level on visual perceptions of speed. The results will be published in the form of a Master's Thesis, and there is a possibility that they may be published in a psychological journal.

Instructions: If you are required to wear glasses or contacts while driving, you will need to do so while undertaking this experiment. Firstly, you will answer a simple questionnaire about your driving history. After that, you will be asked to watch videos of day and night scenes. There are two videos in each set. One video will be of a day-time driving scene, and the other video will be of a night-time driving scene. After both videos have been shown, a screen will appear with the words 'video one' and 'video two' on it, and you will be required to indicate which video you believe was faster by clicking on the appropriate word. After you have clicked on the appropriate word, a second screen will appear with a line showing the numbers 1 to 10, and you will be required to click on the line at the point representing the level of confidence you felt in your answer, with 1 meaning absolutely no confidence and 10 meaning absolute confidence. After you have clicked on the line, the screen will go black for a short period and then the next set of videos will be shown. After the final set of scenes, you will see a screen that says you have completed the experiment. At this point, alert the researcher that you have finished. Eye movement will be measured during this experiment. For this purpose, you are required to place your head in the bracket in front of the screen at the start of the video section of the experiment, and keep it there until the experiment is concluded.

What will happen to the information collected? The information collected will be used by the researcher to write a thesis. It is possible that articles and presentations may be the outcomes of the research. Only the researcher will be privy to any notes and/or documents. Afterwards, notes and documents will be kept in a safe location for five years and then will be safely destroyed. No participants will be named in the thesis or any publications arising from the thesis, and every effort will be made to disguise participants' identities.

Declaration to participants: If you take part in the study, you have the right to:

- Refuse to answer any particular question;
- Withdraw from the study at any stage without bias or penalty;
- Ask any further questions about the study that occur to you during your participation; and
- Be given access to a summary of the findings from the study when it is concluded.

Who's responsible? If you have any questions or concerns about the project, either now or in the future, please feel free to contact either:

Researcher: Jonathan Kim, email jdk3@students.waikato.ac.nz

Supervisors: Associate Professor John Perrone, email jpnz@waikato.ac.nz

Associate Professor Robert Isler, email psyc2255@waikato.ac.nz

Appendix G: Response screens for Experiment 2

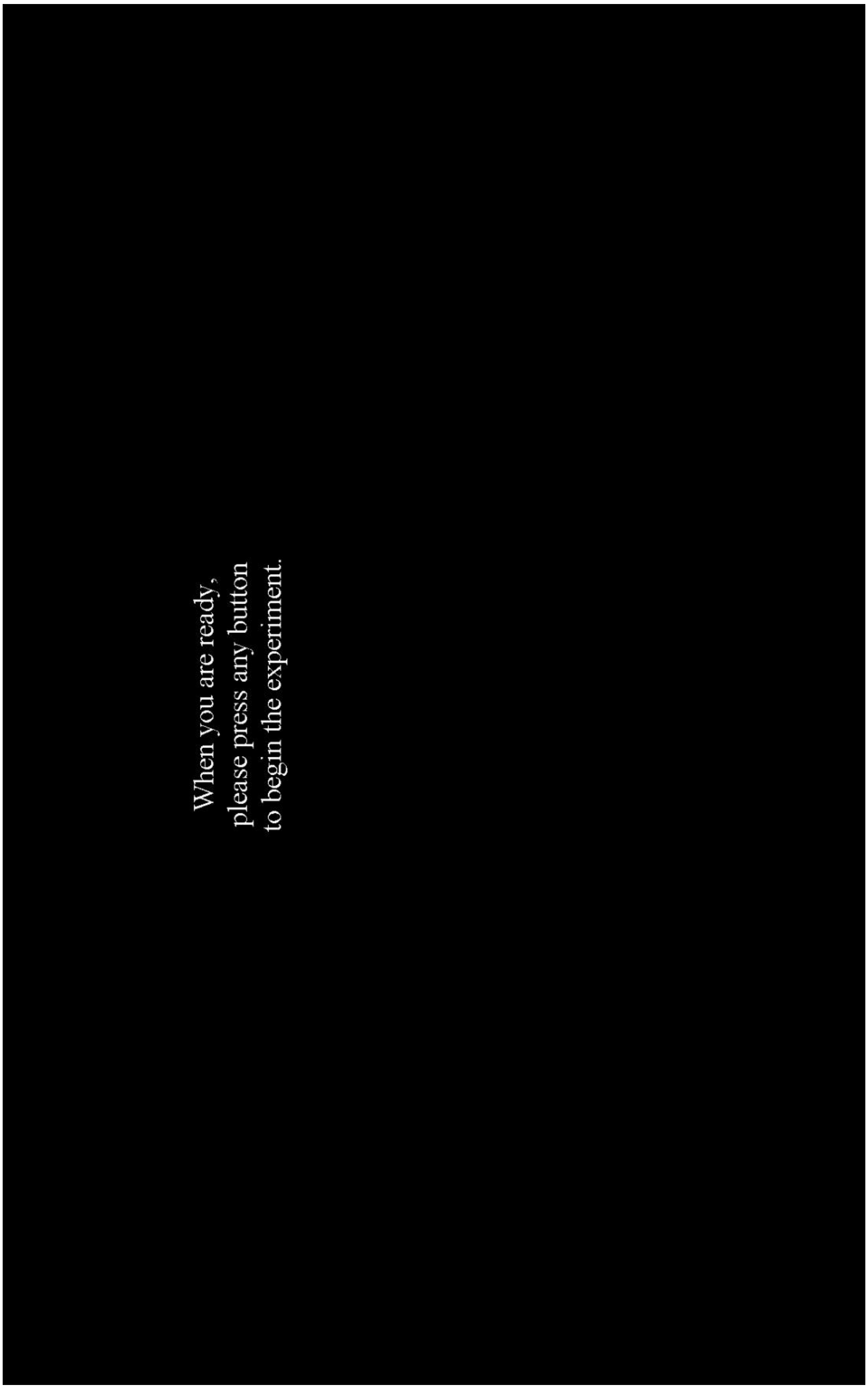


Figure G1: Experimental start screen

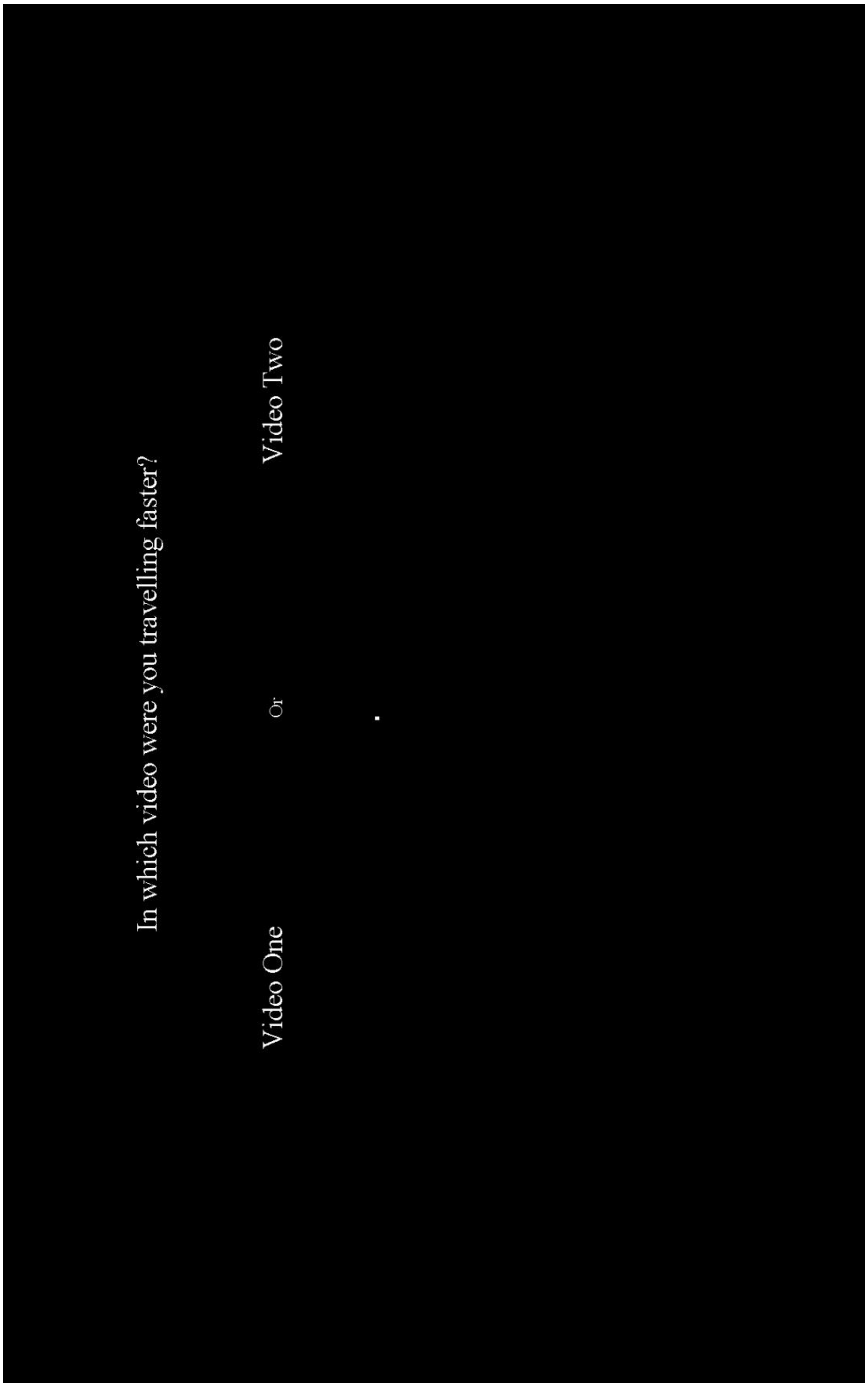


Figure G2: Forced choice response screen. The white dot is the mouse cursor

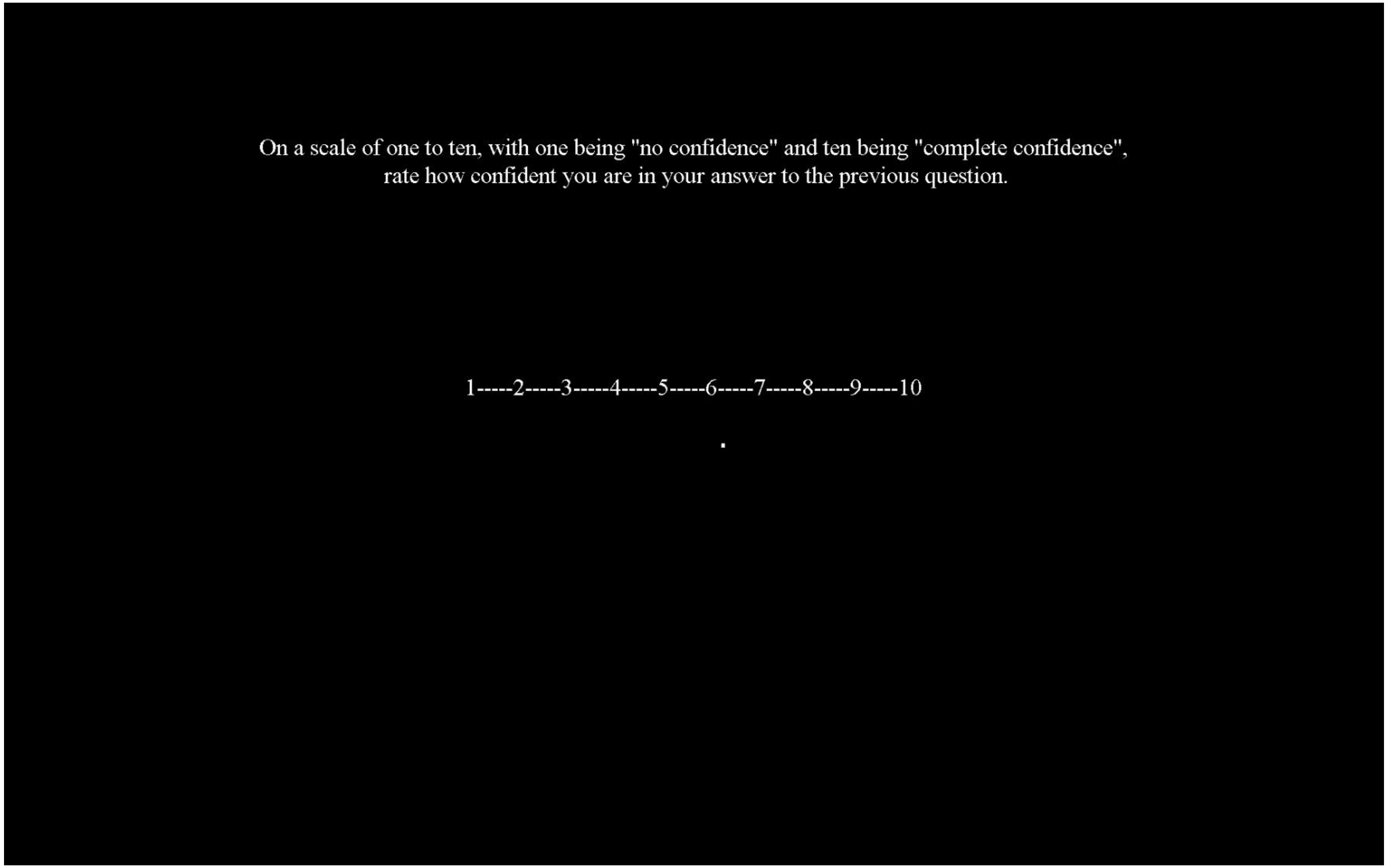
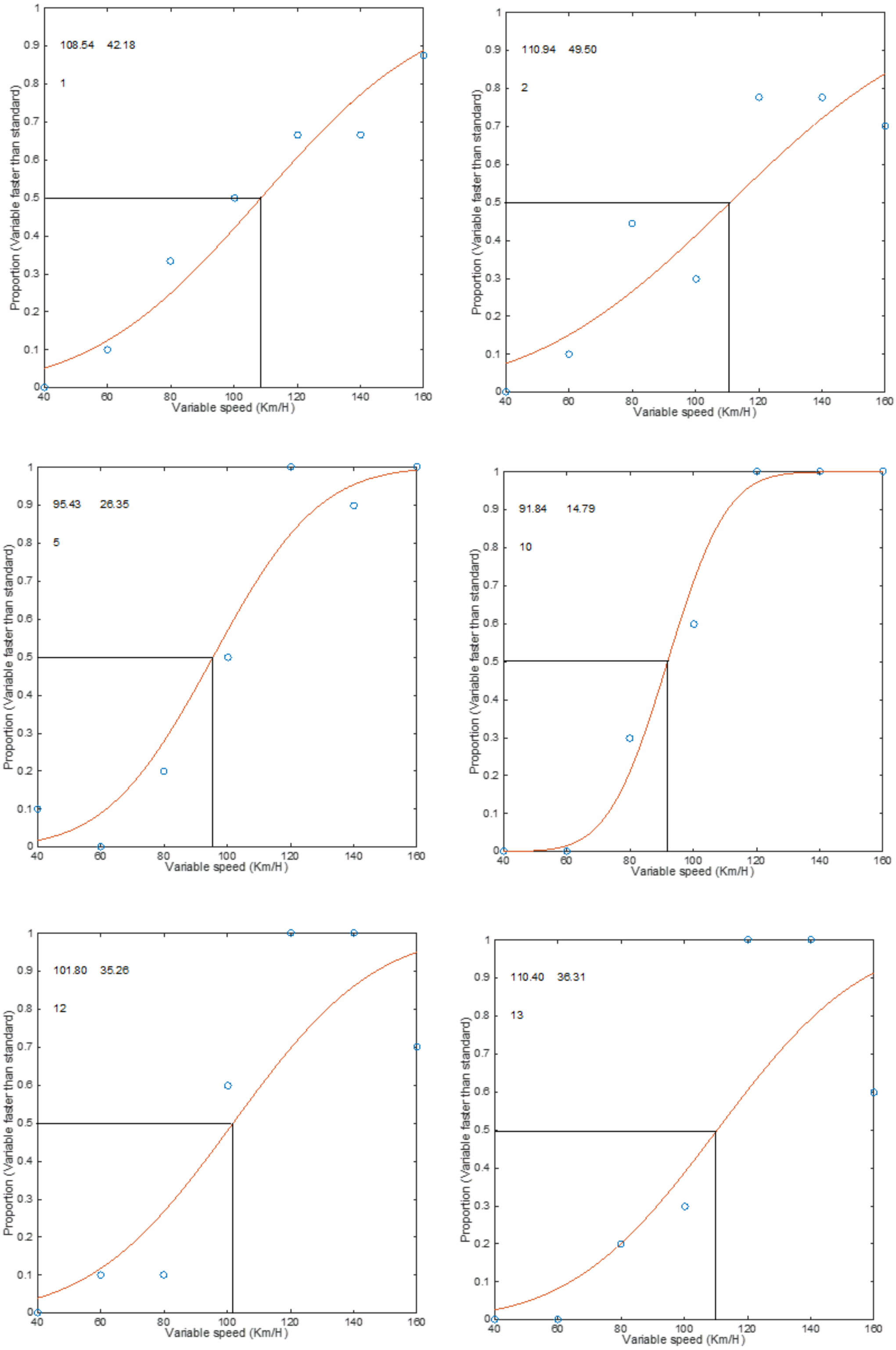


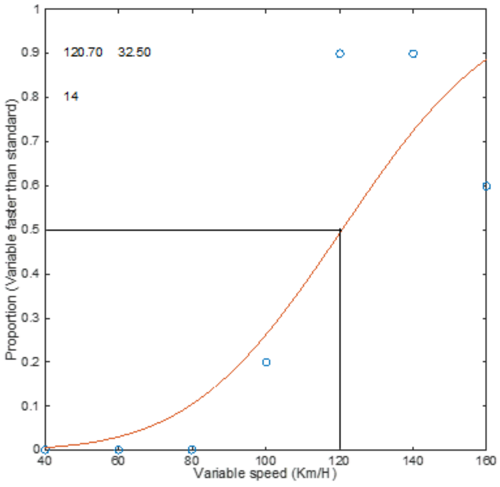
Figure G3: Confidence magnitude estimation response screen. The white dot is the mouse cursor

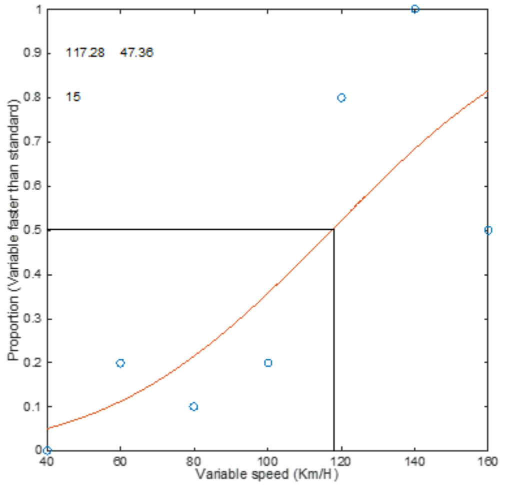
Figure G4: Final experimental screen

Appendix H: Psychometric curves obtained during Experiment 2

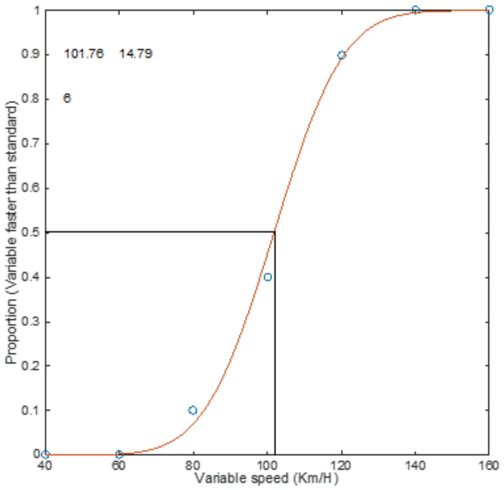
Individual participants' psychometric functions for the 100 km/h day standard condition

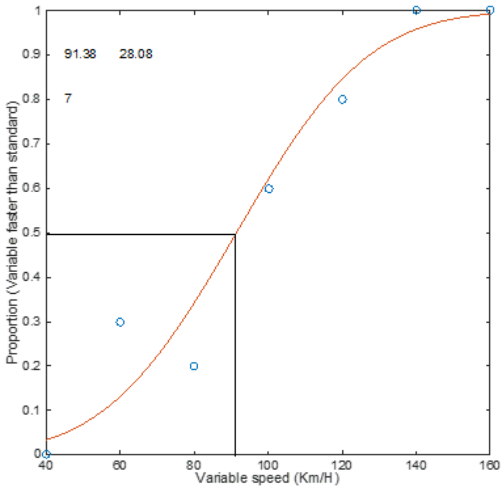


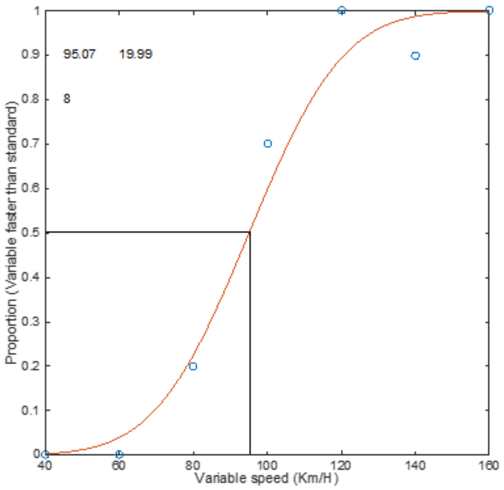


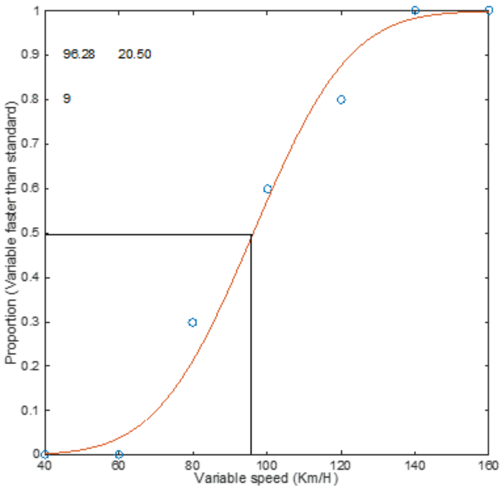


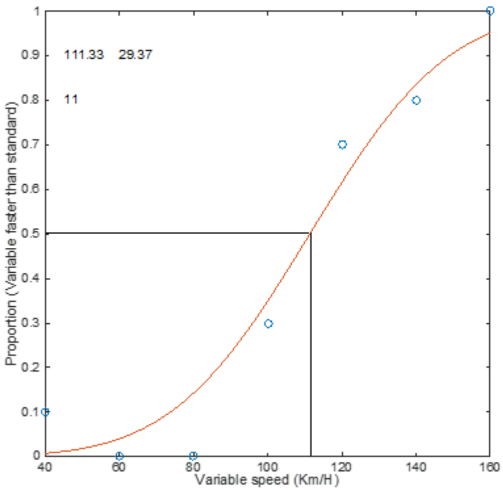
Individual participants' psychometric functions for the 100 km/h night standard condition

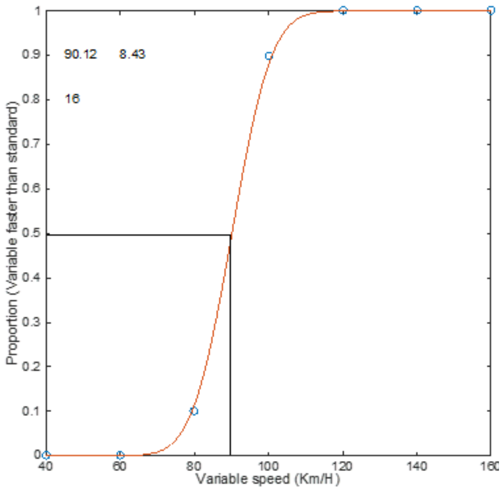


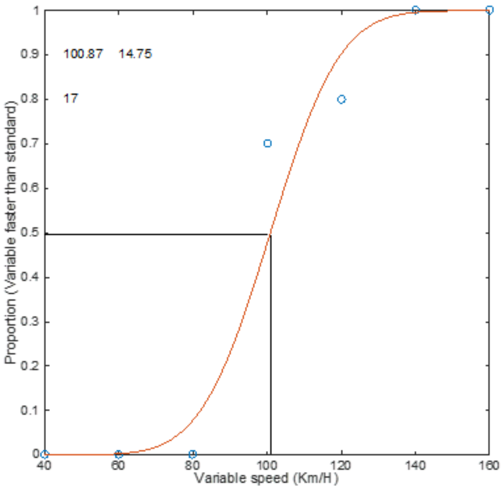


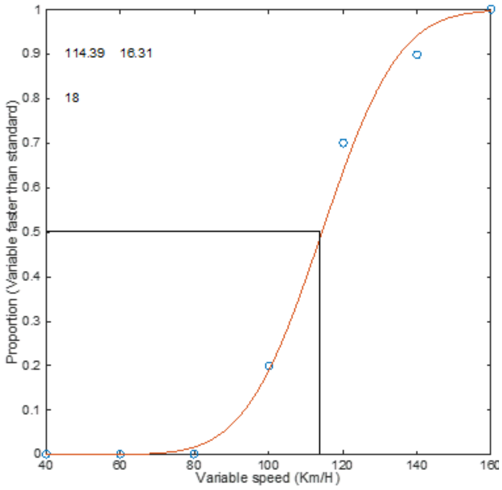


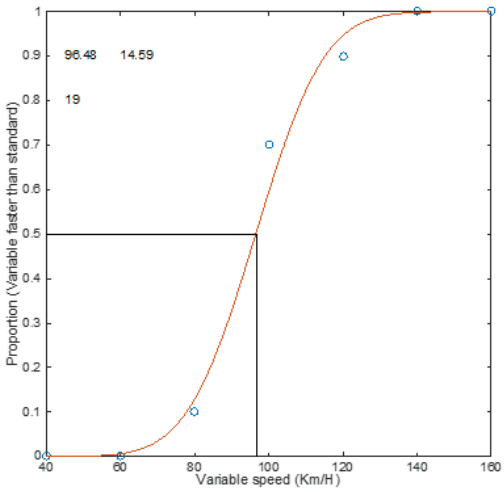



111.33 29.37
11
Proportion (Variable faster than standard)
Variable speed (Km/H)


90.12 8.43
16
Proportion (Variable faster than standard)
Variable speed (Km/H)


100.87 14.75
17
Proportion (Variable faster than standard)
Variable speed (Km/H)


114.39 16.31
18
Proportion (Variable faster than standard)
Variable speed (Km/H)


96.48 14.59
19
Proportion (Variable faster than standard)
Variable speed (Km/H)

Appendix I: Instruction sheet for Experiment 3

Ψ **School of Psychology**

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

Participant Information Sheet

Project Title: Perception of Vehicular Speed under Varied Light Levels

Approval Statement: *This research project has been approved by the School of Psychology Research and Ethics Committee of the Faculty of Arts and Social Sciences, University of Waikato. Any questions about the ethical conduct of this research may be sent to Associate Professor Linda Nikora, member of the Research and Ethics Committee (phone: 838 4466 ext. 8200, e-mail psyc2046@waikato.ac.nz).*

Purpose: This research project is being conducted as a partial requirement for a Masters in Social Science. This project requires the researcher to perform experiments into how individuals perceive vehicular speed under varied light conditions.

What is this research project about? This research project is about watching videos and determining the speed at which the video moved. There will also be a short questionnaire about your background and driving habits. This project should take no longer than 30 minutes. You will be asked to give consent prior to the start of the research project.

Outcome of this research: The main outcome of this research will be determining whether and to what extent light levels have an effect on visual perceptions of speed, and, in doing so, either support or challenge the current understanding of the effect of light level on visual perceptions of speed. The results will be published in the form of a Master's Thesis, and there is a possibility that they may be published in a psychological journal.

Instructions: If you are required to wear glasses or contacts while driving, you will need to do so while undertaking this experiment. Firstly, you will answer a simple questionnaire about your driving history. After that, you will be asked to watch videos of day and night scenes. After a video has been shown, a screen will appear with a line showing speeds from 0km/h to 150km/h, and you will be required to click on the line at the point representing the speed you thought the scene was moving at. After you have clicked on the line, a second screen will appear with a line showing the numbers 1 to 10, and you will be required to click on the line at the point representing the level of confidence you felt in your answer, with 1 meaning absolutely no confidence and 10 meaning absolute confidence. After you have clicked on the line, the screen will go black for a short period and then the next video will be shown. After the final video, you will see a screen that says you have completed the experiment. At this point, alert the researcher that you have finished. Eye movement will be measured during the experiment. For this purpose, you are required to place your head in the bracket in front of the screen at the start of the video section of the experiment, and keep it there until the experiment is concluded.

What will happen to the information collected? The information collected will be used by the researcher to write a thesis. It is possible that articles and presentations may be the outcomes of the research. Only the researcher will be privy to any notes and/or documents. Afterwards, notes and documents will be kept in a safe location for five years and then will be safely destroyed. No participants will be named in the thesis or any publications arising from the thesis, and every effort will be made to disguise participants' identities.

Declaration to participants: If you take part in the study, you have the right to:

- Refuse to answer any particular question;
- Withdraw from the study at any stage without bias or penalty;
- Ask any further questions about the study that occur to you during your participation; and
- Be given access to a summary of the findings from the study when it is concluded.

Who's responsible? If you have any questions or concerns about the project, either now or in the future, please feel free to contact the researcher or supervisors below.

Researcher: Jonathan Kim, email jdk3@students.waikato.ac.nz

Supervisors: Associate Professor John Perrone, email jpnz@waikato.ac.nz

Associate Professor Robert Isler, email psyc2255@waikato.ac.nz

Appendix J: Response screens for Experiment 3

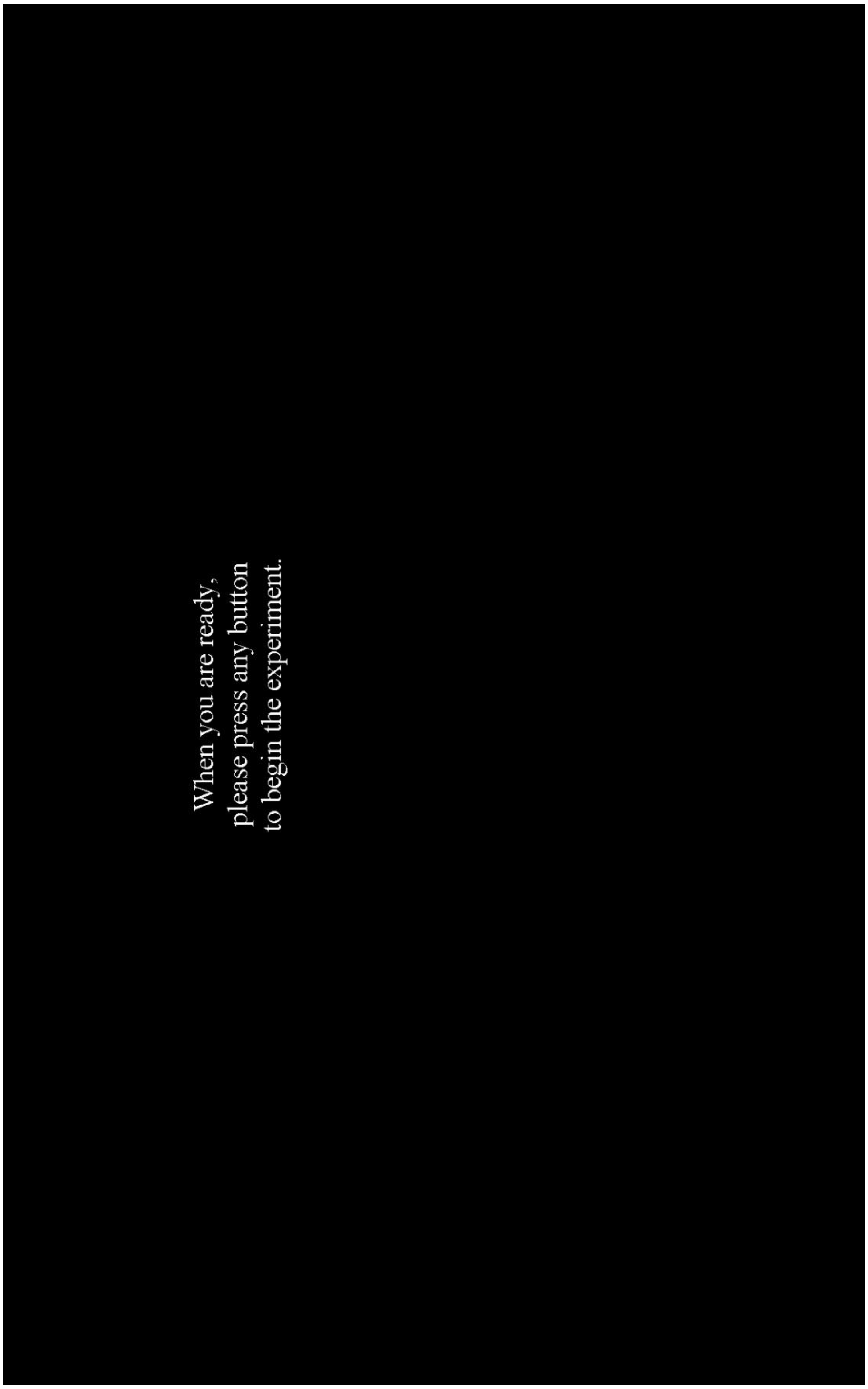


Figure J1: Experimental start screen

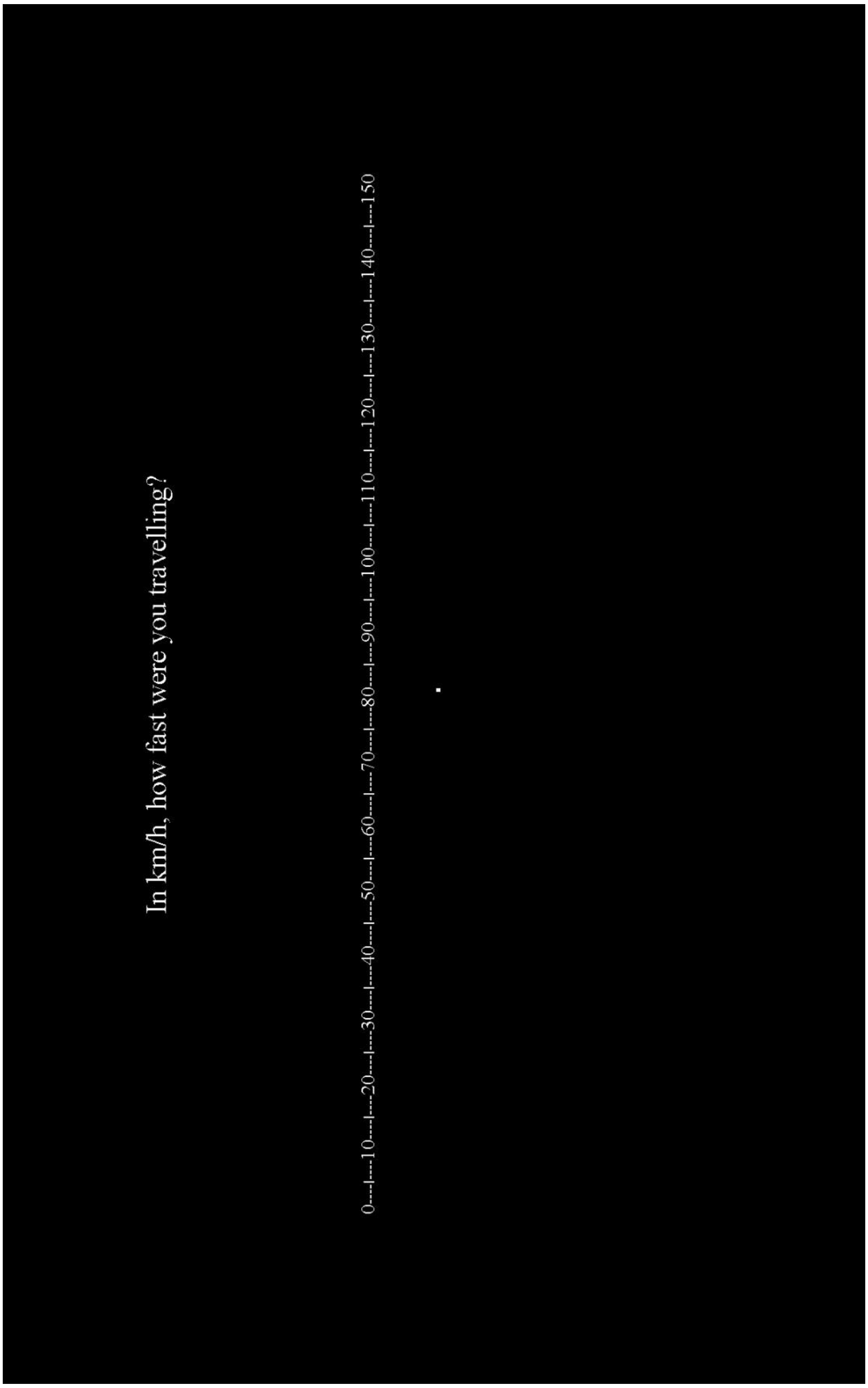


Figure J2: Speed magnitude estimation response screen. The white dot is the mouse cursor

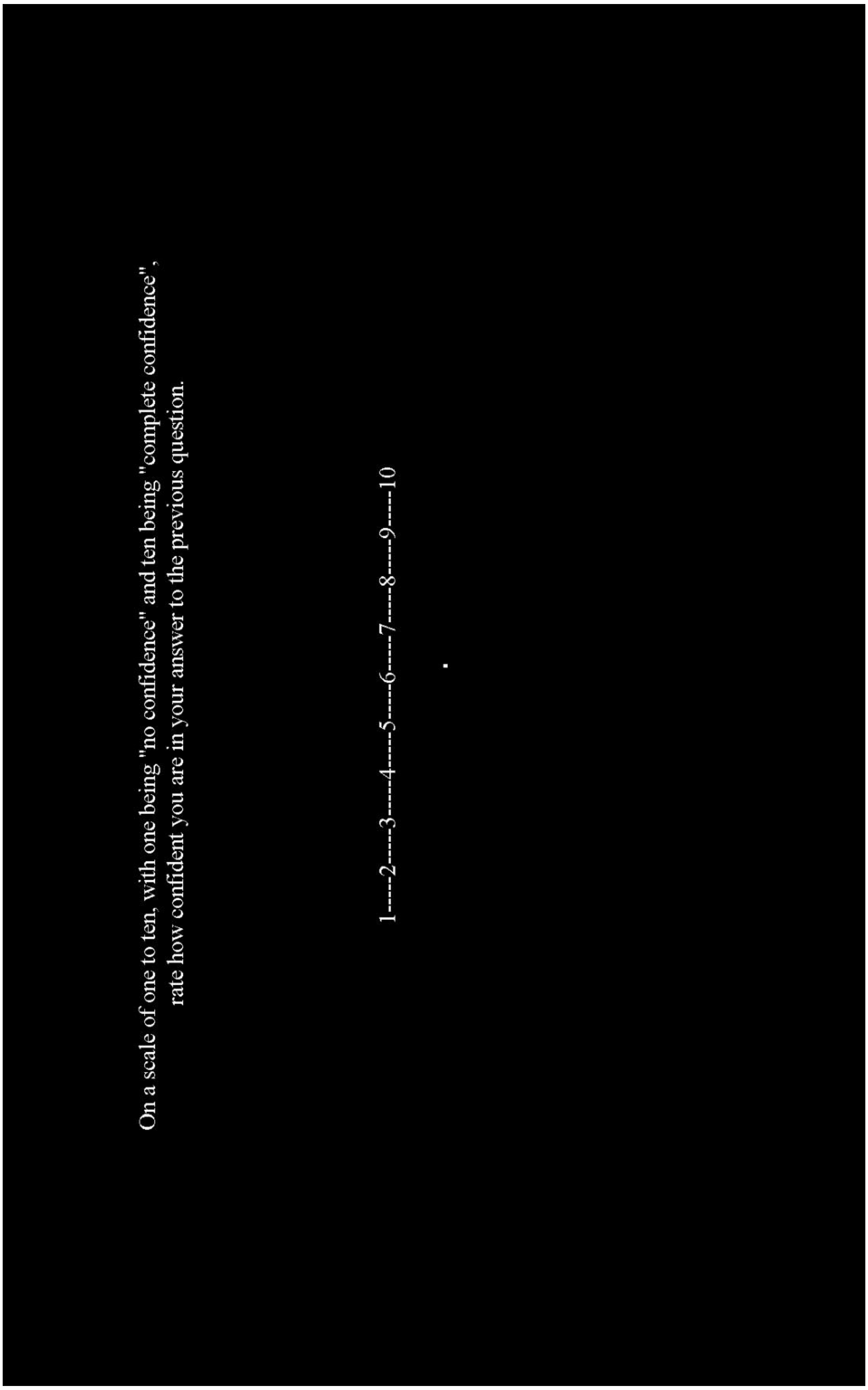
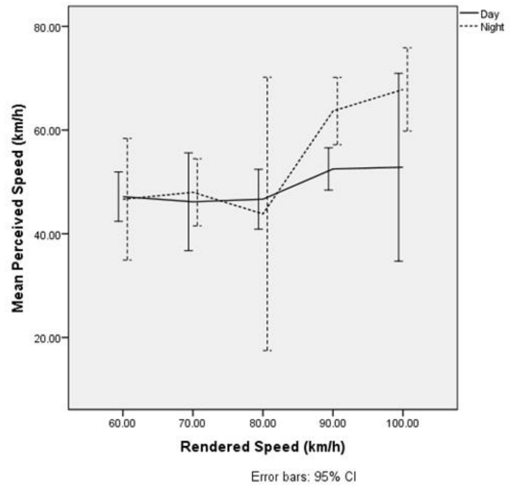
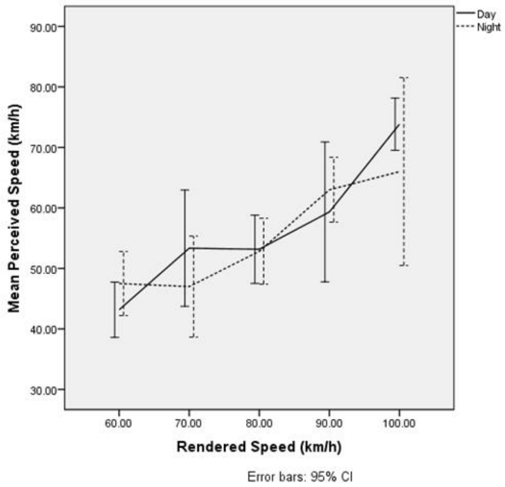


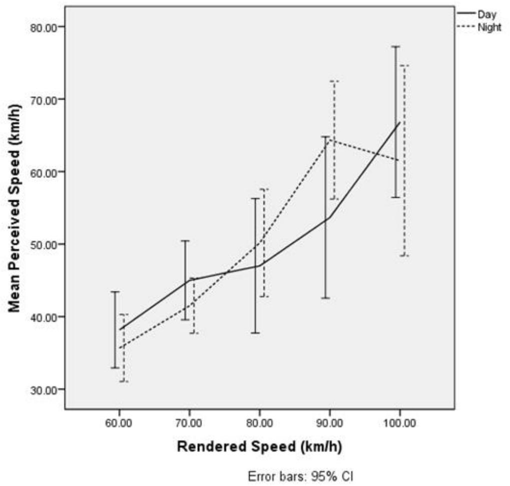
Figure J3: Confidence magnitude estimation response screen. The white dot is the mouse cursor

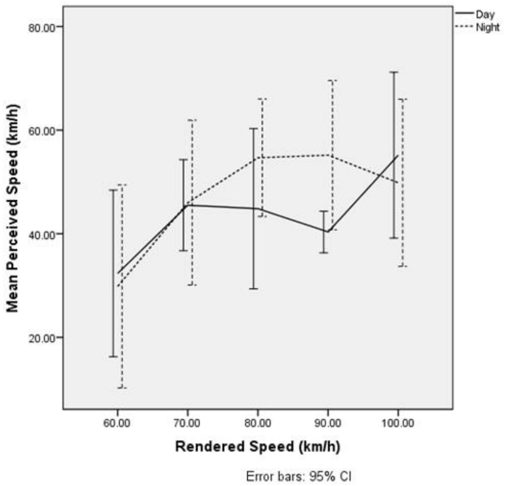
Figure J4: Final experimental screen

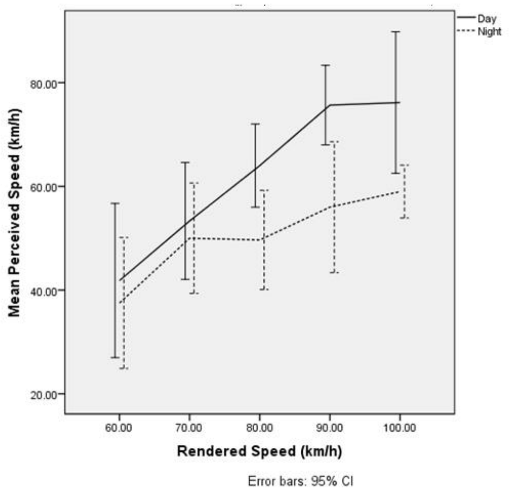
Appendix K: Individual participants' judgements of speed obtained during experiment 3 for both day and night conditions

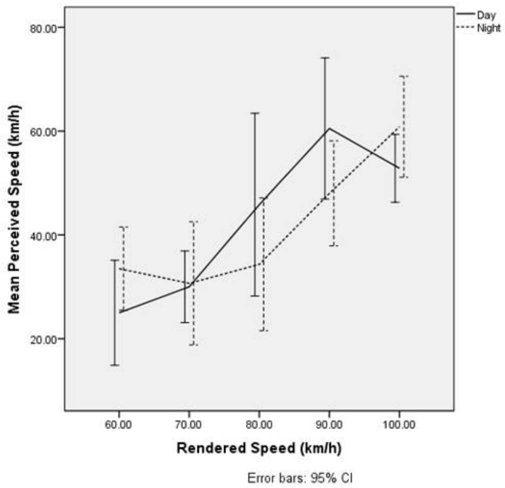


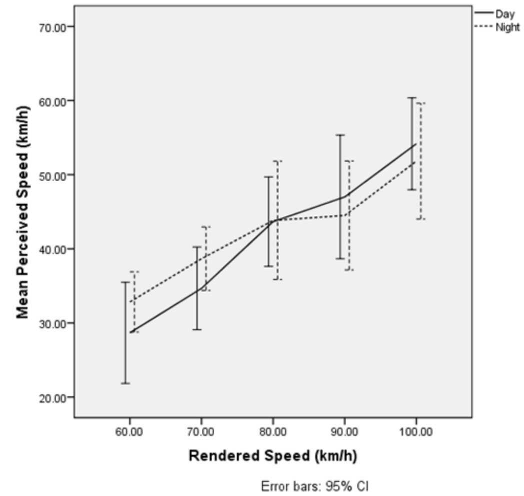


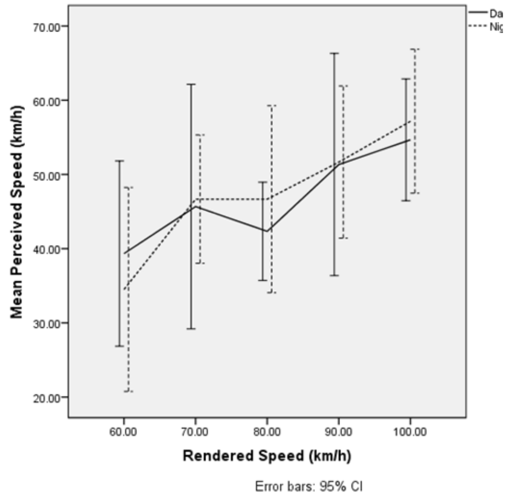


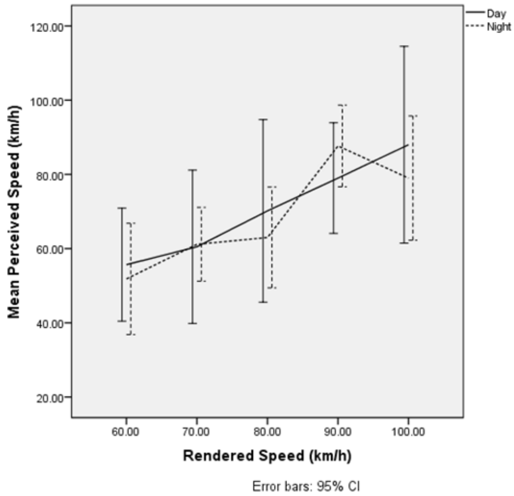


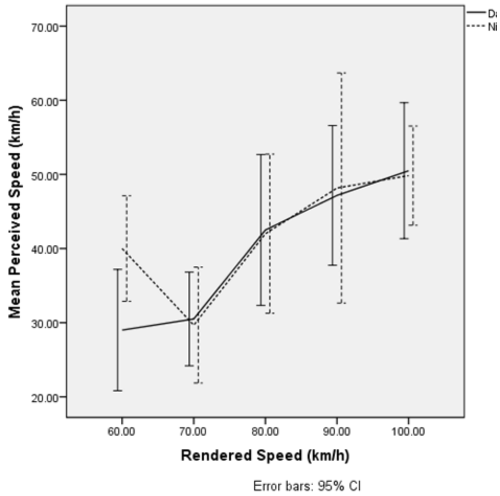


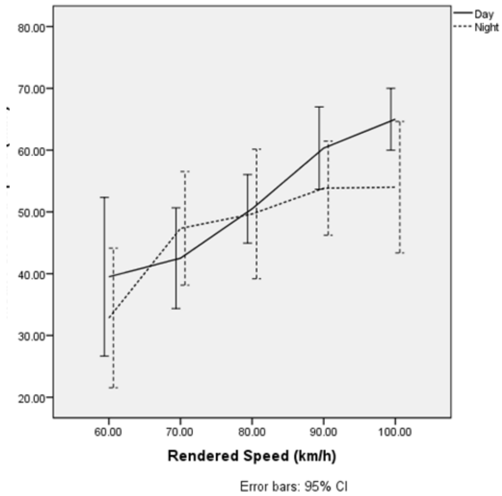


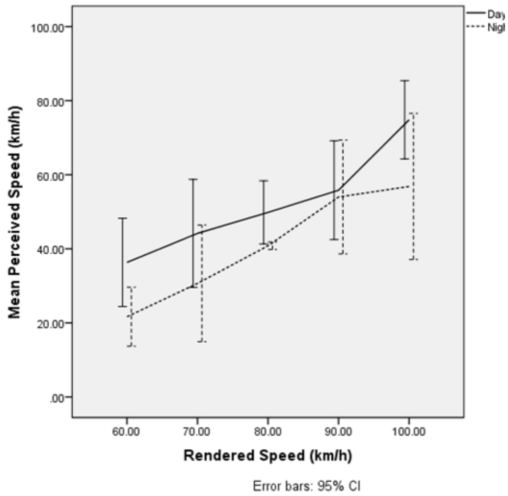

Day
Night
Mean Perceived Speed (km/h)
70.00
60.00
50.00
40.00
30.00
20.00
60.00
70.00
80.00
90.00
100.00
Rendered Speed (km/h)
Error bars: 95% CI

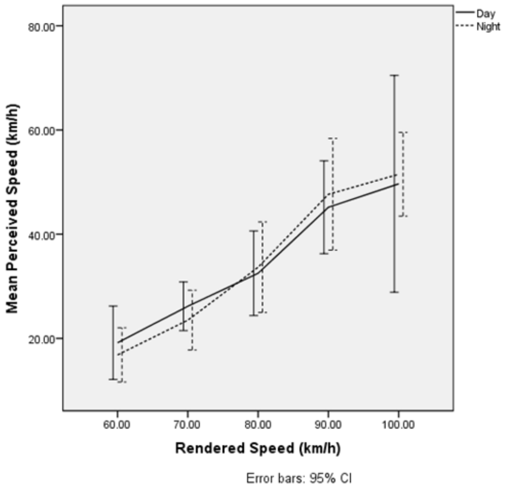

Mean Perceived Speed (km/h)
70.00
60.00
50.00
40.00
30.00
20.00
60.00
70.00
80.00
90.00
100.00
Rendered Speed (km/h)
Error bars: 95% CI

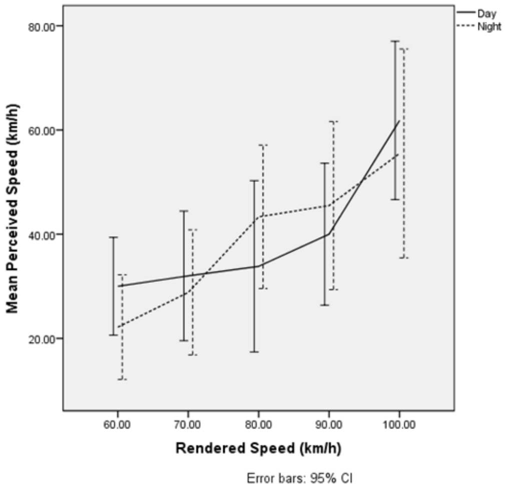

Day
Night
Mean Perceived Speed (km/h)
120.00
100.00
80.00
60.00
40.00
20.00
60.00
70.00
80.00
90.00
100.00
Rendered Speed (km/h)
Error bars: 95% CI

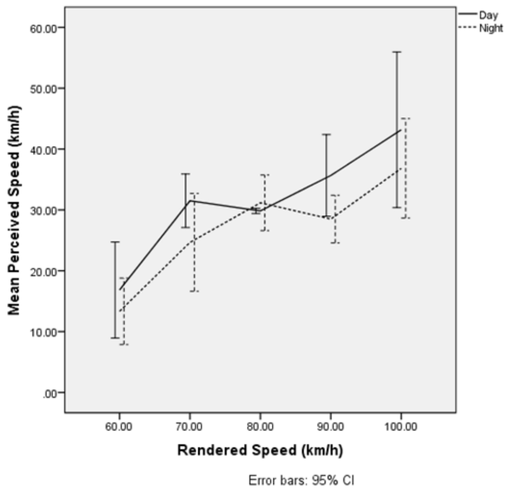

Mean Perceived Speed (km/h)
70.00
60.00
50.00
40.00
30.00
20.00
60.00
70.00
80.00
90.00
100.00
Rendered Speed (km/h)
Error bars: 95% CI

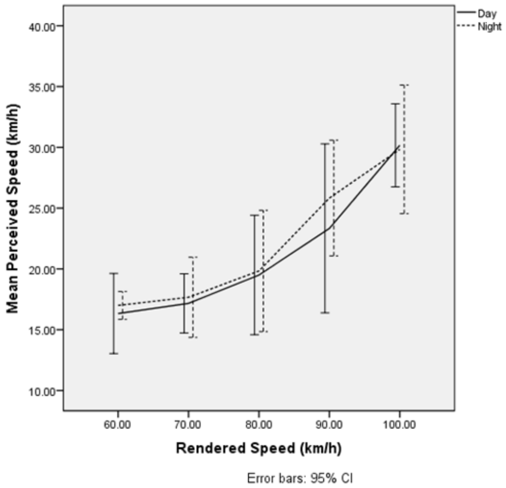

Day
Night
80.00
70.00
60.00
50.00
40.00
30.00
20.00
60.00
70.00
80.00
90.00
100.00
Rendered Speed (km/h)
Error bars: 95% CI


Mean Perceived Speed (km/h)
100.00
80.00
60.00
40.00
20.00
.00
60.00
70.00
80.00
90.00
100.00
Rendered Speed (km/h)
Error bars: 95% CI


Day
Night
Mean Perceived Speed (km/h)
80.00
60.00
40.00
20.00
60.00
70.00
80.00
90.00
100.00
Rendered Speed (km/h)
Error bars: 95% CI


Day
Night
Mean Perceived Speed (km/h)
80.00
60.00
40.00
20.00
60.00
70.00
80.00
90.00
100.00
Rendered Speed (km/h)
Error bars: 95% CI


Day
Night
Mean Perceived Speed (km/h)
60.00
50.00
40.00
30.00
20.00
10.00
.00
60.00
70.00
80.00
90.00
100.00
Rendered Speed (km/h)
Error bars: 95% CI


Day
Night
Mean Perceived Speed (km/h)
40.00
35.00
30.00
25.00
20.00
15.00
10.00
60.00
70.00
80.00
90.00
100.00
Rendered Speed (km/h)
Error bars: 95% CI

Appendix L: Eye movement analysis

The aim of the exploratory analysis carried out in this appendix was to determine whether eye movement behaviour was affected by light levels at 60 km/h, 80 km/h, and 100 km/h, as well as to determine whether eye movement behaviour had an effect on egospeed perception. Due to time constraints, it was not possible to examine the eye movement data from Experiment 3. Custom Matlab software was designed to analyze the eye movements made by each participant during the different scenarios (night versus day). Portions of the eye movement traces that occurred only when the standard speed was the same as the comparison speed were examined in order to reduce the amount of data that needed to be analyzed. As mentioned in the main body of the thesis, for each sequence the Xmean, Ymean, Xspread, and Yspread were determined.

A secondary aim of this analysis was to explore the premises that (1) the presentation order of the lighting conditions may have had an effect on participants' eye movement behaviour, and (2) the speed of the standard condition may have had an effect on participants' eye movement behaviour.

Three three-way MANOVAs and a two-way MANOVA were used to examine eye movement behaviour. The first two three-way MANOVAs tested eye movement behaviour at 60 km/h and 80 km/h respectively, while the two-way MANOVA tested eye movement behaviour at 100 km/h, and the third three-way MANOVA tested differences in eye movement behaviour across all three speed conditions. The independent variables tested for the first two three-way MANOVAs were lighting condition (LC), presentation order of the lighting conditions (POLC), and the order in which participants experienced the 60 km/h and 80 km/h conditions (SSCO). The independent variables tested for the two-way MANOVA were LC and POLC. The independent variables tested for the third three-way MANOVA were LC, POLC, and the speed of the standard condition (SSC). In order to determine whether eye movement behaviour interacted with the effect of lighting on egospeed perception, PSE was tested as a covariate for the first two three-way MANOVAs and for the two-way MANOVA.

Eye Movement Behaviour at 60 km/h

Box's M indicated that within-group covariance matrices are equal (Box's M = 144.611, $F(70, 4293.44) = 1.556$, $p = 0.002$). The results of the MANOVA indicate that LC was not found to be statistically significant (Wilks' Lambda =

0.973, F (4, 52) = 0.355, p = 0.839). POLC was similarly found to not be significant (Wilks' Lambda = 0.958, F (4, 52) = 0.563, p = 0.69). However, the interaction between LC and POLC was found to be statistically significant (Wilks' Lambda = 0.769, F (4, 52) = 3.901, p = 0.008). This is explored below. SSCO (Wilks' Lambda = 0.661, F (4, 52) = 6.653, p < 0.001) and the interaction between SSCO and POLC (Wilks' Lambda = 0.739, F (4, 52) = 4.596, p = 0.003) were also found to be significant, indicating that the order in which participants viewed the speed conditions had an effect on their eye movement behaviour and that, when SSCO was controlled for, the order in which participants viewed the lighting conditions had an effect on their eye movement behaviour. Finally, the PSE was found to be statistically significant (Wilks' Lambda = 0.709, F (4, 52) = 5.337, p = 0.001), indicating that eye movement behaviour interacted with the effect of lighting on egospeed perception at 60 km/h.

Tests of between-subjects effects indicate that the interaction between the LC and the POLC had a statistically significant impact on Yspread (F (1, 55) = 6.155, p = 0.016). Table L1 shows the effect of the interaction between LC and POLC on Yspread.

Table L1.

Effect of the interaction between LC and POLC on Yspread

POLC	LC	Mean Yspread	Standard Error
Day then Night	Day Condition	82.160	6.899
	Night Condition	64.325	6.899
Night then Day	Day Condition	64.605	6.899
	Night Condition	80.843	6.899

		95% Confidence Interval	
POLC	LC	Lower Bound	Lower Bound
Day then Night	Day Condition	68.334	68.334
	Night Condition	50.499	50.499
Night then Day	Day Condition	50.779	50.779
	Night Condition	67.017	67.017

These results indicate that participants had a higher level of Yspread when looking at the first scenario presented to them compared to the second, regardless of which lighting condition was presented first. As there was no significant difference in Yspread between day and night conditions regardless of presentation order, these results do not support the idea that the lighting level of a scenario had an effect on eye movement behaviour.

Tests of between-subjects effects indicate that PSE had a statistically significant impact on Xmean (F (1, 55) = 7.297, p = 0.009) and Yspread (F (1, 55) = 4.481, p = 0.039). In order to explore this further, regression analysis was carried out to find the slope and intercept of the fitted functions. Figure x shows the regression line for the effect of PSE on Xmean, while Figure x shows the regression line for the effect of PSE on Yspread.

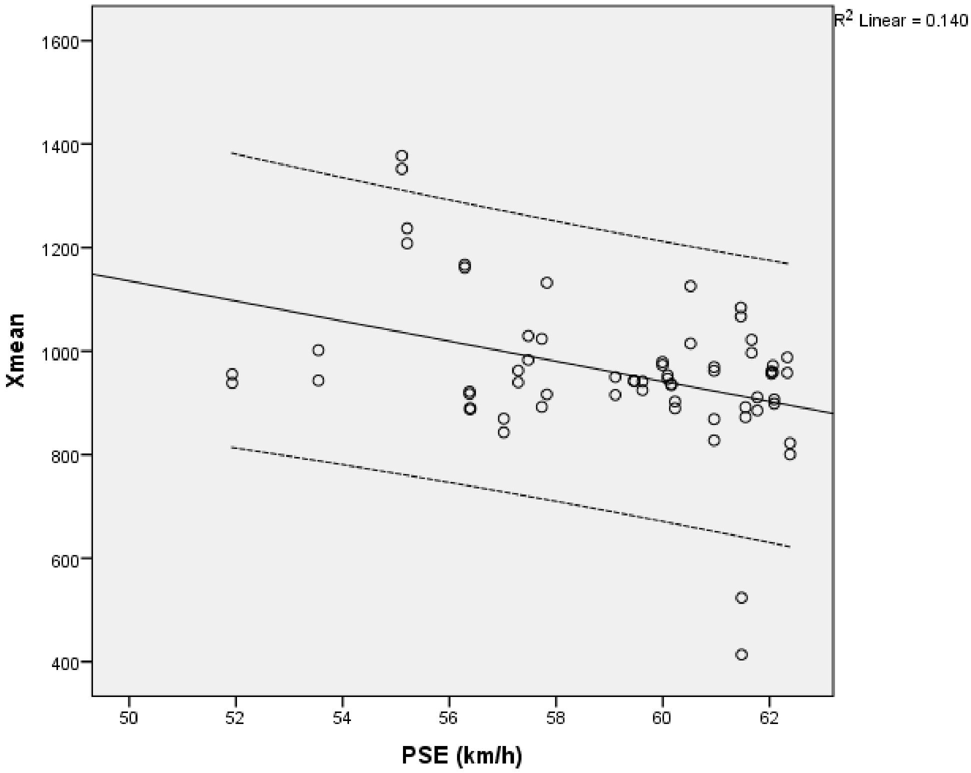


Figure L1. Scatter plot of the effect of PSE on Xmean. The dotted lines show the 95% confidence interval.

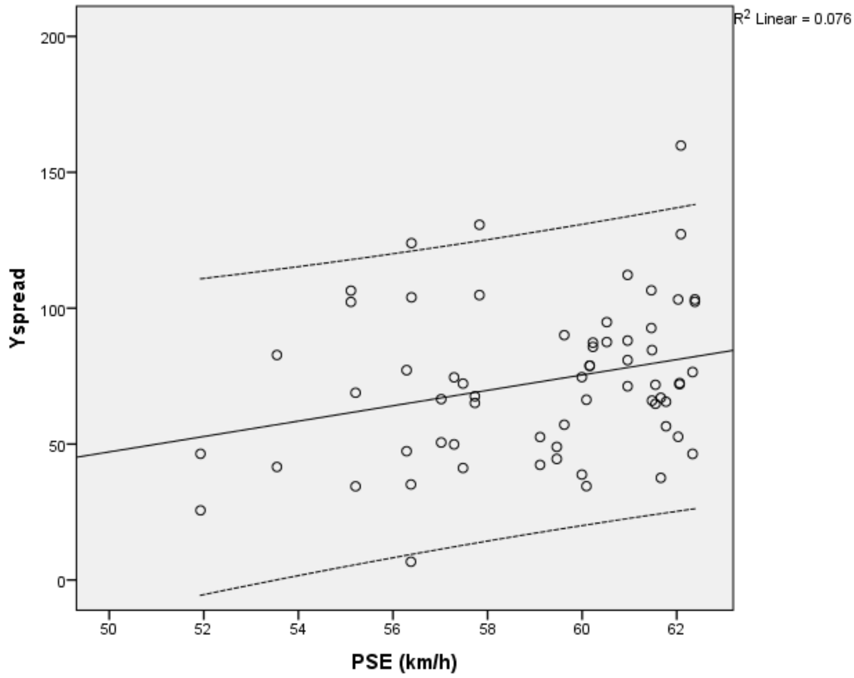


Figure L2. Scatter plot of the effect of PSE on Yspread. The dotted lines show the 95% confidence interval.

The results of the linear regression analysis for Xmean indicate that the slope of the regression line is -19.408 (F (1, 62) = 10.118, p = 0.002), with a Y intercept value of 2106.04. These results indicate a significant slope ($p < 0.05$), and as such support the idea that Xmean decreased linearly as PSE increased. The results of the linear regression analysis for Yspread indicate that the slope of the regression line is 2.831 (F (1, 62) = 5.127, p = 0.027) with a Y intercept value of -94.426. These results indicate a significant slope ($p < 0.05$), and as such support the idea that Yspread increased linearly with PSE.

Eye Movement Behaviour at 80 km/h

Box's M indicated that within-group covariance matrices are equal (Box's M = 113.658, F (70, 4293.44) = 1.223, p = 0.101). The results of the MANOVA indicate that LC was not found to be statistically significant (Wilks' Lambda = 0.979, F (4, 53) = 0.29, p = 0.885). POLC was similarly found to not be significant (Wilks' Lambda = 0.842, F (4, 53) = 2.442, p = 0.058). However, the interaction between LC and POLC (Wilks' Lambda = 0.776, F (4, 53) = 3.83, p = 0.008) was found to be statistically significant. As with the results at 60 km/h, this will be discussed below. Further, the SSCO was found to be statistically significant (Wilks' Lambda = 0.817, F (4, 52) = 2.909, p = 0.03), indicating that the order in which participants viewed the speed conditions had an effect on their eye movement behaviour. Finally PSE was found to not be statistically significant (Wilks' Lambda = 0.871, F (4, 52) = 1.918, p = 0.121), indicating that eye movement behaviour did not significantly interact with the effect of lighting on egospeed perception at 80 km/h.

Tests of between-subjects effects indicate that the interaction between the LC and the POLC had a statistically significant impact on Yspread (F (1, 55) = 5.802, p = 0.019). Table x shows the effect of the interaction between LC and POLC on Yspread.

Table L2.

Effect of the interaction between LC and POLC on Yspread

POLC	LC	Mean Yspread	Standard Error
Day then Night	Day Condition	74.583	6.877
	Night Condition	60.393	6.877
Night then Day	Day Condition	72.389	6.877
	Night Condition	90.075	6.877

		95% Confidence Interval	
POLC	LC	Lower Bound	Lower Bound
Day then Night	Day Condition	60.802	88.365
	Night Condition	46.612	74.175
Night then Day	Day Condition	58.607	86.171
	Night Condition	76.294	103.857

These results indicate that participants had a higher level of Yspread when looking at the first scenario presented to them compared to the second, regardless of which lighting condition was presented first. As there was no significant difference in Yspread between day and night conditions regardless of presentation order, these results do not support the idea that the lighting level of a scenario had an effect on eye movement behaviour.

Eye Movement Behaviour at 100 km/h

Box’s M indicated that within-group covariance matrices are equal (Box’s M = 45.032, F (30, 2398.35) = 1.122, p = 0.296). The results of the MANOVA indicate that the LC was not found to be statistically significant (Wilks’ Lambda = 0.968, F (4, 26) = 0.213, p = 0.929). However, the POLC (Wilks’ Lambda = 0.499, F (4, 26) = 6.553, p = 0.001) and the interaction between LC and POLC (Wilks’ Lambda = 0.687, F (4, 26) = 2.967, p = 0.038) were found to be statistically significant, indicating that the order in which participants viewed the lighting conditions had an effect on their eye movement behaviour and that, when POLC was controlled for, the lighting level of a scenario had an effect on eye movement behaviour. Further, the PSE was found to be statistically significant (Wilks’ Lambda = 0.69, F (4, 26) = 2.921, p = 0.04), indicating that eye movement behaviour interacted with the effect of lighting on egospeed perception at 100 km/h.

Tests of between-subjects effects indicate that the interaction between LC and POLC had a statistically significant effect on Yspread (F (1, 29) = 5.077, p = 0.032). Table x shows the effect of the interaction between POLC and LC on Yspread.

Table L3.

Effect of the interaction between LC and POLC on Yspread

POLC	LC	Mean Yspread	Standard Error
Day then Night	Day Condition	95.359	6.533
	Night Condition	83.190	6.533
Night then Day	Day Condition	54.467	6.144
	Night Condition	70.247	6.144

		95% Confidence Interval	
POLC	LC	Lower Bound	Lower Bound
Day then Night	Day Condition	81.998	108.721
	Night Condition	69.829	96.551
Night then Day	Day Condition	41.902	67.032
	Night Condition	57.682	82.812

These results indicate that participants had a higher level of Yspread when looking at the first scenario presented to them compared to the second, regardless of which lighting condition was presented first. As there was no significant difference in Yspread between day and night conditions regardless of presentation order, these results do not support the idea that the lighting level of a scenario had an effect on eye movement behaviour.

Tests of between-subjects effects indicate that POLC had a statistically significant effect on Xmean (F (1, 29) = 7.443, p = 0.011) and Yspread (F (1, 29) = 16.511, p < 0.001). Table x shows the effect of POLC on Xmean and Yspread.

Table L4.

Effect of POLC on Xmean and Yspread

Eye Movement Type	Standard Condition	Mean	Standard Error
Day then Night	Day Condition	82.160	6.899
	Night Condition	64.325	6.899
Night then Day	Day Condition	64.605	6.899
	Night Condition	80.843	6.899

		95% Confidence Interval	
Eye Movement Type	Standard Condition	Lower Bound	Lower Bound
Day then Night	Day Condition	932.110	1071.815
	Night Condition	808.046	939.762
Night then Day	Day Condition	79.160	97.725
	Night Condition	54.345	71.848

These results indicate that participants had a higher Xmean and Yspread for both day and night scenarios when the day scenario was shown first than when the night scenario was shown first. This result indicates that the significant difference in WF found between the day standard and night standard conditions at 100 km/h may have been caused by differences in eye movement behaviour.

Tests of between-subjects effects indicate that PSE had a statistically significant impact on Ymean (F (1, 29) = 10.468, p = 0.003). In order to explore this further, regression analysis was carried out to find the slope and intercept of the fitted functions. Figure x shows the regression line for the effect of PSE on Ymean.

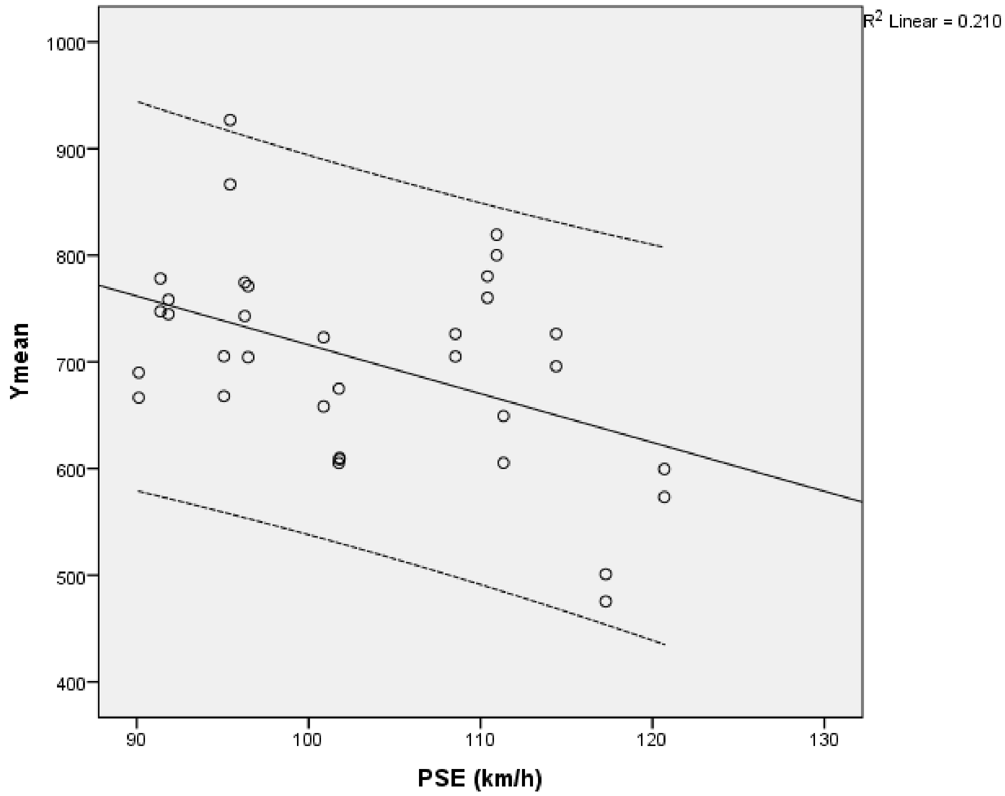


Figure L3. Scatter plot of the effect of PSE on Ymean. The dotted lines show the 95% confidence interval.

The results of the linear regression analysis for Ymean indicate that the slope of the regression line is -4.575 (F (1, 32) = 8.525, p = 0.006), with a Y intercept value of 1173.36. These results indicate a significant slope ($p < 0.05$), and as such support the idea that Ymean decreased linearly as PSE increased.

Differences in Eye Movement Behaviour over 60 km/h, 80 km/h, and 100 km/h

Box's M indicated that within-group covariance matrices are equal (Box's M = 184.857, F (110, 11006.254) = 1.431, p = 0.002). The results of the MANOVA indicate that SSC does not have a statistically significant effect on eye movement behaviour (Wilks' Lambda = 0.973, F (4, 147) = 0.515, p = 0.845). However, the interaction between SSC and POLC was found to be statistically significant (Wilks' Lambda = 0.861, F (4, 147) = 2.862, p = 0.004) indicating that, when POLC is controlled for, the speed of the scenario had an effect on eye movement behaviour. Further, while neither POLC (Wilks' Lambda = 0.958, F (4, 147) = 1.598, p = 0.178) or LC (Wilks' Lambda = 0.991, F (4, 147) = 0.346, p = 0.847) had a statistically significant effect on eye movement behaviour, the interaction between POLC and LC was also found to be statistically significant (Wilks' Lambda = 0.831, F (4, 147) = 7.498, p < 0.001). The interaction between SSC, LC, and POLC was found to not be significant (Wilks' Lambda = 0.993, F (4, 147) = 0.135, p = 0.998). These results indicate that SSC, LC, and POLC do not have significant effects on eye movement behaviour by themselves, but that both SSC and LC have significant effects on eye movement behaviour if the effect of POLC is controlled for.

Tests of between-subjects effects indicate that the interaction between SSC and POLC had a statistically significant impact on both Xmean (F (1, 150) = 6.232, p = 0.003) and Yspread (F (1, 150) = 6.568, p = 0.002). Figure x shows the effect of the interaction between SSC and POLC on Xmean, while Figure x shows the effect of the interaction between SSC and POLC on Yspread.

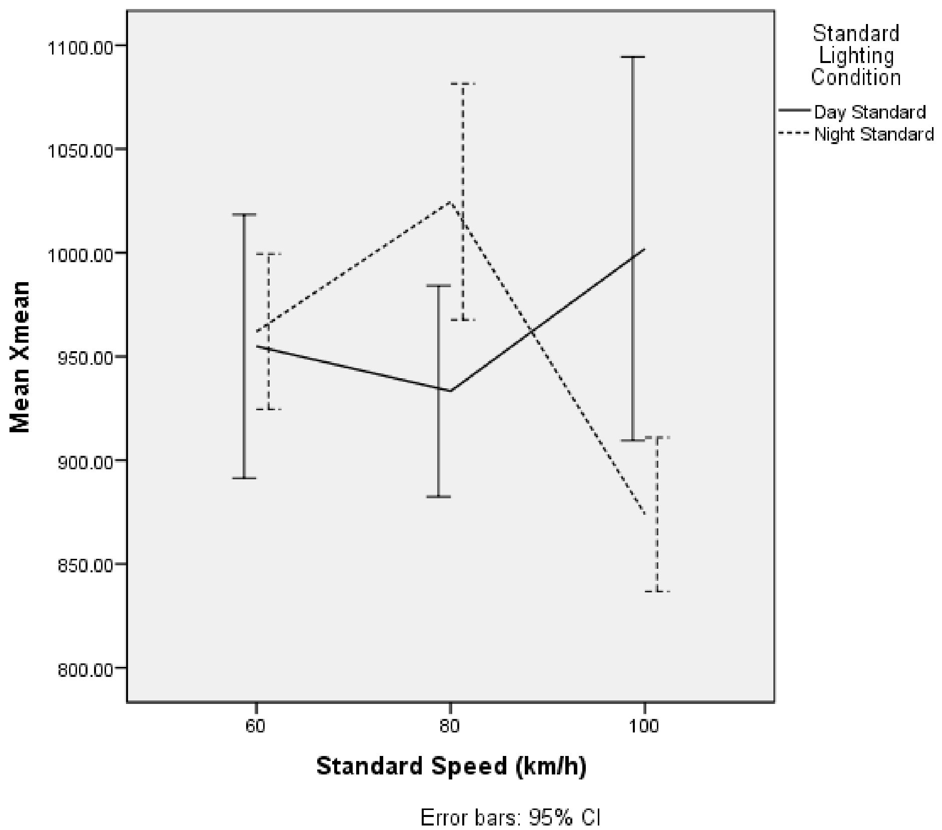


Figure L4. Effect of the interaction between SSC and POLC on Xmean

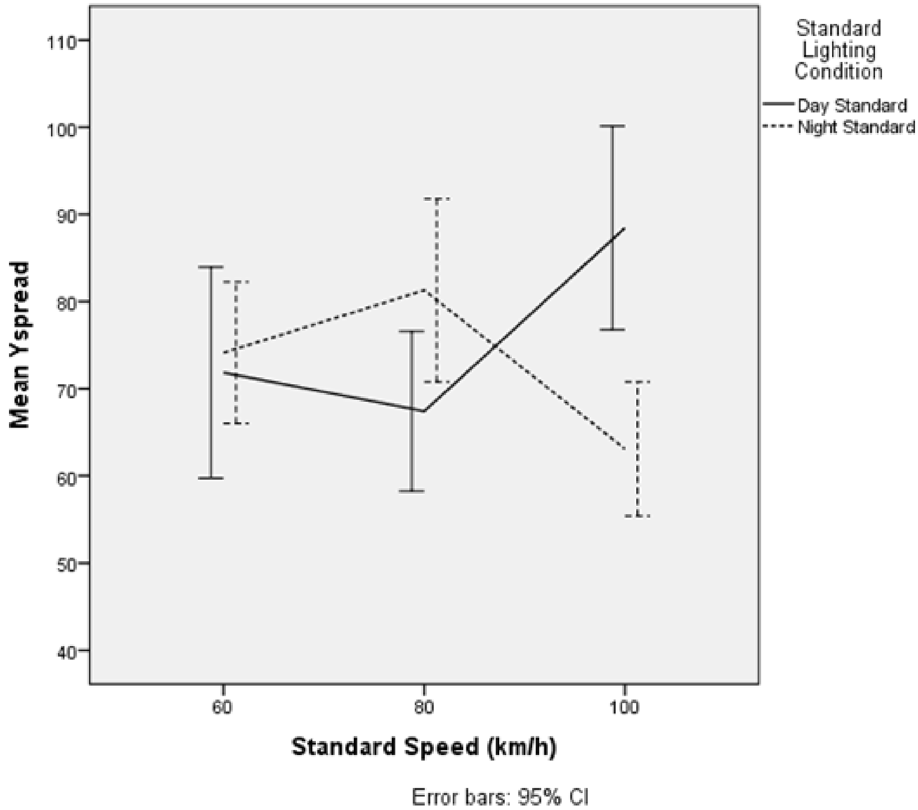


Figure L5. Effect of the interaction between SSC and POLC on Yspread

The results indicate a statistically significant difference in Xmean for the night standard condition between 80 km/h (estimated mean = 1024.62, 95% CI [973.47 to 1075.76]) and 100 km/h (estimated mean = 873.9, 95% CI [805.711 to 942.097]) and a statistically significant difference in Yspread at 100 km/h between the day standard condition (estimated mean = 88.443, 95% CI [75.84 to 101.05]) and the night standard condition (estimated mean = 63.1, 95% CI [51.21 to 74.98]). Interestingly, Figure x and Figure x indicate that the effect of POLC on Xmean and Yspread grew between 60 km/h and 80 km/h, and became inverted at 100 km/h. These results indicate that, when POLC is controlled for, significant differences exist in Xmean between 80 km/h and 100 km/h, and that when SSC is controlled for, significant differences exist in Yspread at 100 km/h between the day standard and night standard conditions.

Tests of between-subjects effects indicate that the interaction between LC and POLC had a statistically significant impact on Xmean (F (1, 150) = 13.922, p < 0.001). Figure x shows the effect of the interaction between LC and POLC on Xmean.

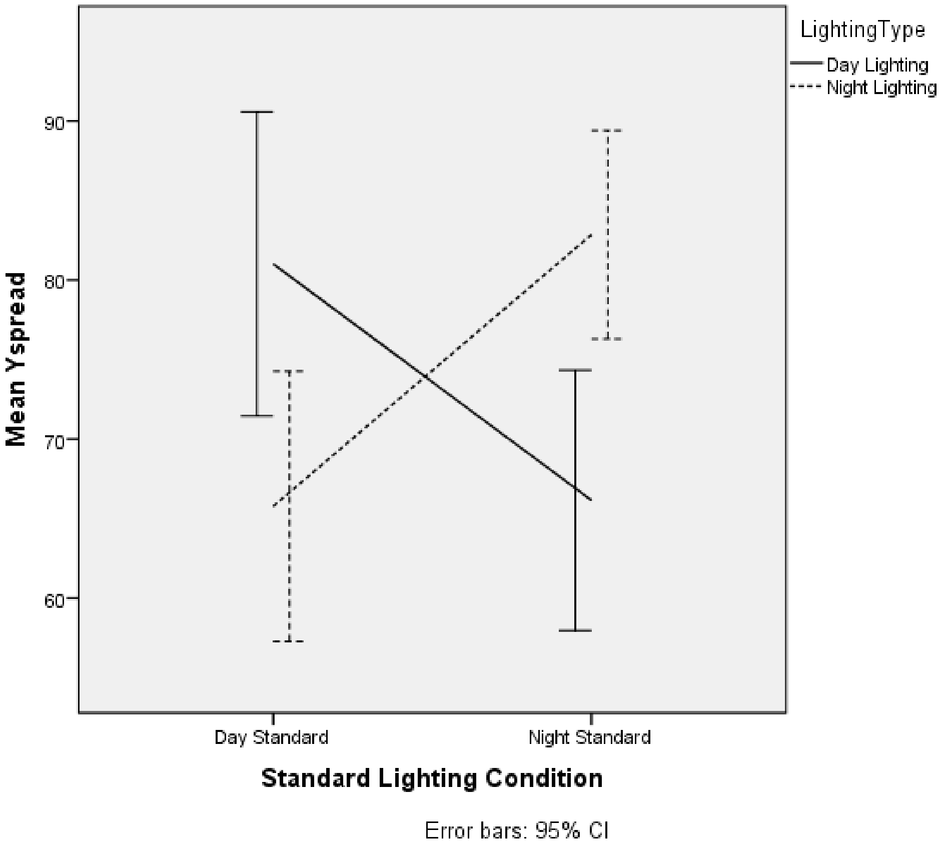


Figure L6. Effect of the interaction between LC and POLC on Yspread

The results indicate a statistically significant difference in Yspread for the night standard condition between the day conditions (estimated mean = 64.56, 95% CI [56.39 to 72.72]) and the night conditions (estimated mean = 81.12, 95% CI [72.96 to 89.29]) and for the day conditions between the night standard condition and the day standard condition (estimated mean 83.268, 95% CI [74.86 to 91.67]). These results indicate that, when POLC is controlled for, lighting has an effect on Yspread across all three speed conditions examined in this study.

Discussion

In this appendix, the eye movement data gathered during Experiments 1 and 2 was examined in order to test whether light levels had an effect on eye movement behaviour, and whether eye movement behaviour had an effect on egospeed perception. The results did not seem to support the idea that light levels had an effect on eye movement behaviour, and partially supported the idea that eye movement behaviour had an effect on egospeed perception.

The analysis also explored the premise that presentation order of the lighting conditions had an effect on participants' eye movement behaviour. The results partially support this premise, as presentation order was found to have a significant effect on Xmean and Yspread at 100 km/h, and the interaction between the presentation order of the lighting conditions and lighting condition was found to have a statistically significant effect on Yspread across all of the speed conditions.

The analysis also explored the premise that the speed of the standard condition had an effect on eye movement behaviour. The results partially supported this premise, as the interaction between SSCO and POLC was found to be statistically significant, but SSCO by itself was not.

Analysis of the eye movement data found that the lighting level of a scenario by itself did not have a statistically significant effect on eye movement behaviour at any of the speed conditions. As mentioned above, the interaction between the presentation order of the lighting conditions and lighting condition was found to have a statistically significant effect on Yspread across all of the speed conditions, indicating that when presentation order is controlled for lighting had an effect on eye movement behaviour. However, examination of the data indicates that the effect was that when the results are split into two groups organised by which lighting condition had been seen first that there were within-group differences, as the results when studied indicate across the board that Yspread was greater for the condition that was observed first regardless of lighting level.

The findings of this exploration of the eye movement data is contrary to previous research (Konstantopoulos, Chapman, and Crundall, 2010), which found that drivers adopted different eye movement strategies during day and night conditions. A possible reason that light levels were not found to have an effect on eye movement behaviour in this study is that the effect of presentation order may have been too strong and washed out any effect that light by itself may have had. It is unfortunate that the eye movement data from Experiment 3 was unable to be examined, as presentation order would did not play a role in that experiment.

It is interesting that PSE was not found to be correlated to eye movement behaviour at 80 km/h when it was at both 60 km/h and 100 km/h, as this indicates that eye movement behaviour was only found to be correlated to PSE for the speed conditions where light has no significant effect on egospeed perception. A possible reason for this finding is that participants may find it easier to differentiate between scenarios when they observe a significant difference in egospeed, and as such do not need to focus as much on the task in order to determine which scenario is faster, meaning that they are less reliant on the visual information obtained through eye movements than they are for the speed conditions where lighting was not found to have a significant impact on egospeed perception.

An interesting finding was that presentation order only had a significant effect by itself on eye movement behaviour at 100 km/h, while the interaction between presentation order and lighting condition was found to be significant across all three speeds examined. A possible reason that presentation order was only found to have a significant effect on eye movement behaviour at 100 km/h is that the same visual perception mechanism could have been used for both standard conditions at 60 km/h and 80 km/h but not at 100 km/h. This would be in keeping with the results of Experiment 2, which found that the WF for the day standard condition at 100 km/h was statistically significantly different from all other lighting/speed standard conditions examined in Experiments 1 and 2, and that there was no significant difference between any of the other lighting/speed conditions examined. A possible reason that the interaction between presentation order and lighting condition had an effect on eye movement behaviour regardless of speed is that participants could have created a companion trace during the first scenario presented to them that they could compare the second scenario to, with the creation of the comparison trace requiring participants to actively look over a wider area than they were required to when comparing the second scenario to the first. Further, the finding that standard speed and presentation order had an effect on eye movement behaviour is interesting, as the results indicate that the Xmean and Yspread mirrored the effects, significant or not, found in Experiments 1 and 2 for the effect of lighting on egospeed perception. Specifically, there is a small difference between the PSE, Xmean, and Yspread for each standard lighting condition at 60 km/h (with day standard having a lower PSE, Xmean, and Yspread than night standard), which increases in size at 80 km/h, and then reverses at 100 km/h (with day standard having a higher PSE, Xmean, and Yspread than night standard).

Another interesting finding was that while PSE was found to be significant at both 60 km/h and 100 km/h, the eye movement behaviour found to be significant at each of these speeds was different (Xmean and Yspread at 60 km/h, Ymean at 100 km/h). When considered alongside the finding that presentation order only had an effect on eye movement behaviour at 100 km/h, and the finding that Xmean and Yspread changed by an equal amount for the night standard condition as for the day standard condition at 100 km/h compared to 80 km/h, this finding suggests that a different visual perception mechanism was used at 100 km/h than was used at lower speeds, but that perception of the night standard condition at 100 km/h shared more visual perception mechanisms with perception of both standard lighting conditions at 60 km/h and 80 km/h than it did with perception of the 100 km/h day standard condition.

In summary, it was found that light levels did not have an effect on eye movement behaviour both across all speed conditions examined in Experiments 1 and 2, and for each speed condition separately, and presentation order was only found to be statistically significant at 100 km/h. However, the interaction between presentation order and lighting level was found to be statistically significant, but the results indicated that this was due to participants looking over a wider range on the Y axis for whichever scenario they perceived first. Eye movement behaviour was found to be statistically significantly correlated to the PSEs obtained for the 60 km/h and 100 km/h standard speed conditions tested in Experiments 1 and 2. Finally, it was found that speed by itself did not have an effect on eye movement behaviour, but that the interaction between speed and presentation order did have an effect, with the eye movement behaviour mirroring the effect of lighting on eye movement behaviour, significant or non-significant, across all three standard speed conditions.