PERCEPTUAL ERRORS IN JUDGING THE APPROACH OF MOTOR VEHICLES

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Declaration of Authorship

I Mark Gould hereby declare that this thesis and the work presented in it is entirely my own. Where I have consulted the work of others, this is always clearly stated.

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Abstract

Motorcycles are vastly overrepresented in road accident statistics across the world, with 61% of all car and 75% of all motorcycle accidents occurring at road junctions (Department for Transport, 2010a). When drivers attempt to negotiate their way safely out of a road side junction and into the flow of traffic, the most dependable cues for judging whether an approaching vehicle poses an immediate threat are its optical size and its rate of expansion on the retina (Lee, 1976). While this information may appear to be the most reliable, research has demonstrated that individuals gauge the time-to-passage (TTP) of smaller vehicles less accurately than larger vehicles (e.g. Caird & Hancock, 1994). This thesis investigated the perceptual mechanisms that underlie driver's abilities to make judgements about the immediacy of the threat posed by approaching vehicles at roadside junctions. This is investigated in three areas; judgements of relative speed, detection of vehicle approach and the effect of conspicuity aids.

The first experimental chapter explored decrements in judgements of motorcycle approach speed when only the white headlight is available as a cue on a black background, and how accuracy is improved by adding two flanking lights to the solo headlight in order to create a triangular headlight arrangement. The chapter also investigated the optimal configuration of the tri-headlight arrangement on the accuracy of approach speed judgements. In the following chapter, participants gauged motorcycle and car speeds within a virtual city scene as the ambient light level was manipulated. The study demonstrated that the enhancement in

performance through the use of the tri-headlight occurred once the contour of the motorcycle and motorcyclist could no longer be differentiated from the background, whereas decreasing ambient light level did not affect car speed judgements.

In Chapter 5, the thesis progressed to investigate the ability of individuals to detect whether a motorcycle or car was approaching their viewpoint within a virtual city scene. Individuals displayed significantly poorer thresholds for detecting an approaching motorcycle compared with an approaching car. Additional foveal motion caused a significant decrement in detection thresholds for cars but not motorcycles, although this is likely to be due to a ceiling effect for motorcycle detection. In Chapter 6, the role of additional motion was investigated further as thresholds for the detection of vehicle approach were assessed in the presence of simulated self-motion, which lead to significant impairment in detection thresholds for cars and motorcycles. In Chapter 7, the effect of a high visibility vest on detection thresholds was investigated, but no significant effects were found.

Overall, the thesis demonstrates the limitations of the human perceptual system in judging the relative speed of a motorcycle compared with a car stimulus, a problem which is exacerbated under low levels of luminance. However, the simple engineering solution of additional headlights is shown to vastly improve these speed judgement impairments under low levels of luminance. The thesis provides evidence that individuals are less sensitive to the detection of motorcycle approach compared with a car stimulus. The effect of additional scenic motion is shown to negatively affect car detection sensitivity, while simulated self-motion is shown to impair detection thresholds for motor vehicles. Implications for road design are discussed. Lastly, the thesis demonstrates that high visibility garments do not significantly improve detection capabilities for motorcycles.

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Chapter 1 – General Introduction

1.1 Introduction

Road traffic accidents account for approximately 1.2 million deaths every year and are the leading cause of human death and serious injury (Rifaat, Tay & de Barros, 2012). Further, road traffic accidents contribute to around 43,000 fatalities and more than 1.8 million injuries in the European Union every year (ERSO, 2008). In the UK alone, there were a total of 208,648 casualties, including 1,850 fatalities and 22,660 serious injuries in 2010 (Department for Transport, 2010a). However, it is clear that road traffic accidents are not evenly distributed across all vehicle types. Whilst accounting for just 1% of all UK traffic, motorcycles accounted for 19% of all road traffic fatalities and 26% of all injured road users in 2010 (Department for Transport, 2010a). Further, this highly disproportionate accident rate is not confined to the UK. Similar accident statistics have been found across Europe (European Commission, 2010; Sraml, Tollazzi & Rencelj, 2012), Canada (Alberta Transportation, 2009), UAE (Hefny et al., 2009), Malaysia (Manan & Várhelyi, 2012) and New Zealand (Ministry of Transport, 2009). Beyond the human cost, road traffic accidents are also estimated to cost economies approximately €160 billion in the European Union alone (ERSO, 2008). If motorcycle accidents account for approximately 20% of all road traffic accidents in the EU, then the cost of these accidents could amount to €32 billion.

In order to reduce the number of motorcyclist casualties on the road, it is first necessary to understand the nature of motorcycle accidents. The three most prevalent types of accident in the UK are failure to give way at road junctions, loss of control on a bend and manoeuvrability accidents such as overtaking (Clarke, Ward, Bartle & Truman, 2004). A failure to give way at a road junction occurs when a vehicle pulls out onto a main carriageway and fails to give way to an approaching motorcycle (Crundall, Clarke, Ward & Bartle, 2008a). Statistics indicate that a failure to give way at road junctions account for two thirds of all collisions involving a motorcycle and another vehicle (Hurt et al., 1981). Within the sub-category of failure to give way at road junctions, the accident type "looked but failed to see" (LBFTS) is evident (Crundall et al., 2008a). This accident refers to a situation where a driver pulls out into the path of an oncoming motorcyclist and the driver claims not to have seen the motorcyclist approaching (Brown, 2002; Herslund & Jorgensen, 2003; Williams & Hoffman, 1974). In the past, the high fatality rates among motorcyclist led to the misconception that these road users were the source of the problem (Hancock, Wulf, Thom & Fassnacht, 1990). However, accident statistics stated that in 9 out of 10 configurations of collision between motorcycles and automobiles, it was the driver who had failed to give way to the motorcyclist that led to the accident (Hancock et al., 1986; Hurt et al., 1981). More recently, in an analysis of accident statistics, Clarke, Ward, Bartle and Truman (2007) demonstrated that 38% of accidents from a sample of 1790 motorcycle collisions involved a ROWV and further than in 65% of these cases, the driver reported that they had failed to see the motorcyclist.

1.2 Look But Fails to See Errors (LBFTS)

In LBFTS collisions, motorcyclists often report that the driver of the violating vehicle had made eye contact with them prior to the collision (Pai, 2011) and often, the motorcycle is located very near to the junction when the car decides to pull out (Gershon, Ben-Asher & Shinar, 2012). Crundall et al. (2008a) have argued that failure to give way at road junctions can be attributed to a failure to look or a failure to correctly appraise and/or judge the motorcycle's trajectory. The authors suggest that the LBFTS problem could be broken down into three components; 1) did the driver look, 2) did the driver perceive and 3) did the driver correctly appraise the oncoming motorcyclist. More specifically, the authors referred to whether the driver actually looked in the correct direction of the approaching motorcyclist, whether they actually processed the visual information of the approaching motorcyclist and lastly, whether they accurately judged the movement, speed and trajectory of the motorcyclist. Crundall, Humphrey and Clarke (2008b) investigated whether drivers looked at and perceived motorcycles and cars within a photographic scene at either a near, intermediate or far distance, with varying time to passages (TTP). TTP refers to the time available before an object passes a given target point and the ability to calculate this is crucial for animal survival (Gibson, 1979; Regan and Vincent, 1995). The first experiment in the paper presented static imagery of a road scene taken from a drivers' perspective to the participant for 250ms. The experiment manipulated the distance and average TTP at which the target vehicle was located, ranging from near (~1s), intermediate (~2s) and far (~3s). The experiment showed that a significantly lower proportion of motorcycles were detected when they were located at the far distance, compared with the near and intermediate distances. The authors furthered these findings by introducing a decision making aspect to their second experiment. Participants were asked not only if there was a motorcycle within the scene after a 5000ms display duration, but also asked whether they would pull out from the junction. The data showed that participants were more willing to pull out in front of vehicles located at a far distance, compared with a near distance and intermediate distance. However, a limitation of the study described by the authors is that all of the stimuli used were static and that dynamic stimuli may have increased the saliency of the motorcycle within the scene.

Crundall, Crundall, Clarke and Shahar (2012) further investigated the visual abilities of individuals in spotting and appraising motorcycles at roadside junctions. The study investigated the effects of experience (novice, experienced and dual drivers) and two types of conflicting scenario (car or motorcycle). The authors addressed their previous limitations by introducing dynamic stimuli through video footage. Each video clip featured a decision, where participants were asked to execute a manoeuvre as quickly as safely possible; in the instance of a t-junction decision, participants were asked to press a button when it was safe to make a right-hand turn. The results demonstrated that all drivers gave motorcyclists a larger safety margin than cars. However, the dual drivers were more cautious than the novice drivers, while the experienced drivers lay in between. The first gaze duration, which the authors stated was a measure of immediate processing difficulty, was also assessed within the experiment. The authors demonstrated that the first gaze duration of experienced and dual-drivers were similar for approaching cars, but shorter for experienced drivers compared with dual-drivers when a conflicting motorcycle was present. Motorcycles represent a harder visual stimulus to process and thus the authors would have expected longer first fixation durations. This was not the case and it may therefore have been the case the experienced drivers did not realise that they were looking at a motorcycle. Furthermore, the mean fixation durations demonstrated that dual-drivers dedicated the most time to approaching motorcycles compared with novice and experienced driver groups. The authors proposed that the difference between the groups could be due to experience alone causing a bias in terms of expectancy; a far lesser proportion of motorcycles are present on the road compared with cars, which may account for inappropriate visual search strategies.

While there are several causal factors in motorcycle accidents, failure to give way at road junctions and LBFTS accidents are particular issues for motorcycles which appear to have strong, simple perceptual components (Crundall et al., 2008a). Furthermore, it is clear that the perception of vehicle approach plays a critical role in crashes at junctions, with statistics indicating a misjudgement of another vehicle's path/speed to be the second largest cause of accidents in the UK (Department for Transport, 2010a).

The focus of the current thesis is to investigate some of the perceptual processes that underpin a driver's ability to accurately judge the approach of a motorcycle. While Crundall and colleagues (2008a; 2008b; 2012) have focused on the eye movements of drivers and their ability to identify a motorcycle within a road scene at different distances, the thesis will split appraisal into two areas; detection of approach motion and judgement of speed of approach. In order to address the perceptual issue of vehicle approach judgements, it is necessary to review the literature concerned with how individuals gauge when a vehicle will arrive at their observation position and the optical cues involved in this process. Chapter 1 will discuss the theory of tau (Lee, 1976) and the evidence for its use in calculating TTP in both animals and humans. The chapter will then move onto discussing the concept of immediacy in making pull out judgements and how visual looming might be utilised as a cue. The chapter will then outline research surrounding looming sensitivity under different lighting conditions, during additional object motion and simulated observer motion, before briefly discussing the issue of conspicuity. Lastly, the chapter will outline the overall aims of the thesis.

1.3 Use of Optical Cues

Time to passage (TTP) refers to the time available before an object passes a given target point and the ability to calculate this is crucial for animal survival (Gibson, 1979; Regan and Vincent, 1995). If questioned regarding how they make TTP judgements, individuals might intimate that they simply judge the speed and distance of an oncoming object. However, speed and distance are two metric properties of the 3D environment that the human perceptual system is not attuned to accurately calculating (Gibson, 1979). For example, research has demonstrated that individuals are poor at judging absolute distance when a target is more than a few metres away from their heads (Collewijn & Erkelens, 1990). Distance can be inferred from cues such as height in the scene, scaled by eye-height, but this is very unreliable, particularly in natural road contexts (Wann, Poulter and Purcell, 2011). For example, a vehicle that is travelling at 30mph and situated 65 metres away from the observation point will have a TTP of five seconds. However, an increase or decrease in the slope of the road by just one degree could mean that this depth cue would indicate that the vehicle is approximately 266 metres away or just 37 metres away respectively. Additionally, Tresilian, Mon-Williams and Kelly (1999) demonstrated that vergeance cues gained from binocular disparity are only useful as the fixation distance of the object becomes nearer or other additional retinal cues are reduced; these cues would not therefore be of use when judging the TTP of an approaching vehicle.

When an object approaches the eye of an observer on a direct trajectory, it produces symmetrical optical expansion (Schiff, 1965 as cited in Lee, 1976) and this expansion provides the observer with information regarding the trajectory of the object (Andersen and Kim, 2001). The most reliable cue to the distance for an approaching vehicle therefore is its optic size on the retina, $\theta(t)$, while the rate of change of optic size, $\dot{\theta}(t)$ is correlated with the speed of approach; thus the ratio of the two can indicate TTP without the requirement to metrically judge distance, $z(t)$, speed, *v(t)* or vehicle size (Lee, 1976). Lee (1976) argued that the precise TTP of any solid object at any given distance, travelling at any speed can be calculated in principle with this retinal calculation:

$$TTP = \frac{z(t)}{v(t)} = \frac{\theta(t)}{\dot{\theta}(t)} \tag{1.1}$$

This calculation was originally documented by Hoyle (1957), but Lee (1976) termed the theory 'tau' in his article relating to the perceptual mechanism that underlies a driver's ability to accurately execute a braking manoeuvre when following another vehicle. Lee (1976) believed that this optical invariant was a key mechanism required in order to accurately judge TTP. Several studies were then conducted that appeared to support Lee's (1976) assertion.

Wagner (1982) demonstrated that the deceleration of houseflies when approaching a landing target was largely due to the relative retinal expansion velocity. Additionally, Lee and Reddish (1981) studied video footage of the diving behaviours of gannets and noted the time at which the animals folded their wings before entering the water; the authors argued that the initiation of this wing folding behaviour occurred at a specific tau value. However, Wann (1996) questioned a number of the conclusions in the aforementioned studies. Firstly, the work carried out by Wagner (1982) implied that tau was the single optical variable utilised by houseflies in order to calculate TTP. Conversely, additional research conducted by Borst and Badhe (1988) forwarded evidence that the landing behaviours of houseflies were influenced by a number of factors, including target size, target structure, extent of travel and target stability. Secondly, while the data reported by Lee and Reddish (1981) seemed appealing on first glance, the majority of the data were collected when the gannets were starting their dive from ~31cm above the water, the dive duration lasting ~250ms.

1.4 Size-arrival bias and the problem of smaller objects

Wann (1996) argued that while the tau hypothesis possessed explanatory power for TTP judgements, some of the evidence that was forwarded to support the argument did not stand under scrutiny. Evidence that visual cues that are not accounted for by tau can affect judgements of object approach can be found in the size-arrival effect literature. DeLucia and colleagues (1991a; 1991b; 1994; 1997; 1999; 2003) have conducted a number of studies investigating the cues that individuals use when calculating TTP. DeLucia (1991a; 1991b) demonstrated the size-arrival effect; optically larger objects were perceived as arriving at an observation point sooner than their optically smaller counterparts. More specifically, the authors noted that in a computer simulation of floating objects, a large far object appeared closer than a small near object. These effects were also repeated in subsequent experiments using longer duration times, textured objects and high resolution photographic animations (DeLucia 1991a, 1991b). The authors also found that this effect was not present when the objects had a closer starting distance and presented relatively faster expanding rates. In a further study, DeLucia, Kaiser, Bush, Meyer & Sweet (2003) investigated the role of a range of visual information in order to further examine exactly which pictorial depth cues could influence TTP judgements. The authors investigated the effects of relative size, height in the visual field, occlusion, motion parallax and texture density on TTP judgements across a number of experiments. The results demonstrated significant effects for all of these cues. More specifically, TTP judgements improved in accuracy in the presence of these cues, thus suggesting that that the visual system may rely solely on less reliable optical cues in the absence of more reliable cues. This may be reflective of the visual system's adaptability in the presence of limited spatial and temporal demands. Thus, while many of the additional optical cues mentioned here would lead to inaccurate TTP estimates when used in isolation, they may be of use in certain situations, particularly when attentional demands are high; e.g. when executing a pull out manoeuvre from a junction.

Additional support for the notion of the adaptability of the visual system was forwarded by Smith, Flach, Dittman & Stanard. (2001). The authors conducted a study whereby participants were asked to release a pendulum so that it would strike a simulated travelling ball, which travelled towards the observer at a constant speed. Participants were tested across five sessions, but only data from the first and fifth sessions were analysed. The data from experiment one demonstrated that participants consistently responded too early to slow travelling balls compared with fast travelling balls. The authors argued that this was consistent with the use of an expansion strategy, whereby participants released the pendulum once the ball had reached a critical optical size. The second experiment aimed to test whether object size affected judgements. The study ensured that the large and small balls began their movement with the same optical size by increasing the distance of the larger ball from the observer. The experiment showed that individuals consistently missed the larger ball with the pendulum. However, the participants improved from session one compared with session five, more so than a reliance on expansion information alone would postulate. The authors concluded that optical angle and expansion rate were two different degrees of freedom that could be utilised by observers when making TTP judgements to different extents. Yan, Lorv, Li & Sun (2011) attempted to determine whether individuals were most reliant on tau, distance, speed or physical size information when judging TTP. The authors noted that while the majority of their participants demonstrated the use of tau, they were unable to imply that this was the only mechanism used.

1.5 The Current State of TTP Research

While studies have pointed to evidence for the use of tau within TTP judgements (e.g. Lee and Reddish, 1988; Wagner, 1982), a number of studies have provided evidence to the contrary (e.g. Smith et al., 2001). For example, the tau equation proposed by Lee (1976) would argue that the physical size of an object would not affect TTP judgements, while evidence from DeLucia and colleagues (1991a; 1991b;

1994; 1997; 1999; 2003) clearly suggests some kind of size arrival bias. Furthermore, issues with the generalisation of the research that supports tau have been highlighted (Wann, 1996). Specifically, the methodologies within TTP research have often featured extremely short TTP values, which would not translate to many real world judgements, such as pulling out from a road side junction for example. These types of judgement would typically involve the individual trying to decide how immediate the threat of being hit by an approaching vehicle was, opposed to trying to precisely calculate TTP per se. In the specific example of roadside pull out manoeuvres, this would involve a larger TTP of 4-5 seconds (Horswill, Helman, Ardiles & Wann, 2005). The ability to calculate immediacy would not rely on TTP, but could rely on one part of the tau equation, visual looming $\dot{\theta}(t)$. However, while we know that all animals and human beings are sensitive to visual looming the literature on how this sensitivity varies across different scenarios is relatively sparse.

1.6 Reliance on looming by animals

The ability of animals and humans to extract cues of visual looming is critical for survival (Guest & Gray, 2006). Neuronal sensitivity to visual looming has been demonstrated in various animals including locusts (Hatsopoulos, Gabbiani & Laurent, 1995; Guest & Gray, 2006) and pigeons (Sun and Frost, 1998; Wu, Niu, Yang & Wang, 2005). In locusts, research has demonstrated that the Lobular Giant Movement Detector (LGMD) and the Descending Contralateral Movement Detector (DCMD) both respond to looming stimuli (Hatsopolous et al., 1995; Guest and Gray, 2006). In pigeons, three classes of neurons have been located in layer 13 of the optic tectrum (Sun and Frost, 1998) and the nucleus rotundus (Wu et al., 2005), both of which respond to TTP, angular velocity and the object reaching a critical optical size.

1.7 Reliance on looming by humans

While a vast amount of research on the role of $\dot{\theta}(t)$ in TTP judgements has been carried out on animals and insects, studies have also demonstrated neurological correlates of looming in humans. In a functional magnetic reasonance imaging (fMRI) study, Field and Wann (2005) showed participants two simulated spheres that approached the observer viewpoint at speeds ranging between 7-14 m/s. The authors noted an increase in the blood oxygen level dependence (BOLD) response in the superior parietal and motor cortices. Further research by Billington, Wilkie, Field and Wann (2011) demonstrated the involvement of an extensive network of sub-cortical and cortical regions in response to looming stimuli. The frontal, parietal and cingulated cortex responded to both looming and receding stimuli, while the anterior insula displayed greater activation in response to looming stimuli compared with receding stimuli.

Research has also focused on the use of looming as a cue for judging TTP in laboratory settings. Schiff and Detwiler (1979) used a visual display that simulated an object approaching an observation viewpoint. Participants were asked to press a button when they felt the object would have reached their viewpoint if it had continued on the same trajectory and results demonstrated that mean TTP estimates increased as actual TTP increased. The authors argued that their findings provided evidence for the use of $\dot{\theta}(t)$, as TTP estimates were not mediated by object size, distance or velocity. Furthermore, the authors did not find any evidence that the inclusion of background textures mediated TTP judgements and thus concluded that even when three-dimensional information is available, individuals still rely on the rate of two dimensional angular change of the target object. More specifically, participant judgements did not vary significantly in accuracy between displays which featured very little background information (plain terrain and sky) when compared with enhanced backgrounds which featured texture gradients that the authors argued provided static and dynamic distance information as well as distance-change information (grid terrain and grid sky). However, the authors did note an improvement in TTP estimates in conditions featuring the textured gradient information when the object was placed at a large spatiotemporal distance.

In a psychophysical study, Beverley and Regan (1980) noted the presence of detectors within the human visual system that are sensitive to an object's width and shape, as well as the movement of orthogonal edges; evident in visual looming. Todd (1981) conducted a study whereby participants were asked to indicate which of two approaching square objects would collide with their observation point first. The velocity and size of the squares were manipulated and the TTP of one object was fixed to three seconds, while the other was randomly selected using a method of limits procedure (Todd, 1981). The results demonstrated that individuals rely upon visual looming as a cue when judging relative TTP. Further experiments featured a free falling projected ball and observers were asked to judge whether the ball would land in front of their viewpoint. Todd noted that this information could be gained optically from the exact moment when the object was at the peak of its trajectory. Specifically, if an object is at the highest point of its trajectory, then it will always land in front of the observer if the time since it first crossed the horizontal axis is less than the size divided by the rate of expansion. However, the study demonstrated that individuals were not utilising this information and were instead largely relying on the rate of expansion.

1.8 Use of cues other than expansion

A number of studies have also demonstrated that other factors can affect TTP judgements. Cavallo and Laurent (1988) investigated the role of TTP judgements in driving. Participants were placed in a car that approached the rear-end of a mock-up car at a constant speed and trajectory. Initially, when approaching the target vehicle, the participant could not see his environment. The participant was then allowed a viewing window of three seconds when the TTP was either three or six seconds and asked to press a button when he felt that the collision would have occurred (the mock up car was removed in this time window). The authors found significant effects of normal visual field, binocular vision, speed of self-motion and driving experience. Specifically, the authors found that narrowing the visual field led to greater TTP errors, but only with younger drivers compared with older drivers, suggesting that the two groups may utilise different optic variables. However, this effect is not in line with more recent research on functional field of view, where driving experience has been found to correlate with wider visual search strategies in complex driving scenarios (Crundall, Underwood & Chapman, 1999). Additionally, research has also indicated that older drivers are less sensitive to peripheral information (Schieber and Benedetto, 1998), which is not in line with Cavallo and Laurent's (1988) findings. The study also noted that drivers were more accurate in their TTP estimations when viewing was binocular compared with monocular, but only at lower speeds and with nearer targets. This suggests that the visual system may adjust or combine visual looming cues with binocular cues with decreased object distance. Therefore, Cavallo and Laurent's (1988) results suggest that individuals are not solely reliant on $\dot{\theta}(t)$ when judging object approach.

1.9 Attention Capture

As human beings, we are free to attend to objects in our surroundings. The visual system however, is sensitive to events that exhibit a sudden change (Breitmeyer & Ganz, 1976) and research has postulated that this is often due to some behavioural urgency associated with the event (Todd & Van Gelder, 1979; Franconeri & Simons, 2003). The term motion "pop out" is used to refer to this bottom-up process whereby part of the visual scene draws the attention of observer (Rozenholtz, 1999). A number of studies have noted that the abrupt onset of a stimulus can capture attention (e.g. Jondis, 1981), while others have noted that even goal-directed eye movements can be disrupted by the appearance of a newly appearance task-irrelevant stimulus (Theewues, Kramer, Hahn & Irwin, 1998). This affect by task-irrelevant distracters has led to the postulation of the parallel programming of saccades; one stream goal-directed and the other stimulus driven.

Franceroni and Simons (2005) devised the behavioural urgency hypothesis, whereby only stimuli that require the potential need for immediate action attract attention. The authors noted that new objects, objects that move suddenly and (importantly for this thesis) objects that loom are all behaviourally urgent and strongly draw the attention of the observer. A competing theory, the motion onset hypothesis, forwarded by Abrams and Christ (2003), stated that the onset of motion will capture attention regardless of the direction of this motion. In a letter search task, Franceroni and Simons (2003) demonstrated that looming objects drew the attention of observers and the authors argued that despite not being “new objects” within the display, the fact they were looming towards the observer rendered them behaviourally urgent. While the two theories are competing, Abrams and Christ (2006) stated that the onset of object motion is a powerful cue as it intimates that the object may be “alive” and is therefore crucial for survival. This is particularly relevant to road side junction pull outs, where vehicles need to be detected as moving, or “pop out” of the scene, before the immediacy of the danger posed by the vehicle is realised. The following section will focus on the detection of visual looming, which would affect whether motion pop-out occurs at the roadside.

1.10 Looming detection as a component of immediacy judgements

When waiting to pull out from a junction, a driver needs to orientate their gaze in the direction of oncoming traffic and make a decision about whether it is safe to pull out. This decision stage involves a number of processes, including the detection of oncoming traffic motion and the judgement of its speed.

A busy road scene contains a number of vehicles, both stationary and moving. Approaching vehicles within a road scene can be present at various distances and can be travelling towards the observer at a variety of speeds. The ability to discriminate between approaching vehicles and stationary vehicles largely relies on an individual's ability to detect visual looming ($\dot{\theta}(t)$). Hoffman (1994) assessed the information used to calculate TTP across different age groups using video footage of approaching vehicles. The study approximated detection thresholds from the data collected on TTP judgements post-hoc in order to assess the differences in the abilities of individuals to detect looming motion ($\dot{\theta}(t)$). More specifically, Hoffman demonstrated a linear relationship between age and threshold for detection of a looming vehicle; children aged 5-6 years recorded angular velocity threshold values of 0.004 rad s^{-1}, while adults recorded values of 0.002 rad s^{-1}. Wann et al. (2011) furthered this finding by showing that the neural mechanisms needed to detect $\dot{\theta}(t)$ are not fully developed until adulthood. The study investigated the perceptual thresholds for the detection of an oncoming photographic car stimulus on a photographic road background across a number of age groups, ranging from six years of age to adulthood. The authors demonstrated that when the car stimulus used had a fixed TTP of five seconds, children were unable to detect its approach at speeds greater than 0.003 rad s^{-1} (~25 mph). In contrast, adults recorded thresholds of 0.001 rad s^{-1} (~105 mph). The assessment of looming detection thresholds was then used by Purcell et al. (2012), who demonstrated that primary school children with developmental coordination disorder were less sensitive to visual looming compared with gender matched controls. Lastly, Crundall et al. (2008a) noted that the optical expansion of motorcycles on approach can be difficult to perceive and can become motion camouflaged in their review paper on motorcycle accident involvement.

1.11 Looming sensitivity as a component of immediacy judgements

While Wann et al. (2011) demonstrated age as a mediating factor in looming detection, $\dot{\theta}(t)$ is also dependent on the vehicle's size (S), which can be taken as the height, width or combined surface area (using small angles approximation):

$$\dot{\theta}(t) = \frac{S\,v(t)}{z^2(t)} \tag{1.2}$$

According to Equation 1.2, a smaller vehicle will have a lesser rate of expansion compared with a larger vehicle. Further, Equation 1.2 indicates that a vehicle that is travelling at a faster speed will also have a greater looming rate. However, this dependency on vehicle size can lead to problems whereby smaller approaching objects are often misperceived as being further away and thus the driver may misjudge the approach.

Once a driver has detected the approach of an oncoming vehicle, he or she next needs to judge whether there is sufficient time to execute the pull out manoeuvre and avoid a collision. A pull-out manoeuvre itself requires a critical amount of time (TTP) in order to avoid a collision and thus z(t) from Equation 1.2 becomes v(t):

$$\dot{\theta}(t) = \frac{S}{t_c^2 \, v(t)} \tag{1.3}$$

This implies that for an action that requires four seconds, a faster object will be at a far greater distance from the observer and thus is actually more likely to be below an individual's threshold for detecting visual looming. This problem may be particularly prevalent with motorcycle riders, with research demonstrating they are more likely to travel above the speed limit than car drivers (Brenac, Clabaux, Perrin, & Van Elslande, 2006). While this issue would be exacerbated for a motorcycle due to its smaller size, it may also be evident for faster travelling cars. This would create a dangerous illusion whereby faster objects may appear stationary within the scene

(Wann, Poulter & Purcell, 2011) and in terms of motion pop-out theory, may not draw the attention of the driver and thus could lead to a greater risk of a right-of-way collision. Therefore, in a “Look But Failed to See” (LBFTS) collision, the driver may simply not detect the visual looming of the motorcycle within a road scene due to its smaller size, a problem that would be exacerbated at greater distances.

Caird and Hancock (1994) conducted a study that was designed to investigate the TTP of a number of different size vehicles within a driving simulator environment. The experiment featured a prediction motion paradigm whereby the target vehicle would disappear from the display and participants were asked to press a button when they estimated that the vehicle would have reached the front of their car. The study assessed participant judgements for four different vehicle types (motorcycle, compact car, normal car and van). The authors noted a linear trend for the TTP judgements based on the size of the vehicle; the smaller vehicle (motorcycle) yielded the most overestimated judgements while the largest vehicle (van) yielded the most underestimated judgements. This implied that individuals believed that smaller vehicles would arrive later than their actual TTP, which might cause an unsafe pull out judgement. Thus, underestimating vehicle approach is safe than overestimating vehicle approach. This effect of object size had also been noted by Oudejans, Michaels and de Vries (1993) in a study of approaching squares. More specifically, the study demonstrated that on average, individuals perceived larger squares as arriving 0.22s earlier than smaller squares.

Horswill et al. (2005) studied the TTP estimates of cars and motorcycles using video footage. The experiment once again utilised a prediction motion paradigm, whereby participants were asked to indicate when the target vehicle would cross a predetermined point just ahead of the observers' position. The display disappeared when the TTP between this point and the target vehicle was four seconds. The authors demonstrated the same linear trend across vehicle size as noted by Caird and Hancock (1994); motorcycles were judged to arrive later than cars and vans. In order to ensure that this finding was not solely due to the motorcycle size being below the threshold for the detection of motion ($\dot{\theta}(t)$), the authors carried out a second experiment where the display disappeared just one second before the vehicle was due to cross the predetermined point. The same linear trend was displayed and motorcycles were judged to arrive significantly later than cars.

1.12 The effect of lighting conditions on judgements of looming

The majority of research concerned with judging the approach speed of motor vehicles has taken place under optimal lighting conditions (e.g. Caird & Hancock, 1994; Horswill et al., 2005). However, during night-time driving conditions, often only very basic perceptual information is available to drivers and research has demonstrated that individuals are poorer at judging the speed of objects under low lighting conditions (Gegenfurtner, Mayser & Sharpe, 1999). Plainis, Murray and Pallikaris (2006) noted that one factor in the high night-time accident toll is likely to be impoverished visual ability under dim lighting conditions, stemming from the use of rod photoreceptors. These receptors have poor spatial and temporal resolution compared with cone photoreceptors, which mediate detailed vision and thus the authors argued that this could lead to the underestimation of vehicle approach speed at junctions.

When glancing down a poorly lit road, often the only source of vehicular information available to the observer is the headlights of the approaching vehicle. Motorcycles and cars have similar diameters in terms of headlights (i.e. ~20cm). While visual looming relies on the rate of change of optical expansion of an optical image on the retina, Tresilian (1991) argued that TTP could be calculated from the divergence of two features. Specifically, θ would be defined as the gap between two closed contours. In terms of car headlights, this distance would be ~1.6m. Thus, while the ~20cm diameter may not provide a strong looming cue, the separation between the two headlights on a car could provide a stronger percept. This however, would not be true for a single headlight motorcycle. Indeed, research has demonstrated that a greater separation distance between vehicle headlights can lead to significant improvements in distance judgements (Castro et al., 2005).

If this separation of two divergent features assists approach speed judgements and judgements for solo headlight motorcycles are impaired, a possible engineering intervention would be to introduce multiple headlights onto a motorcycle so that separation information is present. Approach speed judgements of solo headlight motorcycles, tri-headlight motorcycles and cars across different lighting levels will be a topic of investigation for the thesis.

1.13 The effect of additional motion on looming detection

While a vast amount of research has opted to focus on looming judgements for a single object within a sparse visual display (e.g. Regan & Beverley, 1979; DeLucia, 1991a; 1991b), this type of research is not very akin to everyday life. A pull out judgement scarcely takes place on a road with no other moving objects and thus it is useful to consider research that has investigated the effects of additional motion on looming detection.

DeLucia and Novak (1997) investigated the effect of distracter looming objects on participant ability to judge which object within an array would reach the observation viewpoint first. The study attempted to account for the size-arrival effect for the “first arriving stimulus” (FA) and the “next arriving stimulus” (NA) so that pictorial size information was not consistent with TTP. More specifically, the authors ensured that the FA object did not always have the largest projected size in the first or last frame. In half of the trials, the projected size of the FA would be smaller than the NA, while it would be larger in the other half of the trials. The authors demonstrated that individuals can judge which of up to eight objects had the shortest TTP at an above chance rate. However, performance was degraded in the presence of misleading relative size information when only two objects were presented in the array. The authors argued that the difference between the effect of misleading size information for displays with only two stimuli compared with more than two stimuli could be due to the fact that in the larger arrays, neither the FA or NA stimuli had the largest optical size on the first or last frame. The authors hypothesised that individuals may be more effective at using multiple optical cues when gauging smaller set sizes, thus misleading information has a greater effect compared with larger set sizes.

Oberfeld and Hecht (2008) conducted a study whereby participants were asked to gauge the TTP of an approaching car in the presence of either a late arriving or early arriving distracter truck, placed in the adjacent lane. The aim of the study was to assess the effect of the irrelevant distracter vehicle on TTP judgements for the target vehicle. The authors found evidence for a contrast effect, where a late arriving distracter caused an underestimation of the TTP of the target vehicle. While the authors were unable to provide adequate explanation for this finding, they argued that the study demonstrated that individuals are unable to ignore irrelevant distracter motion when making TTP judgements. Baurès et al. (2010) carried out a study whereby participants were asked to decide when each of two simultaneously laterally moving objects would reach a target point. The study provided evidence for proactive interference, whereby judgements for the first arriving object were not affected, but judgements for the second arriving object were systematically delayed. The authors argued that the results demonstrated the importance of perceived order of arrival. The studies by Baurès et al. (2010) and DeLucia and Novak (1997) could relate to pull out judgements as vehicles that are judged to be further away from the observer (smaller optical size), even if travelling faster, may be perceived with lower priority.

With regards to a pull out judgement or other road manoeuvres, additional motion may not only occur within the scene. There are a number of scenarios whereby the driver themselves may be in motion when making a decision. For example, in the UK there are a number of "give way" junctions, where individuals are not obliged to stop if they deem entry to the traffic stream safe. Optic flow refers to the changing of the retinal image due to self-motion, but the separation of motion within the scene and optic flow motion is not straight forward. Rushton, Bradshaw and Warren (2007) provided evidence for "flow parsing", whereby individuals subtract retinal motion using optic flow detectors and attribute any remaining motion to objects within the scene. Further, Geri, Gray and Grutzmacher (2010) conducted a study which aimed to investigate the effects of simulated forward motion on TTP estimates. The authors asked participants to press a button when they believed that they would collide with an illuminated circle and demonstrated that simulated forwarded observer motion decreased TTP estimates. Further, the authors noted that this effect increased with the speed of the observer motion and object motion. Wann et al. (2011) investigated the effects of looming detection during the lateral displacement of a target vehicle. The authors noted a detriment in performance in this condition, compared with the initial looming within the foveal field condition, thus suggesting that lateral displacement may be a mediating factor in the detection of looming objects.

While the above research has assessed individuals' abilities to judge the looming of objects in the presence of additional scenic motion, no research has attempted to gauge the ability of individuals to detect looming motion within road scenes where there are additional vehicles and objects present. Further, aside from the study by Wann et al. (2011), there has been very little research into the ability of individuals to detect the onset of visual looming during simulated self-motion. These two investigations will form central themes for the current thesis.

1.14 Conspicuity

Physical conspicuity refers to the degree to which an object can be distinguished from its environment (Hancock et al., 1990). While not an explicit focus for the current thesis, the issue of conspicuity is one of the most researched within the area of road safety research (e.g. Hancock et al., 1990; Mundutéguy & Ragot-Court, 2011) and is one of the most modifiable factors associated with motorcycle accidents (Lin & Kraus, 2009). However, the issue has been noted as extremely complex and studies have yielded mixed results (Crundall et al. 2008a). Hole, Tyrrel and Langham (1996) conducted a study on the conspicuity of motorcyclists and manipulated a number of factors including the clothing worn, the use of headlights, the distance from the observer viewpoint and the environment. The study displayed a number of still images to participants, who were asked to decide whether a motorcycle was present within the scene or not. The results were generally mixed and the authors noted complex interactions between the motorcyclist and the scene. For example, dark clothing was superior for detecting the presence of a motorcycle, but only in semi-rural environments. The authors warned that considering conspicuity factors in isolation can lead to false impressions. However, the authors did note that the contrast between the motorcyclist, motorcycle and the environment may be a key factor in conspicuity. It is worth noting however that participants were cued to search for a motorcycle within the scene, thus the findings may not map onto real life LBFTS errors. Despite these mixed findings, a review paper by Lin and Kraus (2009) noted that drivers who wore reflective or fluorescent clothing had a 37% lower risk of motorcycle collision related injury. While conspicuity research has often proved to be inconclusive, the effect of conspicuity aids on looming detection has not been investigated and this will provide a small section of focus within the current thesis.

1.15 Aims

The primary focus of this research is the investigation of the perceptual skills that underlie the ability of drivers to pull out of a junction safely in the presence of an approaching motorcycle. This focus can be broadly segregated into the ability of drivers to detect the approach of an oncoming motorcycle and their subsequent ability to correctly judge its speed.

Eight experiments will be conducted in order to examine the perceptual skills involved in judging the approach of motorcycles. These experiments will advance from assessing drivers' abilities to judge the speed of travel of motor vehicles in a basic virtual display through to assessing detection abilities within a complex, contextually rich virtual city environment. All of the experiments will take place within a laboratory setting.

In Chapter 2, the methodologies utilised within visual looming research will be discussed. This will involve assessing the different methods available for stimulus presentation, including in-field observations, static imagery, video footage and virtual reality displays. The strengths and limitations of each will then be discussed. Further discussion points will include the types of methodologies, including relative and prediction motion tasks as well as the sequential and simultaneous presentation of stimuli.

Chapter 3 will involve assessing driver ability to judge the speed under reduced perceptual conditions. This will involve displays that feature solid white circles, arranged to represent headlights on different motor vehicles, approaching the observer on a black background. The subsequent results will be compared with judgements of speed of approach for photographic vehicle stimuli on a mosaic tarmac background. The chapter will also investigate driver sensitivity to visual looming along the horizontal and vertical axes and will discuss engineering interventions that could improve speed judgement performance.

Chapter 4 will involve assessing speed judgements in a more contextually rich virtual environment, where photographic vehicle stimuli will approach the participant viewpoint. This chapter will build on the findings of Chapter 3 by introducing the availability of other cues including height in the scene and occlusion, while also increasing the realism of the scene. The chapter will also aim to assess whether ambient light levels within the virtual scene mediate speed judgements for cars and motorcycles.

Chapter 5 will shift focus to the initial requirement for judging vehicle approach by assessing the estimation of detecting a looming object in a scene. This will be achieved by measuring the ability of drivers to detect an approaching motor vehicle within a contextually rich virtual road scene. The chapter will once again use photographic vehicle stimuli and manipulate the extent to which the vehicles loom optically towards the observer viewpoint, in order to investigate whether there is a difference in the thresholds for detection between a car and a motorcycle. The chapter will further this finding by introducing additional object motion within the scene in order to assess whether these factors mediate judgements. Chapter 6 will attempt to discern the effects of additional object motion by investigating the effects of peripheral and foveal motion in turn.

Chapter 6 will assess the thresholds for the detection of approaching motor vehicles for drivers during simulated lateral self-motion. There are a number of scenarios when driving whereby individuals find themselves needing to detect the approach of oncoming vehicles when moving themselves. This chapter is designed to further investigate whether self-motion mediates detection capabilities. Chapter 7 will feature motorcycles wearing fluorescent vests and assess whether the inclusion of this safety garment can aid the detection of an approaching motorcycle within a virtual scene.

Chapter 8 will feature a discussion on the results from the above studies, ideas that could further this research and potential implications and interventions for motorcycle safety.

Chapter 2- Methods

2.1 Introduction

A number of methodologies have been utilised in order to investigate judgements related to time to passage (TTP) and the visual looming of an object towards an observer's viewpoint. This chapter will first discuss three paradigms within this literature. These are absolute and relative discrimination judgement paradigms, and the detection paradigm. The discussion will then progress onto addressing different methods and media that have been used within these paradigms, including naturalistic study, static image displays, video footage and virtual reality displays. Finally, general methods common across all experimental chapters will be detailed.

2.2 Paradigms

2.2.1 Absolute and Relative Judgements

Absolute judgements of TTP involve the participant making a decision about when they believe an object will reach a predefined point or area. One of the most widely utilised experimental paradigms within this subset of judgements is the prediction motion design (Andersen et al., 1999; Andersen & Enrique, 2006; Cavello & Laurent, 1988; Kim, Turvey & Carello, 1993; Schiff & Detwiler, 1979). This entails presenting a moving stimulus to a participant for a set period of time, before occluding or removing the stimulus at a given TTP. Participants are then asked to indicate when they believe that the object would have collided with or passed by the predetermined area, by pressing a button. The discrepancy between the actual TTP and the TTP indicated by the participant is then calculated. Research has used this methodology to demonstrate that TTP is generally underestimated and that this underestimation increases with actual TTP values (Tresilian, 1995). Additionally, prediction motion studies generally demonstrate that the standard deviation of TTP estimates is nearly 50% (Tresilian, 1995). Relative discrimination judgements of TTP typically involve participants making a judgement regarding which object within an array will reach or pass a predetermined point first (Baurès et al. 2010, DeLucia et al., 1991; 2003; 2004; 2008; DeLucia & Novak, 1997; Field & Wann, 2005, Hosking & Crassini, 2011). This involves presenting the objects for a predetermined period of time before they disappear and the participant is asked to make the judgement.

Regan and Hamstra (1993) utilised a relative discrimination paradigm in order to investigate participant use of the instantaneous angular size of an object divided by the rate of increase of this angular size when judging object approach. The authors asked participants to decide whether a target object would arrive sooner or later than the mean average of a sequentially presented array. The authors reported a high level of accuracy for rectangles that approached and then disappeared with a TTP of between one and four seconds. More specifically, the study noted discrimination thresholds between 7-13%. Tresilian (1995) calculated that this high level of discrimination translated to a temporal discrimination time of between 280 and 520 ms. Similarly, Todd (1981) reported extremely high levels of accuracy for simultaneously approaching objects, where participants responses were over 90% accurate for differences in TTP as little as 150 ms. Furthermore, the author noted that the level of performance did not reach chance until the difference between the TTP for each object was 10 ms. These two studies demonstrate a high level of accuracy for relative discrimination tasks, both when the presentation of stimuli is sequential (Regan and Hamstra, 1993) and simultaneous (Todd, 1981). Tresilian (1995) noted however, that relative discrimination tasks often yield higher levels of participant accuracy than prediction motion experiments. While Regan and Hamstra (1993) and Todd (1981) noted temporal discrimination levels between 150 and 520 ms, the prediction motion task used by Schiff and Detwiler (1979), where objects disappeared with a TTP of four seconds recorded a standard deviation of 1.8 s. Researchers have therefore asked why there is a difference in levels of performance.

The main difference between the absolute and relative discrimination TTP paradigms is that absolute judgements such as the prediction motion design rely on an individual's perception of time, while this is not a factor needed for relative discrimination judgements. More specifically, DeLucia (In Press) has stated that the information provided from the display during a prediction motion task is not available at the time that individuals make judgements. Tresilian (1997) argued that the actual decision making action (e.g. press of a button) often occurs a long time after the object of concern had disappeared. The author proposed that individuals may be making use of a cognitive “clocking” mechanism, which they use to “count” the amount of time that the object is displayed for and then “count” the amount of time before a button press should be executed. Relative discrimination judgements however, do not feature this temporal element. Judgements are made during the stimulus presentation or immediately afterwards.

It is worth noting that while relative discrimination paradigms often yield more accurate results than prediction motion studies, they are not without methodological issues. When measuring individuals’ sensitivity to relative rates of looming, there is always a trade-off between matching the start and final optical size of the two objects. Research has demonstrated that differences in final optical size can bias perceptual judgements and alternative suggestions also yield problematic biases (DeLucia, 1991). For example, shortening the presentation time of the faster moving vehicle or randomising the start distance could lead to a reliance on presentation time and the use of final optical size as cues. However, in a series of experiments conducted by Regan and Hamstra (1993), the authors noted that the participants were able to ignore trial to trial variations in start size when making TTP judgements, thus suggesting that in the trade-off mentioned above, final optical size might be more important to control. Additionally, start size is the one variable that is overwritten as soon as the initial frame of the presentation has passed, thus it might be the less salient of the variables available.

Researchers have also mentioned the importance of feedback in relative discrimination paradigms. Tresilian (1995) argued that the human perceptual system will use whatever information is available in order to achieve a satisfactory result. For example, Law et al. (1993) noted that in a relative discrimination task, featuring transversing stimuli, individuals opted to use a “closest first” strategy, when asked to judge which of two objects (a “0” or a “1) would reach a given target point first. Specifically, in the 50% of trials where the closest object arrived first, participants made correct judgements in 94% of trials. Conversely, in the 50% of trials where the closest object arrived second, participants made correct judgements for only 32% of trials. Tresilian (1995) noted however, that participants were not provided with feedback in this experiment and thus that providing feedback on performance may have encouraged participants to use TTP information, opposed to the “closest first” strategy. This concept of providing feedback during practice trials will be used within the current thesis.

As previously noted, relative discrimination judgement research has utilised simultaneous presentation paradigms, whereby participants are asked to indicate which of a number of approaching objects will arrive at a predetermined point first (e.g. DeLucia et al., 1991; 2003; 2004; 2008; Oberfeld & Hecht, 2008; Todd, 1981) and sequential presentation paradigms (e.g. Regan & Hamstra, 1993). However, no direct comparison between participant speed discrimination thresholds for the two presentations has taken place. In terms of making road pull out judgement, a sequential stimulus presentation may be more akin to real life, as drivers are often required to look down the road and view a number of vehicles sequentially before making a decision. Chapter 3 will directly address the accuracy of speed judgements for simultaneous and sequential stimulus presentation paradigms.

2.2.2 Looming Detection Paradigm

As mentioned in Chapter 1, one of the first indicators when making assessments about an approaching object is detecting whether the object is approaching. Regan and Hamstra (1993) claimed to be the first authors to report speed discrimination thresholds for visual looming, through their relative discrimination paradigm. The authors asked participants to judge whether an indicated target stimulus would reach them before or after the mean average of the series of trials. The authors recorded discrimination thresholds of 0.070-0.13 for instantaneous angular size divided by the rate of increase in angular size ($\theta/\dot{\theta}$). Hoffman (1994) carried out post-hoc calculations of thresholds for the detection of visual looming in a study which focused on the ability of participants to gauge the TTP of an approach vehicle. However, some researchers have utilised a looming detection paradigm that involves the participant making a judgement about whether a stimulus moved towards their viewpoint across a number of trials (Purcell et al., 2012; Wann et al., 2011). Wann et al. (2011) and Purcell et al. (2012) utilised a psychophysical staircase procedure that involved manipulating the rate of expansion of an object in order to determine participant threshold for the detection of looming for that object. Wann et al. (2011) presented a photographic car, which approached the observer viewpoint. The TTP of the vehicle was fixed at five seconds for each trial, however the starting angular size was manipulated based on the participant response in the previous trial. For example, if a participant correctly judged a vehicle as looming towards them, the procedure would decrease the starting angular size for the next trial. Conversely, if the participant did not detect a looming vehicle approach, then the procedure would increase the starting angular size for the next trial. This allowed the researchers to calculate the participant thresholds for the detection of an approaching car, in both foveal and extrafoveal regions. Purcell et al. (2012) also utilised this methodology, but instead of placing the photographic vehicle in a photographic road scene, the study featured a mosaic road scene background. Purcell et al. (2012) opted to use this tessellated background as it allowed the use of the same colours and contrast levels as a road scene, but did not provide any relative distance cues.

As mentioned in Chapter 1, the threshold for the detection of looming is a crucial early stage in the judging of vehicle approach and as such will be utilised in chapters 5, 6 and 7 in order to investigate the differences in looming detection thresholds for cars and motorcycles.

2.3 Methods and Media

A number of media have been used within TTP research, including naturalistic, static imagery, video footage and virtual reality.

2.3.1 Naturalistic Study

Research has sometimes focused on the ability of individuals to judge TTP within a naturalistic environment (Castro et al. 2005, Cavallo & Laurent, 1988). Naturalistic studies can provide high levels of ecological validity, as experimenters are able to measure how individuals behave in a real-life setting. However, such studies are often expensive and logistically challenging, particularly in the field of driving research, and it can be difficult to locate suitable track resources. Additionally, naturalistic studies can suffer from a degree of lack of control. For example, when carrying out a TTP task whereby the TTP of a motorcycle might need to vary between some extremes, it might be very difficult for a motorcyclist to ensure that they accurately reproduce the relevant TTP on every trial. Thus for the present set of studies, the naturalistic approach will not be used.

2.4.2 Static Imagery Presentation

A large section of road traffic research has utilised sets of static imagery (Cavallo & Pinto, 2011; Crundall et al., 2008b; 2010; Gershon, Ben-Asher & Shinar, 2012; Hole & Tyrrel, 1995; Hole, Tyrrel & Langham, 1996; Rößger, Hagen, Krzywinski & Schlag, 2012a). As mentioned in Chapter 1, Crundall and colleagues (2008b) have often used this methodology in order to assess drivers' abilities to detect the presence of a motorcycle within a number of photographic road scenes. However, researchers have argued that dynamic imagery should be used in search conspicuity research (Gershon, Ben-Asher & Shinar, 2012) and static imagery is not suited to the purposes of this thesis for a number of reasons. Firstly, static images arguably present a simplified version of the view that a driver has at a junction due to the lack of movement. Secondly, the lack of movement of vehicles within the scene means that speed judgements and detection of motion cannot be measured. Lastly, the lack of motion means that factors such as the size-arrival effect are not taken into consideration (Horswill et al. 2005), as research has demonstrated that dynamic stimuli are needed for this to occur (Crundall et al., 2008b).

2.4.3 Video Footage Presentation

Some studies have opted to use video footage in order to assess TTP factors (Horswill et al., 2005; Schiff & Detwiler, 1979). Horswill et al. (2005) used video footage to assess the effect of vehicle size on TTP estimates using a prediction motion paradigm. The use of video footage allows researchers to present a situation whereby a high level of realism is achieved within the presentation. In contrast it has been argued that virtual reality studies lack this factor due to the difficulty in presenting such a high level of detail through computer image generation (Manser & Hancock, 1996). However, while video footage does not suffer from the same lack of control as naturalistic studies, the measurements recorded are not always as fine-tuned as possible. For example, in the study by Horswill et al. (2005), the authors could only utilise a method of limits design, whereby the vehicle speeds were set to either 30 mph or 40 mph. While the authors were able to note that the TTP of smaller vehicles was later than larger vehicles, despite them travelling at the same speed, the study was unable to assess whether this pattern would vary across a number of different speeds and perhaps assess at which speed the difference in TTP estimates was greatest.

2.4.4 Virtual Reality Presentation

Virtual reality presentations have been utilised within TTP research for a number of years, implemented in both psychophysical designs (Beverley & Regan, 1980; DeLucia et al., 2003; Geri, Gray & Grutzmacher, 2010; Rushton & Wann, 1999, Todd, 1981) and driving simulation research (e.g. Konstantopoulos, Chapman & Crundall, 2010). While Manser & Hancock (1996) argued that the level of detail present within a real life scene is difficult to reproduce in a virtual scene, virtual reality holds several advantages over other methods. The main advantage is the amount of control that can be exercised over manipulations. While some studies opt to use a method of limits design, psychophysical staircase procedures such as parameter estimation by sequential testing can be implemented within a virtual reality environment (e.g. Beverley & Regan, 1980). The advantage of this method is that the researcher is able to accurately assess precise participant thresholds. For example, the Best-PEST (Lieberman & Pentland, 1982) utilises the maximum likelihood estimation of an independent variable that will produce the maximum level of information about the position of the participant threshold based on previous responses. This subsequently results in the best parameter estimation possible (Liberman & Pentland, 1982). For example, in the case of a relative speed discrimination judgement, the procedure would begin with a simple comparison between two different vehicles approaching at noticeably different speeds. After the participant has indicated which vehicle is travelling at the greater speed, each subsequent step of the PEST procedure would be determined by the maximum likelihood estimate of all of the previous correct and incorrect responses. The threshold is then calculated by averaging the last four reversals of the series. This provides a threshold below which participants cannot differentiate between the two different speeds of the approaching vehicles. This method allows researchers to assess precisely where participant thresholds lie and make subsequent suggestions regarding the implications of these thresholds. For example, Wann et al. (2011) were able to measure precise thresholds for looming detection, and determine that young children (5-9 years old) children are less able to detect vehicles approaching at speeds of over 20 mph under certain viewing conditions. Furthermore, the criticism of lack of detail in virtual reality media offered by Manser and Hancock (1996) has largely been addressed due to advances in computer modelling and graphics. However, it is still a valid consideration and the road scenes produced need to be contextually rich; this is a particular issue in chapter 7 where simulated self-motion will be manipulated (DeLucia, In Press).

2.5 General Methods

2.5.1 Participants

All participants were recruited from the Psychology Department at Royal Holloway, University of London. All of the participants had normal or corrected to normal vision, held valid EU driving licenses and were naive to the purpose of the studies. None of the participants held motorcycle licenses. All of the studies were approved by the Psychology Department ethics committee and all participants completed informed consent forms prior to taking part in the experiment.

2.5.2 Apparatus

All stimuli were presented on a 34 x 27 cm Cathode Ray Tube monitor (1024 x 768 pixels). All simulations were scripted in Python and used Vizard 3D simulation tool (Worldviz, USA). The Vizard libraries sit on top of OpenSceneGraph and provide the ability to render highly realistic 3D simulations that are perspective correct and run at the maximum screen refresh rate (60 Hz). The rendering hardware was an Intel dual core CPU with NVidia high performance GPU running under Windows XP. The simulation code used a 60 Hz timer-loop, which ensured that the correct vehicle size and rate of expansion was presented for every frame of each trial. Participants viewed the stimuli under bi-ocular conditions in a dimly lit university laboratory. Participants were seated one metre away from the screen in all experiments and viewed all stimuli binocularly.

2.5.3 Experimental Design

All of the experiments within the present thesis utilised the Best-PEST (Lieberman & Pentland, 1982) psychophysical staircase procedure. The Best-Pest procedure undertakes a series of steps towards the threshold estimate for an individual based upon a probability estimate given certain assumptions, such as the shape of the distribution. On the initial trials this requires a very crude estimate of variance, but this is unimportant as the shape of the distribution evolves as the trials progress. The mathematical procedure is well established and is described elegantly and in detail with sample distribution plots in Zuberbühler (2002, retrieved from http://www.psychophysics.ethz.ch/Downloads/RapEval.pdf). The software calculator developed by Zuberbuhler was not used in the thesis, but a programmed equivalent mathematical operations into Python was used to yield equivalent downward descent as shown in Zuberbuhler (2002, p16, Figure 5). Within this there is a decision that needs to be made as to how many reversals you allow before terminating a series. In principle, the larger the number of reversals the series should converge to the true threshold, but in practice the longer the series the more frustrated the participants becomes when they get to the stage at which they feel they are unable to tell the difference between stimuli. For this reason the number of reversals for the speed discrimination tasks in Chapters 3 and 4 were set to seven, with the threshold calculated as an average of the last four reversals. For the detection tasks (Chapters 5-7), however, the number of reversals was set to ten. The reason for the difference is that in the discrimination task there were two sequential stimuli of 500ms duration that were compared and this makes it easier to converge on the threshold and stay close to it on trials where the two stimuli are very similar. In the discrimination task the stimuli were solo events of either 500ms or 750ms duration. The combination of these brief presentation durations without a direct comparator meant that it sometimes took longer for the series to settle to a steady threshold, because there was a higher incidence of occasional errors above threshold in the early stages. Additionally, participants reported higher levels of difficulty associated with the detection task compared with the speed discrimination task in pilot testing, which might partly have been due to the small size of the target stimulus as participant performance approached threshold. In the speed discrimination task however, the final optical size of the stimuli remained constant, meaning that this was not an issue. The PEST interval value for each trial equated was determined by the maximum stimulus level minus the minimum stimulus level divided by 1000 increments. In all of the experimental chapters, the presentation of stimuli and the different staircase procedures associated with each were interleaved.

All of the stimuli were presented for a period of 500ms in each experiment, although this was increased in chapter 5 in order to assess the effect of increasing display duration to 750ms on performance in a looming detection task (See Section 5.1 for further information). None of the experiments featured a time pressure element, but participants were encouraged to respond as quickly as possible without sacrificing accuracy. All chapters featured photographic images of a target car and a target motorcycle, with dimensions of 1.75 x 1.75m and 1.75 x 0.75m respectively. All studies presented participants with stimuli that had a fixed TTP of four seconds, based on the evidence forwarded by Seward, Ashmead and Bodenheimer (2007) that longer values led to less accurate judgements of TTP in both absolute and relative judgement tasks. This TTP value also has an applied element, as research has intimated that four seconds is enough time to execute a pull out manoeuvre (Horswill et al., 2005). Lastly, all studies featured practice trials where participants were provided with feedback on their judgements.

Chapter 3 - Judging Vehicle Speed in Night-time Conditions

3.1 Introduction

When a driver is waiting to pull out of a junction, they need to judge the time to passage (TTP) of vehicles on the main carriageway in order to assess whether there is sufficient time to manoeuvre and join the line of traffic[1]. As discussed in Chapter 1, the most reliable cue to distance for an approaching vehicle is its optic size on the retina, $\theta(t)$, while the rate of change of optic size, $\dot{\theta}(t)$, is correlated with the speed of approach; thus the ratio of the two can indicate TTP without the requirement to calculate the metric distance, *z(t),* speed, *v(t)* or vehicle size (Lee, 1976).

$$TTP = \frac{z(t)}{v(t)} = \frac{\theta(t)}{\dot{\theta}(t)} \tag{3.1}$$

Further, a problem arises with equation 1, however, because the rate of expansion (looming: $\dot{\theta}(t)$) is dependent on vehicle size (*S*), as seen in equation 2 below:

$$\dot{\theta}(t) = \frac{S\,v(t)}{z^2(t)} \tag{3.2}$$

[1] When making a right turn in the UK, drivers are required to cross a line of traffic before being able to successfully join the flow of traffic on a major road. The same situation also arises when a driver is attempting to turn right across a main road and enter a minor road.

In terms of vehicle speed judgements, this problem means that larger vehicles will loom to a greater extent than smaller vehicles. Specifically, these smaller vehicles could in fact be travelling at a faster speed than a larger object and still be perceived as approaching at a slower speed. If the relative adjustment for object size proposed by Lee (1976) is made, then this should not be an issue. However, a problem can occur if $\dot{\theta}(t)$ drops below the threshold for visual detection. In this instance, the TTP of the vehicle in question tends towards infinity and will be seen as small and static in the visual scene, leading to a misperception of speed.

Research has supported the assertion that visual looming can lead to the underestimation of speed for smaller objects if the observer does not compensate for relative object size (DeLucia & Novak, 1997; Delucia et al., 2003). More specifically, in a study involving the use of video footage of approaching vehicles, Horswill et al. (2005) noted a decreasing linear trend of TTP estimates for vehicle size across the motor vehicles tested (small motorcycle, large motorcycle, car and van). The results demonstrated that as vehicle size increased, TTP judgements decreased. This effect was also present in a study by Caird and Hancock (1994) who demonstrated a decrease in the accuracy of TTP judgements across a full-size car, a compact car and a motorcycle. The two studies demonstrated less accurate TTP judgements for smaller vehicles, which might result in unsafe pull out decisions. However, it is worth noting that the vertical profile of a motorcycle and its rider is often equivalent to or greater than that of a full-size car; indicating that perhaps individuals are more sensitive to detecting looming along the horizontal compared with the vertical axis.

While it is clear that vehicle profile can bias speed TTP judgements in daytime conditions, there has been relatively little research conducted into judging vehicle speed in night-time conditions, where only very basic perceptual information is available to the observer. It may be possible that night-time conditions increase the problem observed in Equation 3.2. As mentioned in chapter 1, when observing a road scene in a poorly lit area, often the only vehicular information available to the individual is gleaned from headlights. In terms of motorcycles, this information usually consists of one headlight with a diameter of ~20cm. While cars have a similar diameter of headlight, they have two such lights which are separated by a gap of approximately 1.6m; this separation is another potential source of optical information in gauging the TTP of a car at night. Tresilian (1991) proposed that TTP could be calculated from the divergence of two features, using a method equivalent to Equation 3.1, with θ defined by the optical gap between the two closed contour edges. Applied research has supported this notion, as evidence has shown that while the distance of a vehicle from an observer is underestimated at short (60-240m) and long (620-870m) and overestimated at medium distances (320-510m), a greater separation distance between vehicle headlights can improve these distance judgements (Castro et al., 2005). However, at a cortical level, this is not a straightforward issue as a closed illuminated contour provides a strong and direct percept for most animals (e.g. Sun & Frost, 1998) and is responded to in equivalent sub-cortical areas in human beings (Billington et al., 2010). There is no equivalent evidence that the human neural system responds in a direct manner to the separation of two features, despite everyday experience suggesting that there could be an advantage to a vehicle including two headlights opposed to one. If headlight separation can act as a cue to TTP, it also seems plausible that the introduction of a multiple headlight configuration onto a standard motorcycle frame could improve speed judgements in night-time conditions.

In terms of a junction pull out scenario, the presentation of vehicles usually occurs in a sequential manner, whereby one vehicle is viewed as approaching and passing, before another is viewed. However, there are other instances in road traffic scenarios where vehicles may be viewed simultaneously; e.g. merging from a slip-road onto a dual-carriageway. It is for this reason that Experiment 1 also aims to address whether individuals are more accurate in making speed judgements in a sequential presentation paradigm compared with a simultaneous presentation paradigm. As far as the author is aware, there has not been a study that has compared the two presentation types, thus this investigation is exploratory in nature. However, Oberfeld and Hecht (2008) provided evidence that an additional approaching vehicle can affect TTP judgements for a target vehicle. Thus, it may be possible that participant performance is impaired by the presence of simultaneously displayed vehicles, due to the need to divide their fixations between two areas of interest.

The aim of Chapter 3 is to assess how accurately individuals are able to discriminate the speeds of motorcycles and cars in night-time conditions. In order to explore this, the study utilized computer generated simulations of different headlight configurations that approached the observer. The study hypothesized that individuals would judge the speed of the car stimulus with greater accuracy relative to the motorcycle stimulus due to the separation of its two headlights. A tri-headlight formation that could be mounted on a standard motorcycle frame was also included in the stimulus set to assess whether it could improve speed judgements compared to the single headlight typical found on the front of motorcycles.

3.2 Method

3.2.1 Participants

A sample of 13 participants, six male and seven female, with an age range from 21-44 years and an average age of 28 years (S.D 8.02) was recruited. The average number of years that drivers had held their licence was 10 years (SD 7).

3.2.2 Experimental Conditions and Design

The methodology utilized in this experiment was a discrimination paradigm that had been used in previous research (Todd, 1981; Field & Wann, 2005). The stimuli were presented in two different formats; sequential and simultaneous. In each condition, participants were asked to indicate which of the two vehicles (presented either simultaneously or sequentially) was approaching at the faster speed. The car stimulus was used as a reference vehicle in all trials, approaching the observation point at a fixed speed of 30mph (13.4ms). The probe vehicle was an identical car, a solo headlight motorcycle, or a tri-headlight motorcycle. The combinations of presentation were therefore; reference car versus probe car, reference car versus solo headlight motorcycle and reference car versus tri-headlight motorcycle. The order in which the reference and probe stimuli were presented and the screen position (left or right) of each stimulus was randomised in both the sequential and simultaneous trials. The speed of the probe vehicle was manipulated using a parameter estimation by sequential testing procedure (Best-PEST; Lieberman & Pentland, 1982), which as discussed in Chapter 2, calculates the optimal increment in speed for each trial based on the observer's previous responses in order to efficiently converge on their threshold performance. The PEST staircases were stopped after the seventh reversal and the threshold was calculated based on the mean average of the last four reversals. Using this procedure, the speed differences between the probe and reference vehicles ranged from -20mph to 180mph, with the looming rate of the vehicle adjusted accordingly. The dependant variable was the threshold speed at which participants were no longer able to discriminate between the speeds of the approaching probe and reference vehicle calculated from each of the conditions below.

3.1.2.1 Night-time Conditions

Three psychophysical staircases were run, one for each of the three headlight approach speed comparisons: two headlights (reference vehicle) versus two headlights (probe vehicle); two headlights (reference vehicle) versus one headlight (probe vehicle); two headlights (reference vehicle) versus a tri-headlight (probe vehicle). All of the main headlights utilized were 20cm in diameter, while the tri-headlight configuration also featured two 10cm diameter flanking lights, situated 30cm below and to the right and left of the main headlight. The car headlights were separated by a distance of 160cm, which was based on the real world separation of car headlights of ~160cm. See Figure 3.1 for images of the headlight configurations.

3.1.2.2 Daytime Conditions

Once again, three psychophysical staircases were run, one for each vehicle approach speed comparison. This condition featured three photographic stimuli; a solo headlight motorcycle, a tri-headlight motorcycle and a car. Once again the car served as the reference vehicle, with an identical car, the solo headlight motorcycle, and the tri-light motorcycle serving as the probe vehicle. The tri-headlight formation was configured in the same way as the stimulus presented in the night-time condition. The stimuli were presented on a mosaic tarmac background and approached the participant viewpoint. The mosaic background was used in order to present a similar colour scale to that encountered on the road, but without the additional cues available within a natural scene, as in Purcell et al., (2012). See Figure 3.2 for vehicle images presented in the daytime conditions.

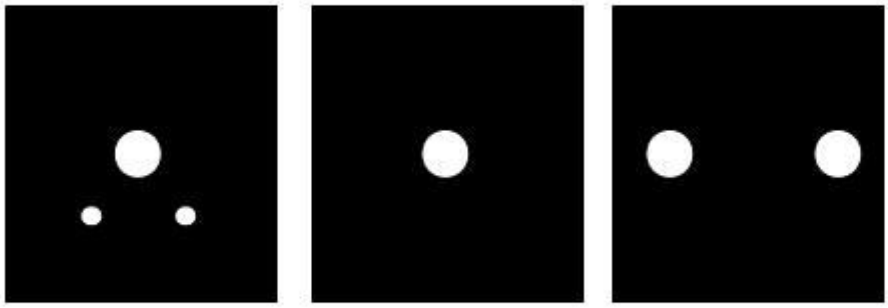

Figure 3.1: Night-time Headlight Stimuli

Figure 3.2: Daytime Vehicle Stimuli

3.1.3 Procedure

Participants sat two metres from the computer monitor, with an eye height of 1.2 metres, and viewed all of the presentations binocularly. Participants were given a small number of trials prior to each condition in order to verify their understanding of the procedure. A crosshair was displayed at the centre of the visual display for a period of 500ms. Participants were asked to focus on the crosshair. In the sequential stimuli trials, each stimulus was displayed alternately for 500ms with an inter-stimulus gap of 250ms. In the simultaneous presentation conditions, the stimuli were displayed at the same time for a period of 500ms. The location of the stimulus on the display (left or right) was randomised and all of the stimuli were presented with a TTP of four seconds. All of the main headlights were placed at the same vertical axis coordinates on the visual display.

After the second stimulus (sequential) or stimulus pair (simultaneous) had disappeared, participants were presented with two square boxes, one on the left and one on the right hand side of the display. Participants were asked to select which box corresponded to the side of the screen where they had observed the stimulus that they felt was travelling at the fastest speed. This was the case for both sequential and simultaneous trials.

The experimental design utilized was repeated measures and all of the participants were tested across all conditions. Counterbalancing was achieved by alternating the order of the three conditions for each participant.

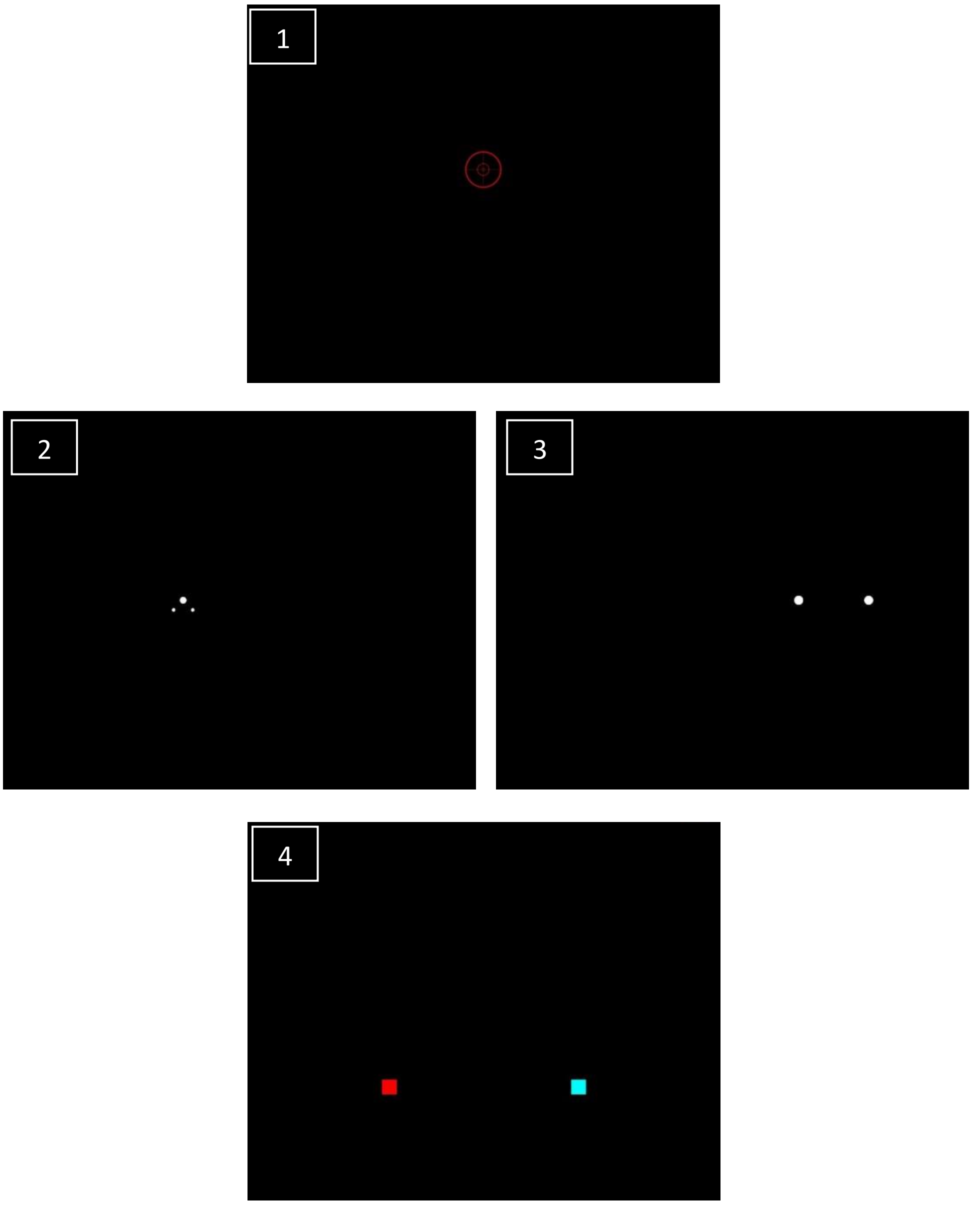

Figure 3.3: Screen shots of the sequential night-time condition. 1) Initial cross-hair presentation; 2) Tri-headlight stimulus approach; 3) Reference car stimulus approach; 4) Decision screen

Figure 3.4: Screen shots of the simultaneous day time condition. 1) Initial cross-hair presentation; 2) Solo headlight motorcycle and reference car stimuli approach; 3) Decision screen

3.3 Results

3.2.1 Night-time and Daytime Driving Conditions

A 2 x 2 x 3 repeated measures ANOVA (Presentation: sequential, simultaneous; Time of day: day, night; Vehicle: solo headlight motorcycle, tri-headlight motorcycle, car) demonstrated a significant main effect of presentation type ($F(1, 12) = 7.14$, $p < .05$, MSe = 411.10, $\eta p^{2} =$ .373) on participant thresholds for speed discrimination between the probe vehicles and the reference vehicle. Participants were more accurate in their judgements in the sequential stimulus conditions compared with the simultaneous stimulus conditions ($p < .05$, 95% CI: -15.751 to -1.604). There was a significant effect of time of day ($F(1, 12) = 34.16$, $p < .001$, MSe = 1434.90, $\eta p^{2} =$ .740), whereby participants were significantly more accurate at judging the speed of vehicles in the daytime conditions compared to the night-time condition ($p < .001$, 95% CI: -48.668 to -22.236). There was a significant effect of vehicle type ($F(1, 12) = 61.94$, $p < .001$, MSe = 1125.68, $\eta p^{2} =$ .838). Specifically, participants were more accurate at judging the speed of the probe car compared with both the probe tri-headlight ($p < .001$, 95% CI: -17.809 to -6.234) and probe solo headlight ($p < .001$, 95% CI: -91.368 to -45.777) motorcycles when all were viewed with the reference car. Participants were also significantly more accurate at judging the speed of the tri-headlight motorcycle compared with the solo headlight motorcycle ($p< .001$, 95% CI: -77.771 to 35.331). Lastly, there was a significant interaction between time of day and vehicle type ($F(1, 12) = 44.29$, $p < .001$, MSe = 1288.16, $\eta p^{2} =$ .787) and an interaction between time of day, vehicle type and presentation type ($F(1, 12) = 3.28$, $p < .05$, MSe = 383.03, $\eta p^{2} =$ .214). In order to present the data in a clear and concise format, separate ANOVAs have been carried out for the sequential and simultaneous stimulus presentation conditions respectively.

3.2.1.1 Sequential Stimulus Presentation

A two-way repeated measures ANOVA (Time of day: day, night; Vehicle: solo headlight motorcycle, tri-headlight motorcycle, car) revealed a significant main effect of time of day ($F(1,12) = 14.28$, $p < .005$, $MSe = 1337.16$, $\eta p^2 = .543$), and a main effect of vehicle type ($F(2, 24) = 30.94$, $p < .001$, $MSe = 863.01$, $\eta p^2 = .721$). Additionally, there was a significant interaction between time of day and vehicle type ($F(2, 24) = 20.80$, $p < .001$, $MSe = 1055.93$, $\eta p^2 = .634$).

In the daytime conditions, participants were significantly more accurate at judging the speed of the car compared with the solo headlight motorcycle ($t(12) = -3.16$, $p < .01$, 95% CI: −19.119 to 3.519), and the tri-headlight motorcycle ($t(12) = -2.52$, $p < .05$, 95% CI: −24.746 to −1.81). This shows there is a judgment error when motorcycles are presented with either a solo headlight or a tri-headlight configuration, and thus there seems to be very little safety benefit of the tri-headlight formation over the solo headlight in daytime conditions. Conversely, in the night-time condition, participants were not significantly more accurate at judging the speed of the car compared with the tri-headlight motorcycle ($t(12) = -1.74$. $p > .05$, 95% CI: −12.526 to 1.388), but were significantly more accurate at judging the speed of the car compared with the solo headlight motorcycle ($t(12) = -5.21$, $p < .001$, 95% CI: −153.059 to −62.767). In addition judgments of the tri-headlight motorcycle were more accurate compared with the solo headlight motorcycle ($t(12) = -5.21$, $p < .001$, 95% CI: −145.094 to −59.594). These results suggest that the tri-headlight formation improves speed judgments for motorcycles in night-time driving conditions to the same level of car speed judgments (data presented in Figure 3.6)

3.2.1.2 Simultaneous Stimulus Presentation

A two-way repeated measures ANOVA (Time of day: day, night; Vehicle: solo headlight motorcycle, tri-headlight motorcycle, car) revealed a significant main effect of time of day ($F(1,12) = 50.73$, $p < .001$, $MSe = 603.06$, $\eta p^2 = .809$), and a main effect of vehicle type ($F(2, 24) = 68.33$, $p < .001$, $MSe = 645.70$, $\eta p^{2\,=}$ .851). Additionally, there was a significant interaction between time of day and vehicle type ($F(2, 24) = 70.32$, $p < .001$, $MSe = 512.05$, $\eta p^{2\,=}$ .854).

Participant speed judgements were more accurate in the daytime condition compared with the night-time condition ($p < .001$, 95% CI: -51.725 to -27.492). In the daytime condition, participants were significantly more accurate at judging the speed of the car compared with the solo headlight motorcycle ($p < .05$, 95% CI: -26.608 to -3.426), and the tri-headlight motorcycle $p < .005$, 95% CI: -20.182 to -6.360). There was no significant difference between the solo headlight motorcycle and the tri-headlight motorcycle ($p > .05$, 95% CI: -9.133 to 12.624) In the night-time condition, participants were significantly more accurate at judging the speed of the car compared with the tri-headlight motorcycle ($p < .05$, 95% CI: -27.533 to -

.911). Additionally, participants were significantly more accurate at judging the speed of the car compared with the solo headlight motorcycle $p < .001$, 95% CI:-184.001 to -99.573). Speed thresholds for the tri-headlight motorcycle were more accurate compared with the solo headlight motorcycle ($p < .001$, 95% CI: -170.790 to -84.339). The data are presented in Figure 3.6, which includes standard error bars (N=13).

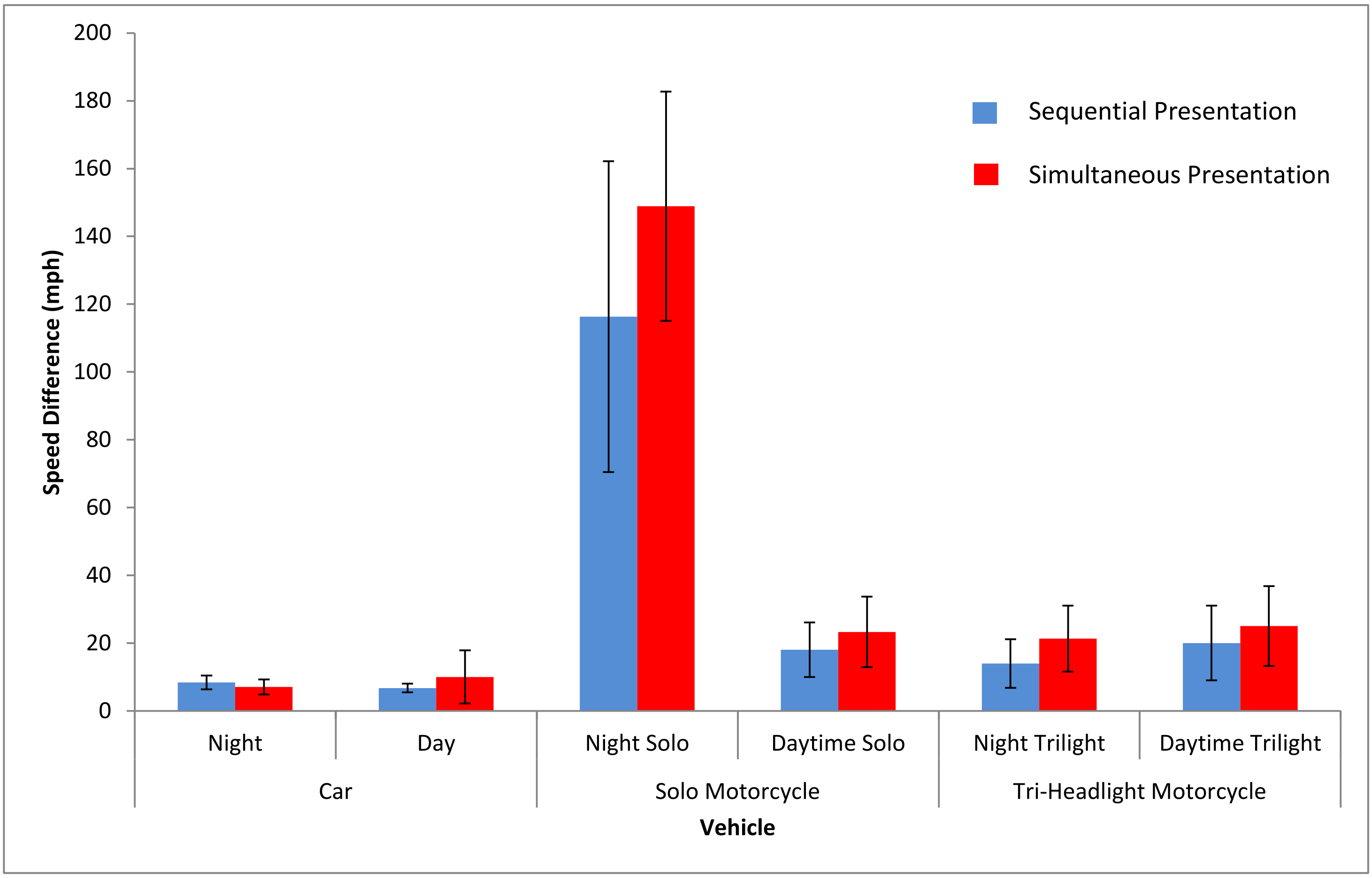

Figure 3.5: Speed difference thresholds for participants across different vehicle stimuli and times of day in the sequential and simultaneous presentation conditions.

3.4 Discussion

The purpose of the study was to examine how accurately individuals are able to gauge the approach speed of motor vehicles in night-time driving conditions, when only the basic perceptual information of headlights in the dark is available. Furthermore, the study examined how accurate individuals are at making these judgements in daytime conditions and whether the introduction of a tri-headlight configuration could be used to improve the accuracy of these judgements. On a methodological note, the study compared sequential stimulus presentation and simultaneous stimulus presentation paradigms.

The results demonstrated that individuals were more accurate at judging the speed of the car compared with both the solo and tri-headlight motorcycles in the daytime conditions. The demonstration of this linear relationship supports previous research (Caird & Hancock, 1994; Horswill et al., 2005). Additionally, the results demonstrated that individuals are extremely poor at judging the speed of the motorcycle when it was only represented by one headlight in night-time conditions. Specifically, in the sequential stimulus presentation condition, participants required a speed difference of 116mph on average before judging the motorcycle to be travelling faster than the reference car that was travelling at 30mph. The introduction of the tri-headlight configuration significantly improved the accuracy of speed judgements at night in both the sequential and simultaneous trials. Specifically, mean threshold judgements improved from a difference of ~116 mph for the solo headlight motorcycle to ~14 mph for the tri-headlight motorcycle in the sequential presentation condition. In the simultaneous condition, speed judgement thresholds improved from a difference of ~148mph for the solo headlight motorcycle to ~21mph for the tri-headlight motorcycle

The results of the methodological investigation provided evidence that participant speed judgements were more accurate in the sequential stimulus presentation trials compared with the simultaneous stimulus presentation trials. The difference between the findings for the two presentation conditions is likely to be explained by the need to deploy a shared sampling strategy in the simultaneous trials. Participants were unable to fixate on one stimulus at a time and then compare them as in the sequential trials, thus a drop-off sampling error may have occurred due to the weaker signal available for the judgement. However, it is not possible to provide a more concrete explanation for this as participant eye movements were not tracked in this experiment, thus I cannot be sure whether participants were time sharing or using peripheral vision during the simultaneous presentations. The sequential presentation however, is akin to a real world pull out manoeuvre, where vehicles are often viewed sequentially at a junction and a decision is then made on whether it is safe to pull out. While the present study did not feature a decision making element that is akin to a pull out judgement, the ability to judge the speed of an oncoming vehicle is a critical contributory factor to this decision.

The extent to which observers struggle to judge motorcycle approach speed based on the solo headlight is concerning. While some might argue that other sources of luminance are often present within a real-world scene (e.g. street lamps), the visible surfaces of a motorcycle and motorcyclist often do not have the same “polished” exterior as a car and thus do not reflect the same amount of ambient light towards the observer. Furthermore, many roads are poorly illuminated and often the only salient feature of an approaching motorcycle after dark is its headlight. In this context, the size of the errors that we observe could be critical. For example, an individual might require four seconds to successfully pull out into a lane of traffic in order to avoid colliding with a motorcycle that is travelling at 30mph. If the motorcycle is in fact travelling at 60mph, this individual only has two seconds to complete the manoeuvre and the risk of an accident occurring increases dramatically.

It could also be argued that drivers may have other depth cues available to them that allow the utilisation of relative distance in order to calculate TTP. However, these cues are not reliable indicators of TTP, as mentioned previously. The calculation of visual looming appears to be the only reliable source of information and this information can only be gathered from the optical expansion of the headlight in night-time conditions.

The present study demonstrated a substantial effect in terms of fitting a tri-headlight configuration to a standard motorcycle frame. This feature dramatically increased the accuracy of speed judgements. For the tri-headlight on average a speed difference of 14mph was required before participants were able to report that the motorcycle was travelling faster than the reference car (this was not statistically significantly different to the 8 mph difference required for the car-car comparison at night) in the sequential presentation condition. However, there was a significant difference between the average speed difference required to detect that the tri-headlight motorcycle was travelling faster than the car in the simultaneous condition.

3.5 Tri-Headlight Configurations

After the first set of experiments demonstrated a significant improvement in speed judgement thresholds between the solo headlight motorcycle and the tri-headlight motorcycle, an additional study investigated a number of different tri-headlight formations in order to examine whether individuals were more sensitive to looming along the vertical or horizontal axis. The accuracy of judgements in daytime conditions was also tested, where the natural contours of both vehicles were visible. Lastly, the study investigated the effects of sequential and simultaneous presentation; it was hypothesized that participant thresholds for speed discrimination would be poorer in the simultaneous presentation conditions compared with the sequential.

3.6 Method

The same group of participants, methodology and procedure as the first set of experiments was followed.

3.6.1 Experimental Conditions

This condition featured four different tri-headlight configurations, all of which were compared with the reference car headlights that were approaching at 30mph. All of the configurations featured a 20cm diameter main headlight and two 10cm diameter flanking lights. One of the tri-headlight configurations was the same as the stimulus presented in the night-time condition, while another was the inverse of this design (flanking lights above main light). The third configuration was a horizontal design, where the flanking lights were situated either side of the main headlight at a distance of 30cm (measured from the centre of the main headlight). The last configuration was a vertical design, which was the same as the above, but rotated 90 degrees. See Figure 3.3 for tri-headlight configuration stimuli.

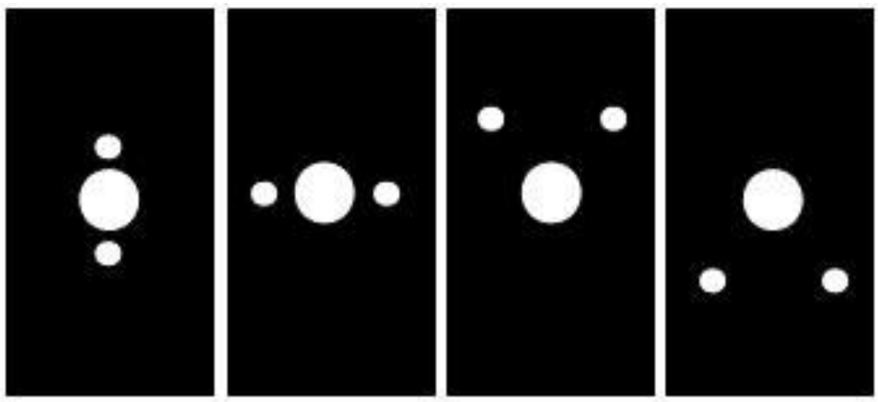

Figure 3.6: Tri-headlight Configurations

3.7 Results

A 2 x 4 repeated measures ANOVA (Presentation: sequential, simultaneous; *Tri-light configuration: triangular, inverse triangular, vertical, horizontal*) demonstrated a significant main effect of presentation ($F(1, 12) = 9.72$, $p < .05$, $\eta p^2 = .436$), whereby participants were significant more accurate at judging the speed of the vehicles in the sequential presentation compared with the simultaneous presentation ($p<.05$, 95% CI: -17.235 to -2.858). There was also a significant interaction between presentation type and type of tri-headlight configuration ($F(3, 36) = 5.32$, $p < .005$, $\eta p^2 = .307$.

3.7.1 Sequential Stimulus Presentation

A one-way repeated measures ANOVA (Tri-light configuration: triangular, inverse triangular, vertical, horizontal) revealed a significant main effect of tri-headlight configuration ($F(3,36) = 8.34$, $p < .005$, $\eta p^2 = .410$). Bonferroni pairwise comparisons demonstrated that there was no significant difference between the accuracy of speed judgements for the original, triangular tri-headlight formation and the inverse of this formation ($p > .05$, 95% CI: -12.823 to 8.429). However, participants were significantly more accurate at judging the speed of the original tri-headlight formation ($p < .05$, 95% CI: -35.892 to -1.182) and the inverse tri-headlight formation ($p < .005$, 95% CI: -27.692 to -4.988) compared with the vertical tri-headlight formation. Lastly, there were no significant differences in the accuracy speed judgements between the original tri-headlight ($p > .05$, 95% CI: -12.823 to 8.429), inverse tri-headlight ($p > .05$, 95% CI: -21.905 to 3.850) and horizontal tri-headlight formations. See Figure 3.8 for data on tri-headlight formations in night-time conditions.

3.7.2 Simultaneous Stimulus Presentation

A one-way repeated measures ANOVA (Tri-light configuration: triangular, inverse triangular, vertical, horizontal) revealed a significant main effect of tri-headlight configuration ($F(3,36) = 10.78$, $p < .005$, $\eta p^2 = .473$). Bonferroni pairwise comparisons demonstrated that there was no significant difference between the accuracy of speed judgements for the original, triangular tri-headlight formation and the inverse of this formation ($p > .05$, 95% CI: -15.772 to 8.817). Participants were significantly more accurate at judging the speed of the original tri-headlight formation ($p < .05$, 95% CI: -53.863 to -1.651) compared with the vertical tri-headlight formation. Participants were significantly more accurate at judging the speed of the original tri-headlight configuration compared with the horizontal headlight configuration ($p < .005$, 95% CI: -77.711 to -17.672). See Figure 3.7 for data on tri-headlight formations in night-time conditions which includes standard error bars (N=13). .

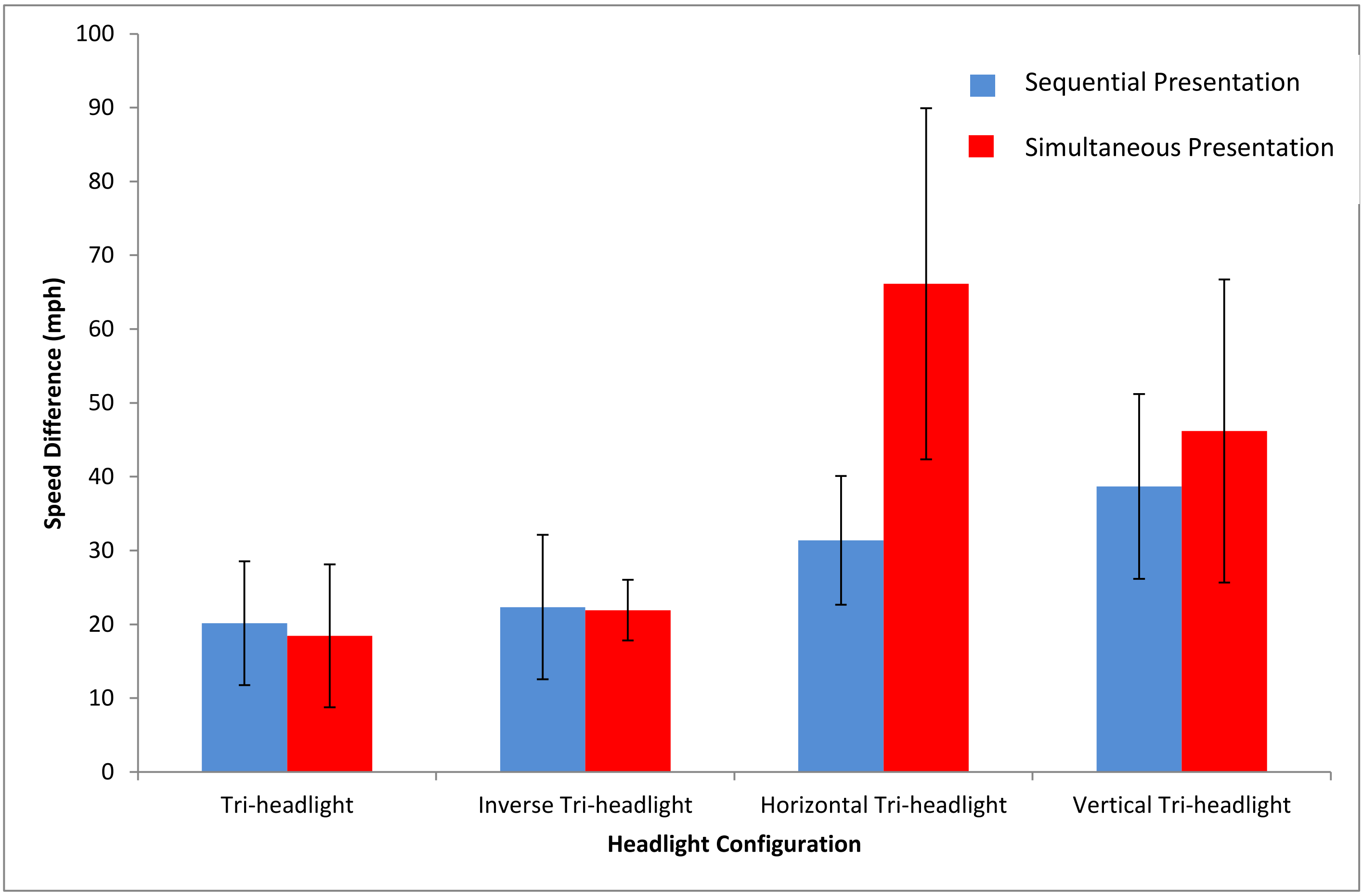

Figure 3.7: Speed difference thresholds for participants across different tri-headlight configurations in night-time driving conditions in the simultaneous and sequential presentation conditions.

3.8 Discussion

The present study furthered the idea of utilising a tri-headlight motorcycle design by exploring a number of different configurations. Overall, the two configurations that utilised lights that separated on both the horizontal and vertical axis yielded the most accurate judgements of speed. The removal of horizontal expansion, thus leaving lights that only separated on the vertical axis, yielded the least accurate judgements. This finding relates to the notion that appears evident in judging speeds in daytime conditions, whereby individuals seem to be more sensitive to looming along the horizontal axis compared with the vertical axis, thus making them more accurate at judging the speed of cars compared with motorcycles. However, the vertical separation does seem to provide some assistance when judging vehicle approach, evidenced by the finding that the horizontal tri-headlight formation was not as effective in improving the accuracy of speed judgements as the triangular headlight formations.

In addition to the benefits that this alternative lighting formation has on driver speed judgements, Rößger Hagen, Krzywinski & Schlag (2012a) demonstrated that the inclusion of a 'T' strip light formation on a standard motorcycle frame led to improved conspicuity compared with a standard solo headlight. It could therefore be possible that the inclusion of the tri-headlight formation presented in this study may also improve conspicuity by adding a "visual signature" to motorcycles, whereby motorcycles are instantly recognizable due to a novel and uniform characteristic, in addition to enhancing estimation of approach speed.

3.9 Summary

The introduction of the tri-headlight formation clearly has implications for motorcycle manufacturers in terms of enhancing safety features of powered two-wheel vehicles. For existing motorcycles with no facility to change the headlight configuration, motorcycle safety could be improved by making riders aware that other motorists have considerable difficulty judging their speed of approach in night-time conditions. The recommendation would be to stress the importance of sticking to the speed limit, as potentially car drivers could perceive motorcycles approaching above the speed limit as travelling at the same speed as cars travelling within the speed limit. There are clearly a number of improvements that can be made to increase motorcycle safety when driving at night, and while the dangers of riding a motorcycle at night might not always be a headline statistic, the perceptual factors observed here could play a part in reducing the number of casualties on the roads at all times of day. For example, the current study has demonstrated that while the problem is exacerbated at night, individuals are still inaccurate at judging the speed of motorcycles during the day. This issue is exacerbated when motorcyclists travel over the speed limit, so one idea might be to reduce motorcycle speeds through engineering or speed enforcement. Finally, in terms of methodology, participant judgements were more accurate in the sequential presentation trials and I have argued that this type of presentation is more akin to a real life pull-out manoeuvre. Therefore, the speed discrimination experiments in Chapters 4 and 5 will also use this presentation type.

Chapter 4 - Judging Vehicle Speed across Different Lighting Levels

4.1 Introduction

As demonstrated in Chapter 3, the misperception of vehicle approach speed may be a key contributory factor in road traffic crash involvement (Hurt et al. 1981; Pai, Hwang & Saleh, 2009; Peek-Asa and Kraus, 1996; Brenac et al., 2006; Department for Transport, 2010a). Furthermore, perceptual limitations in judgements of vehicle approach may be compounded in lower light conditions. Indeed, a disproportionate number of fatal injuries occur on the roads after dark (Pai et al. 2009; Plainis, Murray & Pallikaris, 2006). According to the Community database on Accidents on the Roads in Europe (CARE), while the number of drivers on the road during low level lighting conditions is far fewer than during daylight hours, statistics indicate that approximately 50% of all fatal accidents occur between the hours of 6pm and 6am (ERSO, 2008).

Although it is likely that there are a number of reasons for this high fatality rate (including fatigue and shift-work effects, and also lifestyle factors associated with young drivers driving after socialising), it seems plausible that the perceptual issues under investigation here also play a part. Research has provided a substantial amount of evidence to suggest that drivers are less capable of avoiding collisions under reduced lighting conditions compared with daylight conditions, and accidents involving pedestrians (Sullivan & Flanagan, 2002) and rear-end collisions with other motor vehicles (Sullivan & Flanagan, 2003) are particularly prevalent.

Consequently, there is little disagreement that driver vision in the dark is seriously impaired when compared with daylight conditions (Sullivan et al., 2004).

Chapter 3 demonstrated how a vehicle's optical size $\theta(t)$ divided by its rate of expansion $\dot{\theta}(t)$ can cause issues for smaller vehicles due to the relationship between rate of expansion and the size of the object; ultimately demonstrating that individuals were far less accurate in judging the speed of a solo headlight motorcycle, compared with two car headlights or a tri-headlight motorcycle formation (Gould, Poulter, Helman & Wann, 2012a). However, research on gauging vehicle approach has typically been conducted under optimal lighting conditions (Caird & Hancock, 1994; Horswill et al., 2005), with little consideration of how the accuracy of TTP estimates may be affected under lower luminance levels. It is likely that this problem will be exacerbated for motorcyclists as ambient light levels decrease, as the contours of the rider and vehicle can no longer be depicted.

In terms of the effect of lighting conditions on motion processing, past research has demonstrated that the processing of visual information under low luminance and contrast is much poorer than for brighter objects and that furthermore, individuals are extremely poor at judging the speed of objects under low lighting conditions (Gegenfurtner, Mayser & Sharpe, 1999; Plainis et al., 2006). As indicated in Chapter 1, researchers have provided evidence that this is primarily due to the reliance of the visual system on information provided by rod photoreceptors during low light level conditions, as opposed to the cone photoreceptors that are used during higher lighting levels. More specifically, motion perception using rods is seriously impaired, while spatial and temporal resolution also suffer (Hess, Sharpe & Nordby, 1990; Gegenfurtner et al., 1999).

Given the evidence that human processing of visual motion is degraded when luminance levels are reduced under strict psychophysical conditions, it is possible that judgements of approach speed are also affected in lower light conditions (Pai et al., 2009). Over the course of the year in the UK, motorcycle traffic volume is at its highest between the hours of 7-9am and 3-7pm, with the peak travel time evident between 4-6pm (Department for Transport, 2010b). While research has suggested that road accidents are less prevalent during the longer hours of the summer months (Sullivan and Flanagan, 2002), in mid-December the sun does not rise until 8am and sets before 4pm, thus creating a situation where motorcycles are likely to be travelling during dim light conditions. More specifically, in a mixed logit analysis of UK police reports on traffic collisions (Stats19), Pai et al. (2009) demonstrated that a higher than average number of accidents involving automobile drivers failing to give way to a motorcyclist occurred during dusk street lighting periods, in the evening and midnight/early morning periods of the day and during the autumn/winter months.

One potential countermeasure to improve sensitivity to motorcycle approach is the addition of extra motorcycle headlights. Previous research has demonstrated that a greater separation distance between headlights can lead to improved distance judgements when speed remains constant (Castro et al., 2005). Furthermore, Chapter 3 demonstrated that the introduction of a tri-headlight formation on a standard motorcycle frame, where the distance between the lights increases on both the horizontal and vertical axes during visual looming, can greatly improve the accuracy of speed judgements for motorcycles (Gould et al., 2012a). However Chapter 3 focused on comparing participant speed judgements for circular headlights on a black background, and also judgements for photographic motorcycles and cars on a mosaic tarmac background. Ambient light levels do not change from broad daylight to absolute night in one step, so this chapter looked at judgements of approach speed in a contextual virtual road scene, and investigated how judgements were affected as simulated lighting levels fell incrementally.

The aim of the present study was to determine the extent to which sensitivity to approach speed changes as luminance levels decrease and how speed judgements for motorcycles and cars might be differentially affected. The study utilised computer simulations of photographic images of a car, a solo headlight motorcycle, and a tri-headlight motorcycle approaching the observer viewpoint in a virtual city environment. These simulations took place across five different simulated ambient light level conditions, ranging from levels approximating broad daylight to night-time conditions. The study predicted that the accuracy of speed judgements for the car would be least affected across the reduced lighting conditions, but that the accuracy of judgements for the solo headlight motorcycle would decrease as the simulated light level was reduced. The study predicted that the motorcycle fitted with the tri-headlight formation would enjoy higher accuracy of speed judgements than the single-headlight motorcycle across all lighting conditions.

4.2 Method

4.2.1 Participants

A sample of 14 participants, 8 male and 6 female, with an age range from 22 to 49 years of age and an average age of 32 years (SD 8.93 years) was recruited. The average number of years that drivers had held their licence was 12.5 years (SD 8.99).

4.2.2 Experimental Conditions and Design

The methodology utilised in this experiment was a discrimination paradigm (see Chapter 3), whereby participants were asked to indicate which of two visual stimuli was travelling at the greater speed. Each trial featured a photographic car stimulus that acted as a reference vehicle that always travelled towards the observation point at 30 mph (13.4 ms). A probe vehicle (car, solo headlight motorcycle or tri-headlight motorcycle) approached at a range of speeds and the order of presentation of the reference and probe vehicle was randomized. Chapter 3 demonstrated that participant judgements were significantly better for the sequential stimulus presentation compared with the simultaneous stimulus presentation. The motorcycle headlight and the car headlights were 20cm in diameter, while the car headlights were separated by a distance of 160cm. The tri-headlight configuration consisted of a main headlight diameter of 20cm, with two additional 10cm diameter flanking lights placed 30cm below and to the right and left of the main headlight. All distances between headlights were measured from the centre point of each headlight. The headlight diameters and separation distances were once again created in order to try to reflect real life vehicles. The speed differences between the probe and reference vehicles ranged from -20 mph to +180 mph. As in Chapter 3, the probe vehicle was manipulated using a parameter estimation by sequential testing procedure (Best-PEST; Lieberman & Pentland, 1982). Participant judgements of the speed difference between the probe and the reference vehicle were calculated as the average of the speed differences for the last four reversals. This speed difference threshold calculation formed the dependant variable of the study.

4.2.3 Levels of Ambient Lighting

The vehicle stimuli were presented in a virtual urban city environment and travelled along the road surface towards the observation point. The ambient light levels were adjusted within the virtual scene to simulate five different daylight conditions (daylight, lower daylight, dusk, early evening and night). It is not possible to set these to absolute levels as the maximum level of illumination provided by a CRT on full brightness with a white screen is ~83 cd/m^2 whereas a sunny day in the UK exceeds 690 cd/m^2. However, the difference in absolute levels is not a problem for experiments such as this, as humans perceive relative light levels and an observer may often feel that a computer screen is "too bright" even when its ambient level is well below that of a "grey day". Ambience readings were therefore taken using a photometer at five different times of day. These readings were then converted to provide an index of the percentage decrease in lighting levels over the course of five time periods, resulting in the settings for five levels of ambient light within the virtual scene (see Table 4.1 for values and Figure 4.1 for visual illustration of the lighting conditions). All areas of the virtual scene and the stimuli were programmed to react to the ambient lighting level. The virtual scene did not feature any street lights as the primary focus of the study was to investigate object expansion under differing luminance levels.

Table 4.1: Luminance readings for real scene settings taken at different times of day in the UK during winter and equivalent % decrement settings for virtual scene to provide simulations of different daytime conditions.

Real Scene Luminance Reading cd/m^2	% of max	Time	Virtual Scene Luminance Reading cd/m^2	% of max	Condition
687.65	100	1200	82.52	100	Daylight
194.06	28.22	1412	32.24	26.60	Lower Daylight
21.31	3.10	1635	7.1	2.29	Dusk
3.92	0.57	1703	1.94	0.14	Early Night
0.86	0.13	1726	1.01	0.019	Night

Figure 4.1: Three screenshots of the virtual lighting levels used for daylight, dusk, & early night-time

4.2.4 Procedure

Participants sat one metre from the computer monitor with an eye height of 1.2 metres and viewed all of the presentations binocularly. Participants were then given a small number of practice trials prior to each condition so that their understanding of the procedure could be verified. The participants were asked to click an “OK” button in order to start the series of trials and asked to indicate which of the two sequentially presented stimuli was travelling fastest by clicking on a button with the number “1” or a button with the number “2” in order to select the first or second vehicle respectively. The stimuli were displayed for 500ms each with an inter-stimulus gap of 750ms. The order in which the probe and reference stimuli were presented was randomised. All stimuli had a time to passage of four seconds. The experimental design utilized was repeated measures with the order of conditions randomised for each participant.

4.3 Results

A two-way repeated measures ANOVA was conducted with 5 levels of lighting (daylight, lower daylight, dusk, early night, night) and the 3 vehicles types (car, solo headlight motorcycle, tri-headlight motorcycle). This revealed a significant main effect of light level ($F(4, 52) = 3.99$, $p < .01$, MSe = 645.70, $\eta p^2 = .234$) and a significant main effect of vehicle type ($F(2, 26) = 21.29$, $p < .001$, MSe = 599.35, $\eta p^2 = .621$). The ANOVA also revealed a significant interaction between light level and vehicle type ($F(8, 104) = 4.55$, $p < .01$, MSe = 512.05, $\eta p^2 = .259$).

Pairwise comparisons revealed that participants were significantly more accurate at judging the speed of the solo headlight motorcycle in the daylight condition compared with the early night ($p < .05$, 95% CI: -33.537 to -2.825) and the night conditions ($p < .01$, 95% CI = -58.283 to -11.587). The participants were also significantly more accurate at judging the speed of the solo headlight motorcycle in the lower daylight condition compared with the night condition ($p < .05$, 95% CI: -55.555 to -7.327) and in the dusk condition compared with both the early night ($p < .05$, 95% CI: -29.535 to -.589) and night ($p < .05$, 95% CI: -55.129 to -8.503) conditions. The data are illustrated in Figure 4.1, which includes standard error bars (N=14).

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In order to compare the differences in thresholds between vehicles in each lighting condition, additional Bonferroni pairwise comparisons were run. The tri-headlight motorcycle yielded more accurate judgements than the solo headlight motorcycle in the early night condition ($p < .005$, 95% CI: -37.474 to -9.531) and in the night condition ($p < .05$, 95% CI: -72.161 to-9.562). The car stimulus yielded more accurate judgements than the tri-headlight motorcycle in the lower daylight condition ($p < .01$, 95% CI: -30.666 to -4.239) and the night condition $p < .05$, 95% CI: -81.909 to -14.394).

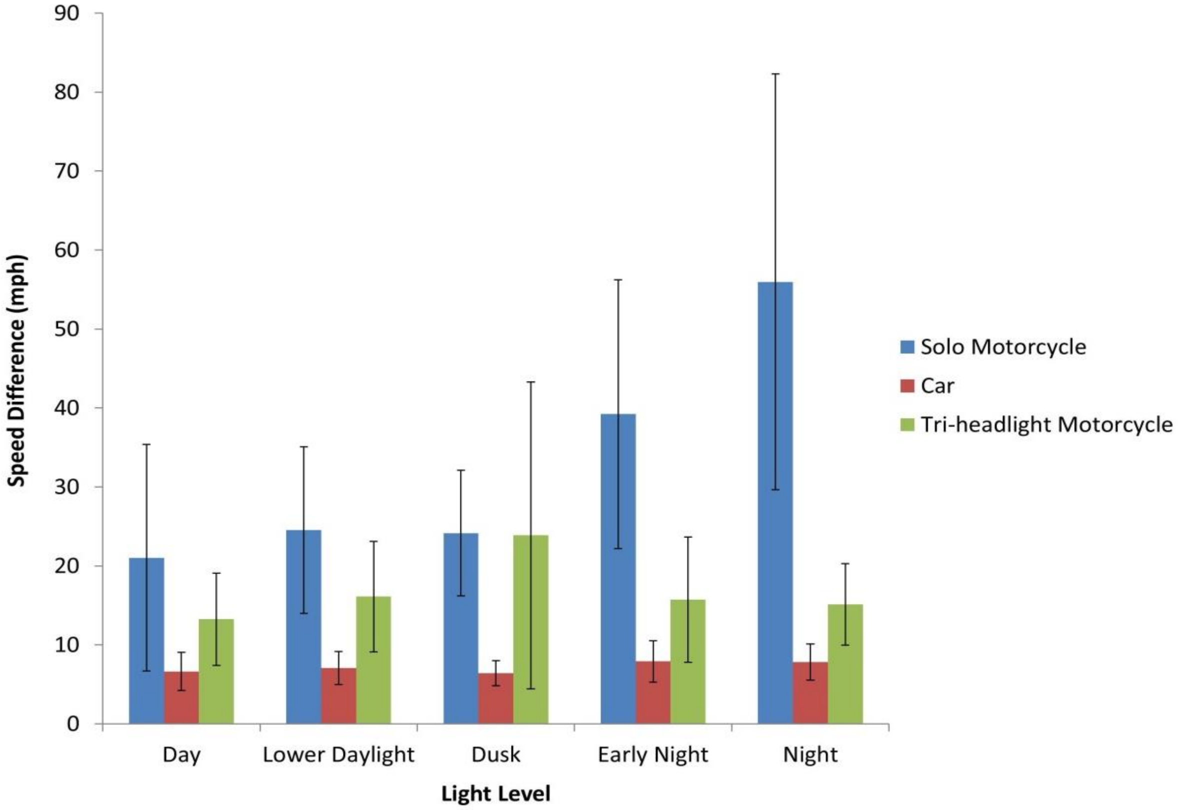


Figure 4.2: Participant judgements for vehicles across ambient light level conditions where the speed difference (mph) between the reference car and the probe vehicle was manipulated

4.4 Discussion

The present study examined how accurately individuals were able to judge the speed of motorcycles and cars across a number of different ambient light level conditions. The results demonstrate that the accuracy of individuals' judgements remained constant across all lighting levels for the car stimulus, with additional optical information about the rate of separation of vehicle headlights available as an additional cue for perceiving TTP in night-time driving conditions (Castro et al., 2005; Gould et al., 2012a). The results show that participant estimations of the solo headlight motorcycle speed became significantly less accurate in the degraded lighting levels of the early night and night-time conditions. This is presumably because unlike a car the visible extent of a motorcycle changes dramatically as the light level falls. The decrement appeared to be most dramatic just after our simulation of dusk conditions (Figure 4.2). The finding that participants were significantly more accurate at judging the speed of the car compared with the solo headlight motorcycle across all conditions provides support for previous assertions that there is a linear relationship between vehicle size and accuracy of approach speed estimation (Caird & Hancock, 1994; Horswill et al., 2005; Gould et al, 2012a). The potential impact of the effect is that observers' judgements for the solo headlight motorcycle declined from a 21 mph speed difference in the daylight condition, to a 39 mph and 56 mph speed difference in the early night and night-time conditions respectively. This means that a motorcycle travelling at over 70mph at night-time would be perceived as travelling at the same speed as a car travelling at 30 mph in night-time conditions. If a driver was looking for a time gap of approximately four seconds to execute a pull out manoeuvre from a junction, the errors observed for judging the approach rate of motorcycles in evening/night-time conditions would have reduced that time to below two seconds. Without increasing the physical size of the motorcycle so that the frontal surface area and headlight distance are equivalent to that of a car, this is unlikely to change.

Introducing motorcycle headlight separation is one way of maintaining the visible width of the vehicle as night falls, and the addition of the tri-headlight formation considerably reduced the degradation in speed judgements under lower light conditions in this experiment. There appears to be some variability in judgements for the tri-headlight at dusk (see Figure 4.2), but this may be noise in the data as it is not in line with the other trends observed. The maintenance of daylight performance levels during night-time conditions confirms the efficacy of the tri-light and demonstrates that the effect demonstrated in Chapter 3 (Gould et al., 2012a) holds for contextual scenes with realistic lighting levels. It is important to acknowledge, however, that the introduction of the tri-headlight configuration does not eradicate perceptual errors. Judgements were still poorer than those for the car, and the errors for the tri-headlight would still have reduced the pull-out time available to a driver from four seconds down to approximately three seconds. While this is less than optimal, the introduction of the tri-headlight formation could prove decisive in whether a motorcycle collision is narrowly avoided or a failure to give way collision takes place. The difference between the car and tri-headlight motorcycle is in line with the separation that is possible for the headlights. If the tri-headlights could be spaced 1.6m apart the present study would predict that the relative difference would disappear altogether, but that would render a motorcycle as far less useful as a small manoeuvrable vehicle. An alternative would be to space the lights vertically (e.g. using the lower parts of the bike and the riders helmet), but in this study the focus was upon a solution that could be engineered into a motorcycle, or be a structured addition to existing bikes. However, while our findings in Chapter 3 used extremely basic stimuli, the study did note that the vertical separation of the headlights was least effective formation at improving the accuracy of speed judgements. This does not exclude other means of increasing the conspicuity of the rider, such as reflective vests. However for the conditions and scenario that have been considered in this study, reflective clothing may not have helped as it would only have been illuminated when car headlights shine directly upon it. This will not necessarily occur when cars are waiting to pull out from junctions, which is a manoeuvre that is particularly associated with a failure to give way at road junctions when the approaching vehicle is a motorcycle. The research on the efficacy of enhanced rider conspicuity is inconclusive (Hole, Tyrrel & Langham., 1996; Pai, 2011) and part of this may be due to the illumination that is directed towards a reflective vest when the observer is waiting at a transverse junction. The effects of fluorescent clothing on the detection of vehicle approach will be discussed at greater length in Chapter 7.

Chapter 2 discussed the trade-off that is evident in the area of driving research between the ecological validity of applied research and the control that can be achieved within a laboratory setting. In this study, while we selected a methodology that measured drivers' abilities to discriminate between the speeds of three different vehicles, we assessed this within a contextually rich virtual scene. This allowed us the ability to exercise stricter control over naturalistic features such as additional traffic and auditory noise within the scene etc. and calculate thresholds for speed discrimination while also including additional cues such as relative height in the scene and occlusion that would be present in a real world scene. It remains the case, however, that our data were not collected on the road using real vehicles, although it is difficult to see how a methodology with equivalent experimental control could be translated to the road. What we demonstrate here is that some of the essential perceptual judgements that would be required at the roadside are impaired when presented with a single headlight vehicle under poor lighting conditions. These errors may be even greater in a natural road scene where there are other distracters, as it is unlikely that they would improve when there is increased visual 'noise' that is typically experienced in natural road scenes.

UK Road traffic casualty statistics show that motorcyclists are more likely to be killed or seriously injured on the road than any other road user (Department for Transport, 2010a). Furthermore, research has demonstrated that the motorcycle-automobile accident involvement at night is higher relative to daylight hours (Pai et al., 2009) and that motorcycle conspicuity is inadequate in dark and low light conditions (Williams & Hoffman, 1979). The issue of how to reduce motorcyclists' accident risk under sub-optimal luminance levels is not straightforward, but our study has provided evidence that the inclusion of the tri-headlight configuration is an engineering intervention with potential for reducing the level of misperception that occurs when considering motorcycle approach speed. Recent UK media campaigns have attempted to increase driver awareness that motorcycles may not be noticed when drivers scan a road scene. In addition to that, our studies suggest that even if they notice a motorcycle in the scene, drivers might not be accurate in their judgment of the speed at which it is travelling. It would therefore be beneficial for future safety campaigns to also aim to increase driver knowledge of the potential for inaccurate judgements of vehicle approach, particularly for motorcycles, and stress that under low luminance conditions these errors may increase significantly.

On a closing note we would suggest that our findings with single headlight motorcycles also probably apply to cars where there is only one clear headlight. When a bulb blows in a car headlight there is normally still a sidelight illuminated this is much lower intensity and has poor visibility at ~50 m. Most drivers are unaware that continuing to drive with only one headlight may lead other drivers to grossly misperceive their approach speed and lead to other drivers pulling across their path. If confirmed this is an issue that could be addressed through public information on night-time driving.

4.4.1 Summary

Chapter 4 has demonstrated that a driver's ability to gauge the approach speed of motorcycles seems to decline steeply as the contour of the motorcycle becomes more difficult to discriminate from its background. This causes individuals to rely on the expansion rate of the solo headlight alone and renders judgements inaccurate. The chapter has also briefly discussed this in relation to implications for cars where one headlight is not functioning. Chapter 4 has also demonstrated that while the introduction of the tri-headlight formation onto a standard motorcycle frame does not eliminate these perceptual errors completely, such a small engineering intervention significantly improves the accuracy of driver speed judgements.

Chapter 5 – Detection of Vehicle Approach in the Presence of Additional Motion

5.1 Introduction

Research has demonstrated that approximately 61% of all car accidents and 75% of all motorcycle accidents occur at road junctions (Department for Transport, 2010). Chapters three and four have provided perceptual evidence compatible with the assertion that one of the most prominent causes of motor vehicle collisions is a failure to judge the speed or path of another vehicle correctly; this aligns with data collected on contributory factors in injury accidents collected by the police when they attend accident scenes, and collated by the Department for Transport (Department for Transport, 2010a). The chapters also noted that the perceptual errors associated with a misjudgement of motorcycle speed are increased under levels of low luminance (Gould et al., 2012a; Gould, Poulter, Helman & Wann, 2012b; Peek-Asa & Kraus, 1996; Pai et al., 2011). However, statistics indicate that a large number of accidents also occur under optimal daytime conditions (Association des Contructeurs Europeans de Motocycles, 2004). Furthermore, in a large number of "look but failed to see" accidents, the motorcycle has been recorded as being quite close to the vehicle waiting at the junction (Gershon, Ben-Asher & Shinar, 2012), suggesting that the driver has failed to detect its presence altogether.

Chapters 3 and 4 have forwarded evidence that individuals may utilise a vehicle's optical size $\theta(t)$ divided by its rate of expansion $\dot{\theta}(t)$ (Lee, 1976) in order to gauge the speed of an approaching vehicle. However, using small-angles by approximation to simplify the differentiation of $\theta(t) = a\tan(z(t)/v(t)) \approx z(t)/v(t)$ then the first derivative is:

$$\dot{\theta}(t) = \frac{S\,v(t)}{z^2(t)}$$

(5.1)

Chapter 1 stated that in the above equation, S is the object size, which can be taken as the height, width or combined surface area and thus according to this equation, a smaller object will have a lower expansion rate than a larger object (e.g. DeLucia, 1991a, 1991b; DeLucia & Novak, 1997; Horswill et al., 2005). Additionally, if an object is travelling at a faster speed, it will have a faster rate of expansion and thus loom more. However, executing a manoeuvre often requires a critical amount of time (tc) for completion of the action, and substituting (v(t).tc) for z(t) in equation 2 gives:

$$\dot{\theta}(t) = \frac{S}{t_c^2\,v(t)}$$

(5.2)

This implies that for a manoeuvre that requires a specific time, such as the four seconds required to pull out from a junction (Horswill et al., 2005), a faster object will be at a far greater distance from the observer and thus is more likely to be below an individual's threshold for detecting visual looming ($\dot{\theta}(t)$).

While there has been an extensive amount of research carried out into judging TTP, very little has focused on individual's ability to detect the onset of the visual looming of an object within a scene. Regan and Beverley (1979) found that under strict psychophysical conditions, simple-edge motion can be detected at approximately 0.003 rad s^{-1}. Hoffman (1994) assessed individual's abilities to detect object approach across a number of age groups through the use of video footage. In a post-hoc analysis, the study demonstrated that adult's thresholds for detection of looming motion was 0.002 rad s^{-1}. Wann et al. (2011) furthered this finding by using a psychophysical procedure to study the perceptual thresholds for the detection of visual looming across a number of age groups, from six years of age to adulthood. As noted in section 1.9, adults recorded an average looming detection threshold of 0.001 rad s^{-1} (~105 mph). In most sports-skills, the threshold for the detection of $\dot{\theta}(t)$ is unlikely to be a limiting factor. However, in the case of vehicle approach, where the observer is looking for a four second time window, a vehicle approaching at >50mph may drop below the threshold for detection. This problem may be particularly prevalent with motorcycle riders, with research demonstrating they are more likely to travel above the speed limit than car drivers are (Brenac et al., 2006; Walton & Buchanan, 2012). However, while this issue would be exacerbated for a motorcycle due to its smaller size, it may also be evident for faster travelling cars. This would create a dangerous illusion whereby faster vehicles may appear stationary within the scene (Wann, Poulter & Purcell, 2011) and as looming objects have been found to capture attention (e.g. Franconeri & Simons, 2003), may not draw the awareness of the driver, leading to a greater risk of a right-of-way collision.

A number of studies that have investigated individuals' abilities to judge the TTP of a target object within an array of objects. As mentioned in section 1.12, DeLucia and Novak (1997) assessed participant ability to judge which object in an array had the shortest TTC. The authors demonstrated that in an array that contained up to eight objects, participants were able to judge which object had the shortest TTC at an above chance rate. However, the authors did note that performance was degraded in the presence of misleading relative size information when only two objects were presented in the array. More specifically, responses may have influenced by the optical size of the objects when only two were present within the display. However, DeLucia and Novak (1997) did not account for whether the objects within the visual display were within foveal or peripheral vision.

Oberfeld and Hecht (2008) conducted a study where participants were asked to judge the TTP of an approaching car in the presence of a late or early arriving distracter truck, which was also approaching the observation point. The authors noted a contrast effect, whereby a late arriving distracter caused an underestimation of TTP of the target vehicle. The authors postulated that the findings may have been due to some kind of "safety" bias, whereby participants opted to underestimate the TTP of the target vehicle in order to exercise a cautious approach to the "danger" posed. However, this explanation was refuted in an additional study, which featured abstract stimuli and demonstrated the same result. The authors noted that while they were unable to fully explain the effect, and despite a number of theories of TTP stating otherwise (e.g. Lee, 1976), observers seem unable to ignore irrelevant distracter looming objects. Baurès, Oberfeld and Hecht (2010) asked participants to provide two judgements as to when two laterally moving balls would reach a target finish line. The study provided evidence for proactive interference, whereby the TTP judgements for the leading object was not impaired by the trailing object, but the TTP judgment for the trailing object was systematically delayed. The authors argued that perceived order of arrival is therefore critical for TTP judgements, thus it could be argued that objects that are further away in the scene may be considered lower on this perceived order of arrival. The study by Oberfeld and Hecht (2008) demonstrated how individuals perform when viewing a relatively sparse road scene, while Baurès et al. (2010) showed how individuals perform when viewing simple geometric shapes in a sparse visual environment. However, in the real world, there is often a large amount of clutter and additional motion within the visual scene. As previous research has demonstrated that there is an effect of additional moving objects on TTP judgements, we would also expect additional moving objects to negatively affect detection thresholds for visual looming.

On a methodological note, the studies featured in Chapters 3 and 4 utilised display time durations of 500ms. The current study opted to investigate thresholds for looming detection for two display durations, 500ms and 750ms. Previous experiments using static image stimuli have opted for presentation durations of 250ms, which have been argued to represent the time of a glance along an empty side road (Crundall et al., 2012), while video based studies have opted to use display times of 2 and 5s in prediction motion paradigms (Horswill et al., 2005). However, when pulling out of a junction, there is a trade-off between the amount of time taken to make the judgement and the amount of time available to perform the manoeuvre. One would expect that with a greater viewing time, detection thresholds should significantly improve. This increase in viewing time will however, result in less time to execute the pull out manoeuvre. One might suggest that in a busy urban environment, a driver would be unable to take a long time about pulling out from a junction. The current study therefore opted to compare the detection thresholds for participants with a 500ms presentation duration and a 750ms presentation duration.

5.1.1 Experiment 1

Road junctions are often busy environments. The ability to detect looming motion in the presence of additional peripheral and foveal motion could be crucial for safe pull-out manoeuvres. The aim of the present chapter was to investigate drivers' abilities to detect approaching motorcycles and cars within a contextually rich simulated city scene. The chapter aimed to assess whether the thresholds for drivers' abilities to detect these motor vehicles is moderated by additional motion. This additional motion will then be further broken down in an additional study in order to investigate the effects of foveal and peripheral motion in turn. The first study also aimed to assess whether thresholds for detection of visual looming are improved by an increase in display time from 500ms to 750ms. These display durations were designed to build on the assertion by Crundall et al. (2012) that a glance along an empty road would take ~250ms with a static image. It is understood that if a driver had an unlimited amount of time to make a pull out judgement then less perceptual errors would occur. However, real world situations, particularly when driving in high volumes of traffic, do not afford long periods. It could be suggested that a one second viewing duration of an oncoming vehicle down a road in peak travel times might be too long to afford a successful pull out judgements. It therefore seems important to investigate whether an additional 250ms on top of the 500ms viewing times presented in Chapters 3 and 4 might lead to significantly lower thresholds (and ultimately safer pull out judgements) for detecting a looming stimulus.

5.2 Method

5.2.1 Participants

A sample of 20 participants, 8 male and 12 female who ranged from 18 to 43 years of age, with an average age of 23 years (SD 6.58), took part in Experiment 1. The average number of years that drivers had held their licence was 5.15 years (SD 6.26).

5.2.2 Design

Experiments 1 and 2 featured a perspective correct visual simulation of photographic images of vehicle approaching the observer viewpoint. Each of the experiments featured target trials and null trials. In the target trials, the target vehicle changed in size and speed to simulate approach at different rates of looming with a fixed TTP of four seconds. The lowest speed used was 30 kph / 18.64 mph. The target vehicle was manipulated using a parameter estimation by sequential testing procedure (Best-PEST; Lieberman & Pentland, 1982 – see Chapter 2). This procedure calculated the optical increment in angular size and speed for each trial based on the participant's previous response to efficiently converge on their threshold performance. The PEST staircases were stopped after the tenth reversal and the threshold was calculated as the average of the last four reversals. In the null trials, the vehicle in question remained static at the same optical size as the initial image equivalent to the target trials. Participants with false positive responses greater than 33% in the null trials were excluded from the analysis. The threshold values are presented in rad/s and were converted into m/s using Equation 5.3 and 5.4 and presented in mph in order to allow the findings to demonstrate the speeds at which participants were no longer able to detect the looming of an approaching car or motorcycle. This allowed us to apply our findings to real world scenarios and speed limits.

$$\text{SPEED (ms)} = \frac{\text{Size of Vehicle}}{\text{Threshold(rad/s)} \times \text{TTP}^2} \tag{5.3}$$

$$\text{SPEED (mph)} = \frac{\text{Speed(ms)}}{1609} \times 3600 \tag{5.4}$$

5.2.3 Experimental Conditions

The experiment featured a total of eight conditions. Conditions one and two displayed the motorcycle target vehicle stimulus approaching the observer in the presence of additional motion within the scene or additional stationary vehicles within the scene. The above conditions were repeated with the car target vehicle stimulus instead of a motorcycle in conditions three and four. The psychophysical staircases for all four conditions were interleaved. Conditions one to four featured a display time of 500ms and were repeated in conditions five to eight with a display time of 750ms. Additional motion referred to the additional movement of objects within the scene. More specifically, there were two cars traversing the screen laterally at a speed of 30 mph, located in the foreground and background, which had a start position of 14 degrees and 5.7 degrees visual angle respectively. There was an additional vehicle that was always present in the lane adjacent to the target vehicle and either loomed towards the observer viewpoint or remained stationary, located at a visual angle that ranged between 0.6 and 0.7 degrees. Lastly, a pedestrian walked towards the observer viewpoint on the sidewalk at a visual angle which varied between 9-9.4 degrees. The TTP of the pedestrian and the adjacent vehicle were randomised, but were always greater (e.g. further away or slower) than the four second TTP of the target vehicle in order to ensure that the target vehicle was the more immediate threat. None of the additional moving objects were on trajectories that would interfere with the target or any other vehicles. The probe vehicle was located at a visual angle of 2.2 degrees. The dependant variable of the study was the detection threshold at which participants could no longer detect an approaching vehicle as looming towards them.

5.2.4 Procedure

Participants were given a small number of practice trials with verbal feedback provided by the experimenter. The initial screen presented to the participants featured the city scene background, with contextual information such as buildings and road markings, and participants were asked to click the “Next” button, which was displayed at the foot of the screen. The target stimulus (motorcycle or car), and the additional objects (vehicles and a pedestrian) were then displayed for a duration of 500ms. On their disappearance, a red line divided the screen in half vertically and a “None” button replaced the “Next” button at the foot of the screen. Participants were asked to click on the side(s) of the screen that corresponded to the location where they observed a vehicle approaching them. The maximum number of vehicles that could approach the participant in one trial was two (the target vehicle and the additional moving vehicle located in the adjacent lane).

Participants were informed that they were to make two clicks on every trial and that they should indicate if they only saw one vehicle approach them or did not see any vehicles approaching them, by clicking on the “None” button the correct number of times (once or twice respectively). For example, if a participant only detected one vehicle approaching their viewpoint, they would click on the corresponding side and then register that they had not seen any other vehicle approaching by clicking on the “None” button. However, if a participant saw two vehicle approaching their viewpoint, they clicked on the location of those vehicles and the display would automatically display the “Next” button. Participants clicked the “Next” button when they were ready to proceed to the next trial.

Figure 5.1: Visual display featuring (1) start screen, (2) start position for trial featuring a car stimulus, (3) start position for trial featuring a motorcycle stimulus and (4) the decision screen

5.3 Results

A three-way repeated measures ANOVA was conducted with two levels of display time (750ms, 500ms), two levels of target vehicle (motorcycle, car) and two levels of motion (no additional motion, additional motion). There was no significant effect of display time ($F(1,19) = .008$, $p > .05$, $MSe = .001$, $\eta p^2 = .000$). There was a significant main effect of vehicle type ($F(1,19) = 28.27$, $p < .001$, $MSe = .001$, $\eta p^2 = .598$). More specifically, participant thresholds for detection were higher (poorer) for the motorcycle stimulus than for the car stimulus. Although there was no significant main effect of additional motion ($F(1,19) = .54$, $p > .05$, $MSe = .001$, $\eta p^2 = .0.28$), the ANOVA revealed a significant interaction between vehicle type and motion ($F(1, 19) = 5.93$, $p < .05$, $MSe = .005$, $\eta p^2 = .238$).

Bonferroni pairwise comparisons demonstrated that participants were significantly less accurate at detecting the approach of the oncoming car stimulus in the presence of additional object motion, when compared with their accuracy with no additional object motion ($p < .005$, CI:.005, .020). There was no difference in participant detection of the approaching motorcycle stimulus in the presence of additional vehicle motion compared with the absence of additional vehicle motion ($p > -.05$, CI: -.025 - .006).

Table 5.1: Mean detection threshold judgements expressed in rate of expansion (rad/s) and speed (m/s and mph) for Experiment 1.

Target Vehicle	**Display Duration (ms)**	**Motion Type**	**Mean Target Loom Level (rads/s)**	**Standard Deviation**	**Mean Target Speed (m/s)**	**Mean Target Speed (mph)**
Motorcycle	500	No Additional Motion	.0019	.0011	24.81	55.5
Motorcycle	500	Additional Motion	.0016	.0008	30.09	67.3
Car	500	No Additional Motion	.0008	.0004	131.07	293.2
Car	500	Additional Motion	.0010	.0005	108.94	243.7
Motorcycle	750	No Additional Motion	.0017	.0007	28.06	62.8
Motorcycle	750	Additional Motion	.0017	.0008	28.22	63.1
Car	750	No Additional Motion	.0008	.0004	132.48	296.41
Car	750	Additional Motion	.0011	.0007	100.29	224.38

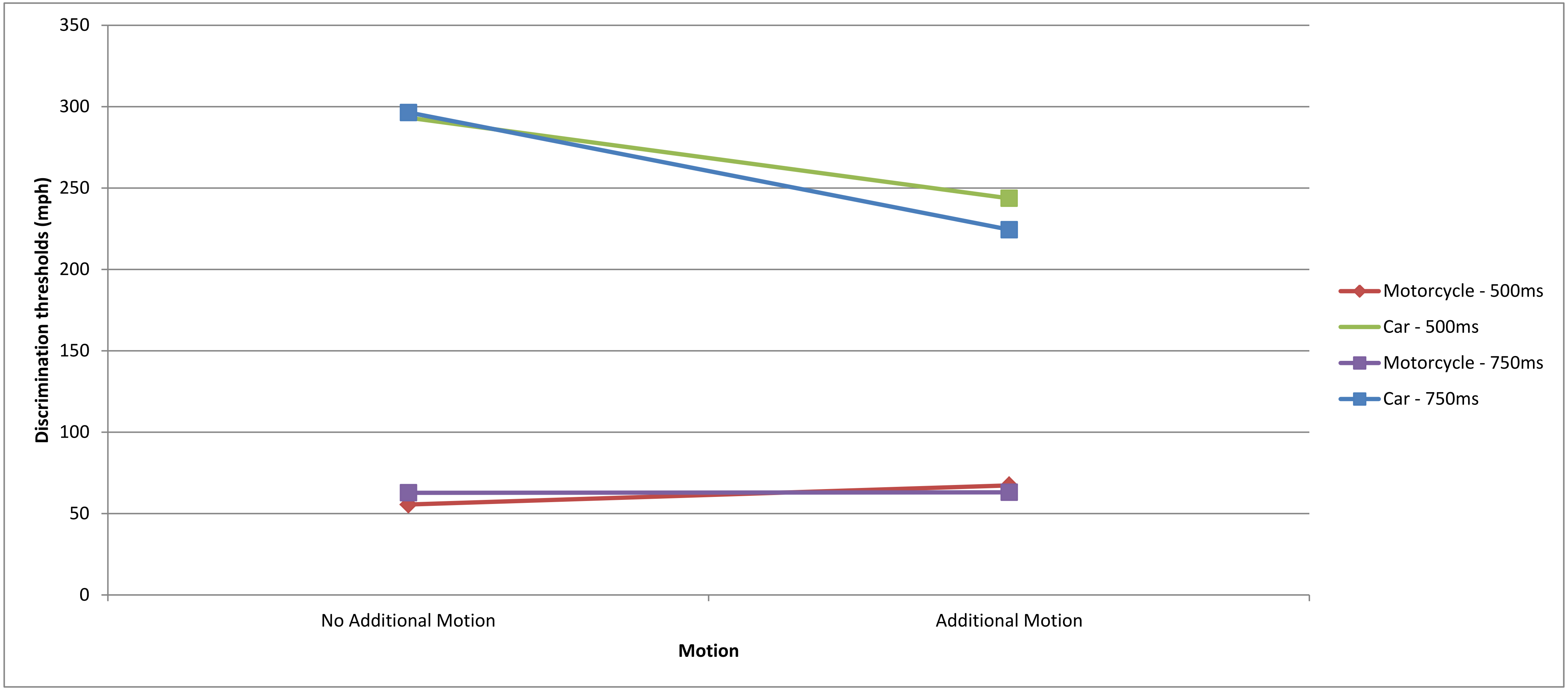


Figure 5.2. Interaction between vehicle type (car, motorcycle) and motion (no additional motion, additional motion)

5.4 Discussion

Experiment 1 demonstrated that individuals display a higher threshold for the detection of motorcycles than cars. This reduces the ability to detect the "pop-out" (Rushton, Bradshaw and Warren, 2007) motion of motorcycles by a factor of 4 (e.g. ~ 60mph for motorcycles vs >240mph for cars). Furthermore, the experiment demonstrated that the presence of additional object motion significantly increased the detection thresholds for the car stimulus, whereas the motorcycle stimulus was unaffected.

The higher thresholds for motorcycles in Experiment 1 supported the assertion that the visual looming of smaller vehicles is more difficult to detect within the scene (Lee, 1976; Wann, Poulter & Purcell, 2011). The finding that additional object motion only increased the detection thresholds for the car stimulus did not agree with our predictions. However, it is worth noting that the threshold for motorcycle detection without additional motion remained higher than for car detection with additional motion, thus implying the possibility of a floor effect. Individuals were so poor at detecting a moving motorcycle, that this performance was unaffected by the movement of other stimuli.

5.5 Introduction

Although Experiment 1 demonstrated that additional object motion can have an effect on a driver's threshold for detecting a looming car within a virtual scene, it is unclear from the findings as to whether it is additional motion in the foveal or peripheral visual field that moderates this effect.

The roles of peripheral and foveal motion detection have been investigated across a number of studies. Lamble, Laasko and Summala (1999) conducted a study where participants drove a car and were asked to follow a lead car, which ultimately decelerated without braking. The authors manipulated the distance at which the car began decelerating, but also asked participants to focus on an additional task that was carried out on a variety of LCD displays throughout the car. The eccentricity of the location of these LCD displays was manipulated, varying from 4 to 90 degrees. Participants were asked to focus on the LCD displays only and brake as soon as they noticed the car in front decelerating. The study revealed that as the eccentricity of the LCD display increased, the detection threshold of the participant increased. Regan and Vincent (1995) conducted a study to investigate participant ability to detect visual looming across the visual field. The authors used a virtually approaching stimulus that varied in location from 0-32 degree eccentricity in the upper, lower, right and left visual field. Through the use of a psychophysical procedure, the authors concluded that TTP, rate of expansion and size can be processed independently, simultaneously and in parallel in foveal vision. However, the authors noted a linear relationship between eccentricity and the independence in which these variables could be processed. More specifically, variations in the rate of expansion produced inaccurate TTP judgements in peripheral vision compared with foveal vision.

In line with this, Wann et al. (2011) found that participant thresholds were higher (poorer) for stimuli displayed in extra-foveal vision compared with foveal vision. The authors therefore argued that if a child did not fixate on an oncoming object when crossing a road the likelihood of an accident could be increased. This difference in detection thresholds for foveal and peripheral vision was also noted for adults. However, I am unaware of any research that has systematically investigated individual's abilities to detect visual looming in the presence of additional moving objects in foveal and peripheral vision. This is a situation that could frequently be encountered when judging whether it is safe to pull out of a roadside junction.

Experiment 2 aimed to separate the two forms of additional motion so that the individual effect of foveal and peripheral motion could be determined. Eye movements were not recorded and therefore the definition of foveal and peripheral motion in this experiment assumed that participants were fixating on the centre of the monitor display. Additional foveal motion therefore related to motion that was proximal to the centre of the display, while additional peripheral motion related to motion that was more distal to the centre of the display. It was predicted that the additional foveal motion would have a negative effect on threshold performance for the detection of an approaching target vehicle based on the interference effect noted by Oberfeld and Hecht (2008) for TTP judgments and the subsequent notion of the importance of perceived arrival noted by Baurès et al. (2010).

5.5.1 Experiment 2

Experiment 2 aimed to separate the two forms of additional motion so that the individual effect of foveal and peripheral motion could be determined. The study predicted that the additional foveal motion would have a negative effect on threshold performance for the detection of an approaching target vehicle. This prediction is based on an interference effect noted by Oberfeld and Hecht (2008) for TTP judgements and the subsequent notion of the importance of perceived arrival noted by Baurès et al. (2010) (see section 5.1 for further details).

5.6 Method

5.6.1 Participants

A sample of 13 participants, 8 males and 5 females who ranged from 18 to 26 years of age, with a mean age of 21 years (SD 2.90), took part in Experiment 2. The average number of years that drivers had held their licence was 3.73 years (SD 2.32).

5.6.2 Experimental Conditions

The experiment featured a total of six conditions. The conditions featured either a car or a motorcycle as the target vehicle that approached the observer in the presence of no additional motion, additional foveal motion or additional peripheral motion. Presentations were displayed for a duration of 500ms. The positioning of the additional moving objects and the additional stationary objects was the same as in Experiment 1. However, additional foveal and peripheral motion were investigated independently. In the additional foveal motion condition, the peripheral objects (vehicles and pedestrian) remained stationary, whereas in the additional peripheral motion condition, the foveal vehicle remained stationary.

5.6.3 Designs & Procedure

The design and procedure was the same as that used in Experiment 1.

5.7 Results

A two-way repeated measured ANOVA was conducted with two levels of vehicle (motorcycle, car) and three levels of additional motion (no additional motion, additional foveal motion, additional peripheral motion). This revealed a significant main effect of vehicle type ($F(1,12) = 6.55$, $p < .05$, MSe = .000, $\eta p^2 = .353$), whereby higher thresholds for the detection of motion were recorded for the motorcycle than for the car. The ANOVA also revealed a significant main effect of additional motion ($F(1,12) = 26.43$, $p < .001$, MSe = .000, $\eta p^2 = .688$). More specifically, participant thresholds for detection were higher (poorer) in the presence of additional foveal motion than in the presence of additional peripheral motion as well as compared to no additional motion. The ANOVA also revealed a significant interaction between vehicle type and additional motion ($F(1,12) = 5.66$, $p < .05$, $MSe = .000$, $\eta p^2 = .321$).

Bonferroni pairwise comparisons revealed that participants were significantly more accurate at detecting the moving car stimulus when there was no additional motion than when there was additional foveal motion ($p < .005$, 95% CI: .000 to.001), however this was not so for the motorcycle stimulus ($p > .05$, 95% CI: -.003 - .001). Participants were also significantly less accurate at detecting both the moving motorcycle stimulus ($p < .01$, 95% CI: .000 to .003) and the car stimulus ($p < .005$, 95% CI: -.000 to -.000) in the presence of additional foveal motion when compared with additional peripheral motion. Lastly, there was no significant difference in participant detection thresholds for the motorcycle stimulus ($p > .05$, 95% CI: -.003 - .001) and the car stimulus ($p > .05$, 95% CI: .000 - .001) when there was no additional motion compared with additional peripheral motion.

Table 5.2: Mean detection threshold judgements (rad/s) and speed (m/s and mph) for Experiment 2.

Target Vehicle	Additional Motion Type	Mean Target Loom Level (rad/s)	Standard Deviation	Mean Target Speed (m/s)	Mean Target Speed (mph)
Motorcycle	None	.0019	.0013	24.18	53.95
Motorcycle	Foveal	.0022	.0013	21.52	48.15
Motorcycle	Peripheral	.0016	.0011	29.17	65.26
Car	None	.0012	.0006	93.34	208.80
Car	Foveal	.0022	.0010	48.98	109.56
Car	Peripheral	.0012	.0008	90.57	202.59

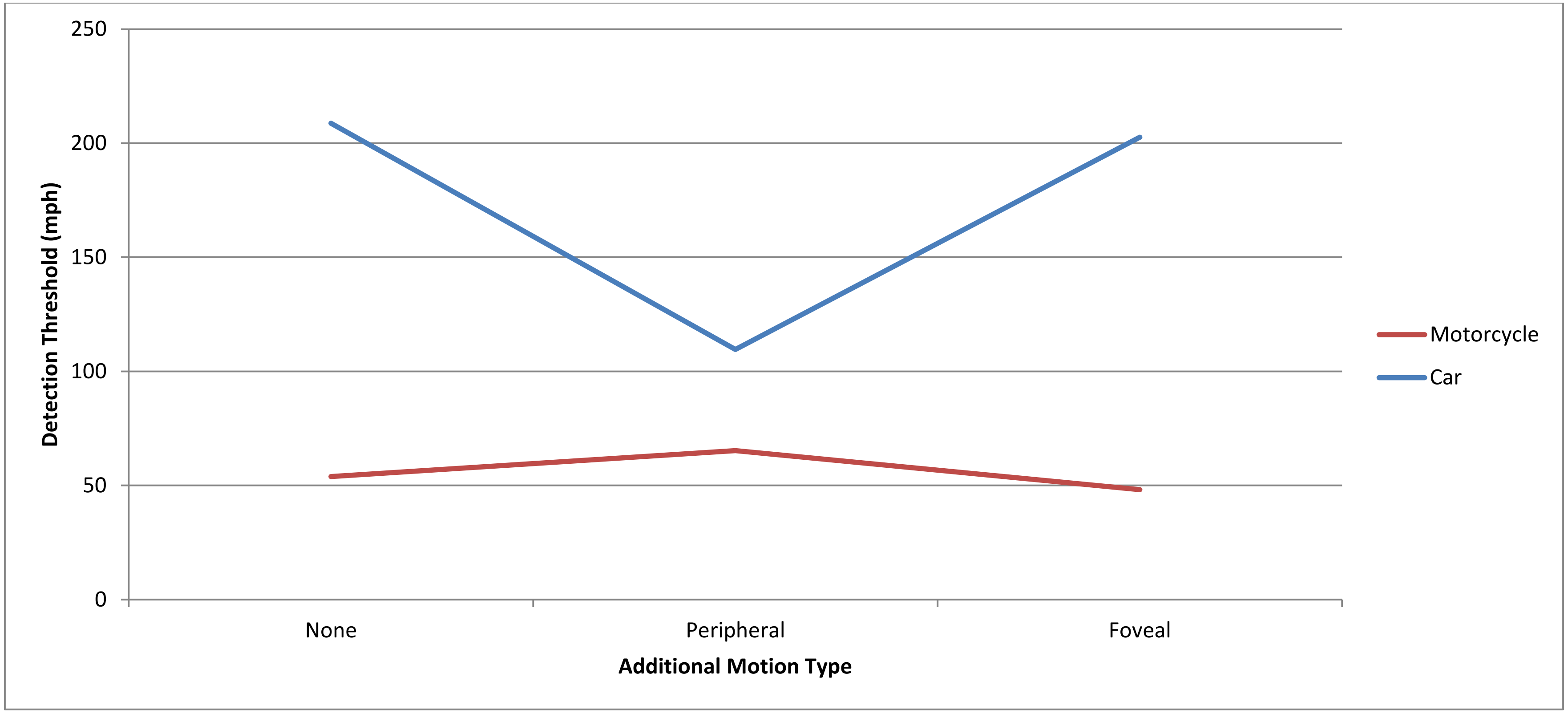


Figure 5.3. Interaction between vehicle type (car, motorcycle) and motion (no additional motion, additional peripheral motion and additional foveal motion)

5.8 Discussion

Experiment 2 replicated the finding from Experiment 1 that threshold judgments for detecting approaching motorcycles were higher than judgments for approaching cars. Although Experiment 1 also demonstrated that additional foveal and peripheral motion were detrimental to detection thresholds, Experiment 2 demonstrated that the foveal motion caused the greatest detriment to performance, whereas motion in the peripheral field, when the target object was in the foveal field, could be largely ignored.

Although additional foveal motion seems to negatively affect detection thresholds, the contributing factors to this impairment are unclear. Two of the factors that may have affected the detection in the current study are the distance of the additional vehicle in foveal motion from the observer viewpoint (hence the optical size) and the looming rate of the distracter vehicle. The percentage of trials where the participants missed an approaching target car (Miss), mistook a stationary target car for an approaching vehicle (FP), missed the additional foveal vehicle approaching (Miss) and incorrectly judged a stationary additional foveal vehicle for an approaching vehicle (FP) are presented in Tables 5.3 (distance) and 5.4 (looming rate). Table 5.3 demonstrates that participants failed to detect an approaching target car on more occasions when it was placed at a greater distance from the observer compared with the position of the additional vehicle. The table demonstrates the same relationship for the additional vehicle. More specifically, when the additional vehicle was placed at a greater distance from the observer compared with the target car, the participants failed to detect its approach. This trend was also observed for the loom level as shown in Table 5.4. When the target car loomed to a lesser extent than the additional foveal vehicle, participants were more likely to fail to detect the approach. The same however, was not true of the additional foveal vehicle, where participants missed a similar number of approaches for the vehicle when it loomed less and more than the target vehicle. The results demonstrate that the distance of the additional foveal vehicle and its looming rate may both be contributing factors to the main effect observed.

Table 5.3: Percentage of trials where participants failed to detect an approaching probe and additional vehicle or incorrectly judged a stationary probe and additional vehicle as approaching for car trials based on which vehicle had the greater start distance

Distance							
Car Trials							
Probe Vehicle				Additional Vehicle			
Closer Distance		Farther Distance		Closer Distance		Farther Distance	
Miss %	FP %	Miss %	FP %	Miss %	FP %	Miss %	FP %
0	0	42.34	1.23	5.39	0	25.64	0

Table 5.4: Percentage of trials where participants failed to detect an approaching probe and additional vehicle or incorrectly judged a stationary probe and additional vehicle as approaching for car trials based on which vehicle had the greater overall loom level

Loom Level							
Car Trials							
Probe Vehicle				Additional Vehicle			
Lesser Loom Rate		Higher Loom Rate		Lesser Loom Rate		Higher Loom Rate	
Miss %	FP %	Miss %	FP %	Miss %	FP %	Miss %	FP %
44.21	1.24	3.08	0	7.69	20.51	5.92	0

5.9 General Discussion

The present study examined the thresholds at which individuals are able to detect the approach of moving motorcycles and cars. The study examined whether additional motion (peripheral, foveal or simulated observer motion) increased the threshold at which participants detected a vehicle. The results demonstrated that individuals displayed a higher threshold for the detection of an approaching motorcycle stimulus compared with the car stimulus across all three experiments. The results of Experiment 1 provided evidence that additional motion within the scene increased the threshold for the detection of a moving car, but had no effect on the moving motorcycle. It can be suggested that that fact that the motorcycle thresholds were unaffected by additional motion may be attributable to a floor effect, whereby individuals were so poor at detecting the approaching motorcycle that their judgments were unaffected by the additional motion. On further investigation, the results from Experiment 2 provided evidence that it was the additional foveal object motion, as opposed to peripheral motion, that impaired participant thresholds for the detection of the target car, which supports previous research that looming judgments can be affected by an additional looming distracter vehicle (Oberfeld & Hecht, 2008).

The finding that drivers display a higher (poorer) threshold for detection of motorcycles compared with cars could be used to explain in part why failure to give way incidents occur so frequently at junctions. The average threshold speed above which observers could not reliably detect looming motorcycles with a TTP of four seconds with no additional vehicle motion car across all three experiments was 53 mph, whereas the average threshold speed for car looming detection was 255 mph in the same conditions. The higher speed estimate of >200mph does not have applied relevance but it equates to the ability to detect a car moving when it is nearly five times the distance of an approaching motorcycle. In road traffic terms, if a motorcycle were to travel at 60 mph on a 40 mph road, there is an elevated probability that a driver at a junction may fail to notice its approach and rather than "popping out" of the visual scene as a consequence of its expansion, it will merge with the static background. This study demonstrated that additional motion within the scene increased the threshold for the detection of the car stimulus. Individuals were able to detect a car moving when it was travelling well in excess of maximum speed limits without additional vehicle motion within the scene, although this detection ability was slightly reduced in the presence of additional moving peripheral and foveal objects.

Experiment 2 demonstrated that the detection of the moving car stimulus without the presence of additional motion was halved in the presence of an additional vehicle in foveal vision, whereas additional vehicles moving in peripheral vision had little or no effect. This finding supports the research by Oberfeld and Hecht (2008) whereby an additional looming vehicle was found to influence participant ability to judge TTP. However, Oberfeld and Hecht (2008) noted a contrast effect, whereby a late arriving distracter vehicle caused an underestimation of target TTP. In the present study, it can be noted that a late arriving foveal vehicle caused a detriment to looming sensitivity. Furthermore, the study appears to support the notion forwarded by Baurès et al. (2010) regarding the importance of the perceived TTP of objects. More specifically, individuals failed to detect approaching objects when they were at a greater distance or lesser loom rate compared with their counterpart vehicle. Thus in the present study, although the TTP of the additional foveal object was always greater than the target object, the larger optical size of the foveal vehicle may have caused individuals to perceive this object as arriving sooner than the faster moving object in the adjacent lane.

It is the case, however, that our simulation of a road scene allowed observers to center their attention on the two lanes where the approaching vehicles appeared, as might occur if the observer was stood by the roadside. In this respect all peripheral objects may have been outside their focus of attention and hence discarded (Folk, Remington & Johnston, 1992), but that is equally likely to be the case in natural settings.

The demonstration that driver detection thresholds for cars are impaired by the presence of a competing looming stimulus has implications for road design. For example, when merging onto a highway, the car of interest should be in the nearside lane (see Figure 5.4). Our research demonstrates that the distance and looming rate of the car in the adjacent lane may impair judgment of the vehicle approaching in the nearside lane. Although the findings from the present study show that individuals are still able to detect a moving car that is travelling over 100 mph in the presence of an additional moving foveal vehicle, our virtual scene did not contain the amount of traffic that is usually evident on the roads during peak daytimes. Based on our findings and previous research, an increase in the number of objects within the scene and additional vehicle motion could increase these thresholds for detection further (Harris et al., 1998). Furthermore, future research could also focus on the ability of individuals to detect oncoming vehicles in the presence of other approaching vehicles, but also receding vehicles that are moving away from the observer.

The finding that individuals have a higher threshold for the detection of a moving motorcycle compared with a car presents a specific safety concern. The relatively small front surface area of the motorcycle means that it is often travelling below the threshold for drivers ability to detect visual looming and thus without increasing the size of the motorcycle, this trend is unlikely to change (Gould et al., 2012a; Gould et al., 2012b).

Figure 5.4: A simplified diagram of the driver mirror view when merging onto a high speed road. The driver needs to judge whether it is safe to merge in front of the car located in the nearside lane, but our experiments demonstrate that the greater optical size of the car in the adjacent lane may impact this judgement.

5.10 Summary

Chapter 5 has provided evidence that thresholds for the detection of approaching motorcycle stimuli are higher than those for approaching car stimuli. More specifically, this would mean that given a fixed time period required to pull out of a junction, a motorcycle may be less likely to be detected as moving within a scene than an approaching car would. Additionally, the experiments noted that detection thresholds for the car stimulus were adversely affected by the presence of an additional vehicle approaching in foveal vision. Conversely, additional peripheral motion did not affect detection thresholds for the car stimulus. On a methodological note, the study has shown that there is no significant difference between presenting the stimuli for 500 ms or 750 ms and the former will be utilized in methodologies from this point onwards.

Chapter 6 - Detection of Vehicle Approach in the Presence of Simulated Self-Motion

6.1 Introduction

Chapter 5 demonstrated that individuals are significantly poorer at detecting the motion of an oncoming motorcycle, compared with an oncoming car. However, additional motion within the scene is not the only type of motion that research needs to consider. Roads in many countries feature left/right hand turn junctions where individuals are required to give way to traffic, but not stop before exiting the junction (for example 'give way' junctions in the UK). This creates a situation whereby individuals may often be attempting to assess the safety of a pull-out manoeuvre while in motion themselves. A large body of research has been conducted around optic flow (the changing of the retinal image due to self-motion) and motion judgements. The research has demonstrated that observer motion can affect TTP judgements (DeLucia et al., 2003; DeLucia & Mather, 2006; Gray & Regan, 2000).

One problem with motion detection during self-motion concerns how observers differentiate between optic flow motion and object motion. MacLeod et al. (1988) proposed the notion of a "motion filter" that only processes moving objects, a process that Rushton et al. (2007) suggest might occur in the MST (medial superior temporal cortex). Rushton et al. (2007) provided evidence for "flow parsing" whereby individuals subtract retinal motion due to self-motion using optic flow detectors and attribute any remaining motion to objects within the scene. In another study, Royden and Connors (2010) investigated motion detection of an object that's motion deviated from the radial optic flow pattern experienced during simulated forward self-motion. The authors argued that global cues (the direction of the flow field) were important for motion detection and not solely the local cue of the movement of the target object. Geri, Gray and Grutzmacher (2010) demonstrated that simulated forward observer motion decreased TTC estimates for looming objects and that this effect increased with the speed of both observer motion and object motion.

DeLucia and Meyer (1999) investigated TTP judgements between two laterally moving objects during self-motion. The self-motion nullified the optical gap constriction between the two objects and the study found that estimates of TTP increased as actual TTP increased whether the scene included self-motion or not. However, the results indicated that lateral self-motion negatively affected TTP estimates under certain conditions (dependant on factors such as background texture, TTP and speed of object motion and self-motion), whereas forward and backward self-motion did not affect judgements of TTP. While these articles have provided a possible explanation about how individuals extract target motion from a scene while the observer is also in motion as well as investigated the effect on TTP judgements, there have been few studies that focus on the effect that lateral observer motion has on looming detection.

Kellman and Kaiser (1995) proposed that lateral target motion could be extracted from a combination of optic flow and binocular disparity during lateral observer motion. The authors suggested that this extraction involved three optical variables; optical change of the nearest point of the target, the optical change of the farthest point of the target and binocular disparity. However, research has demonstrated that the vergeance cues gained from binocular disparity are only useful as the fixation distance of the object becomes nearer or additional retinal cues are reduced (Tresilian, Mon-Williams & Kelly 1999). Therefore while Kellman and Kaiser's (1995) model may be applicable at small object distances, it would not provide explanation with regards to the critical distances typically encountered at roadside junctions.

In the study conducted by Wann et al. (2011), the authors utilised a condition that involved the looming of the target vehicle with additional lateral displacement. More specifically, a photographic stimulus of a car on a photographic background loomed towards the observer, but also traversed the screen laterally. The authors noted a detriment in performance during this condition in foveal vision, compared with the looming only condition for adults. This implies that lateral displacement may increase detection thresholds for looming objects. However, I am unaware of any research that has attempted to investigate the effects of simulated lateral observer self-motion on looming detection ability.

In Chapter 5, the study used a car stimulus as the additional moving vehicle in foveal vision because cars are more frequently encountered on the road, whereas motorcycles only account for approximately 1% of all UK road traffic (Department for Transport, 2010). However, DeLucia and Novak (1997) demonstrated that the optical size of an object may influence TTP judgments. In order to ensure that the additional car stimulus located in foveal vision was not causing some sort of bias due to its size, the vehicle was manipulated between a motorcycle and a car.

The aim of the present study was to determine whether individual sensitivity to car and motorcycle looming is influenced by the presence of simulated lateral observer motion, similar to that encountered when turning out of a junction without stopping. The study predicted that the thresholds for detecting either a car or a motorcycle would be higher during the self-motion condition compared with the no self-motion condition. The experiment featured additional vehicles, although these remained stationary as the aim was to reduce the complexity of the visual scene in order to investigate the level at which individuals are able to detect the approach of one vehicle during self-motion.

6.2 Method

6.2.1 Participants

A sample of 14 participants, 4 male and 10 female, were recruited. They ranged from 19 to 37 years of age, with an average age of 26 years (SD 5.81). Two participants were removed from the analysis due to high false positive readings.

6.2.2 Design

Chapter 6 featured a perspective-correct visual simulation of photographic images of vehicle approaching the observer viewpoint. In the same way as the experiments featured in Chapter 5, each of the experiments featured target trials and null trials. In the target trials, the target vehicle changed in size and speed to simulate approach at different rates of looming with a fixed TTP of four seconds. The lowest speed used was 30 kph / 18.64 mph. The target vehicle was manipulated using a parameter estimation by sequential testing procedure (Best-PEST; Lieberman & Pentland, 1982 – see Chapter 2). The PEST procedure was stopped after the tenth reversal and all other aspects of the design were the same as those featured in Chapter 5 (see section 5.2.2 for further detail).

6.2.3 Experimental Conditions

The design of the experiment followed that of those used in Chapter 5. The experiment consisted of a total of eight conditions. The conditions featured the target vehicle (motorcycle or car) stimulus approaching the observer in a virtual road scene featuring static additional objects (vehicles and a pedestrian) in the presence of lateral self-motion or no self-motion for a duration of 500ms. The lateral displacement (self-motion) simulated the visual consequences of the observer slowly rolling out of a junction at 7.5mph. In such a scenario, objects closer to the viewpoint move through a greater angle of displacement than those that are more distant. For example at the lowest speed we tested (30 km/h) the probe vehicle would translate laterally by 14 degrees as it approached. For a faster vehicle at 80km/h (50mph) this would be reduced to a 5.4 deg displacement. So although the amount of lateral optical displacement varies across vehicle distance this simulates what occurs in a natural visual scene with a moving observer.

Additionally, the type of flanking additional vehicle, which remained stationary in the opposite lane to the target vehicle, had two levels (motorcycle or car). The flanking stationary additional vehicle distance was adjusted in accordance with the target vehicle distance in order to prevent any occlusion during the simulated self-motion. This flanking additional vehicle was randomly positioned so that it was either at a greater or lesser distance than the target vehicle. All of the other additional vehicles were stationary in the start location used in Chapter 5.

6.2.4 Procedure

Participants sat one metre from the computer monitor, with an eye height of 1.2 metres and viewed all of the presentations binocularly. Participants were given a small number of practice trials with verbal feedback provided by the experimenter. The initial screen presented to the participants featured the city scene background, with contextual information such as buildings and road markings. Participants were asked to click the “Next” button, which was displayed at the foot of the screen. The target stimulus (motorcycle or car), the additional vehicles and a pedestrian were then displayed for 500ms with or without simulated self-motion. On the disappearance of the vehicles and pedestrian, participants were asked to select the lane that had contained a vehicle approaching their viewpoint. If they did not detect a vehicle approaching, they were asked to select the “None” button. Participants then clicked the “Next” button in order to continue with the next trial. No more than one vehicle approached the observer viewpoint in each trial.

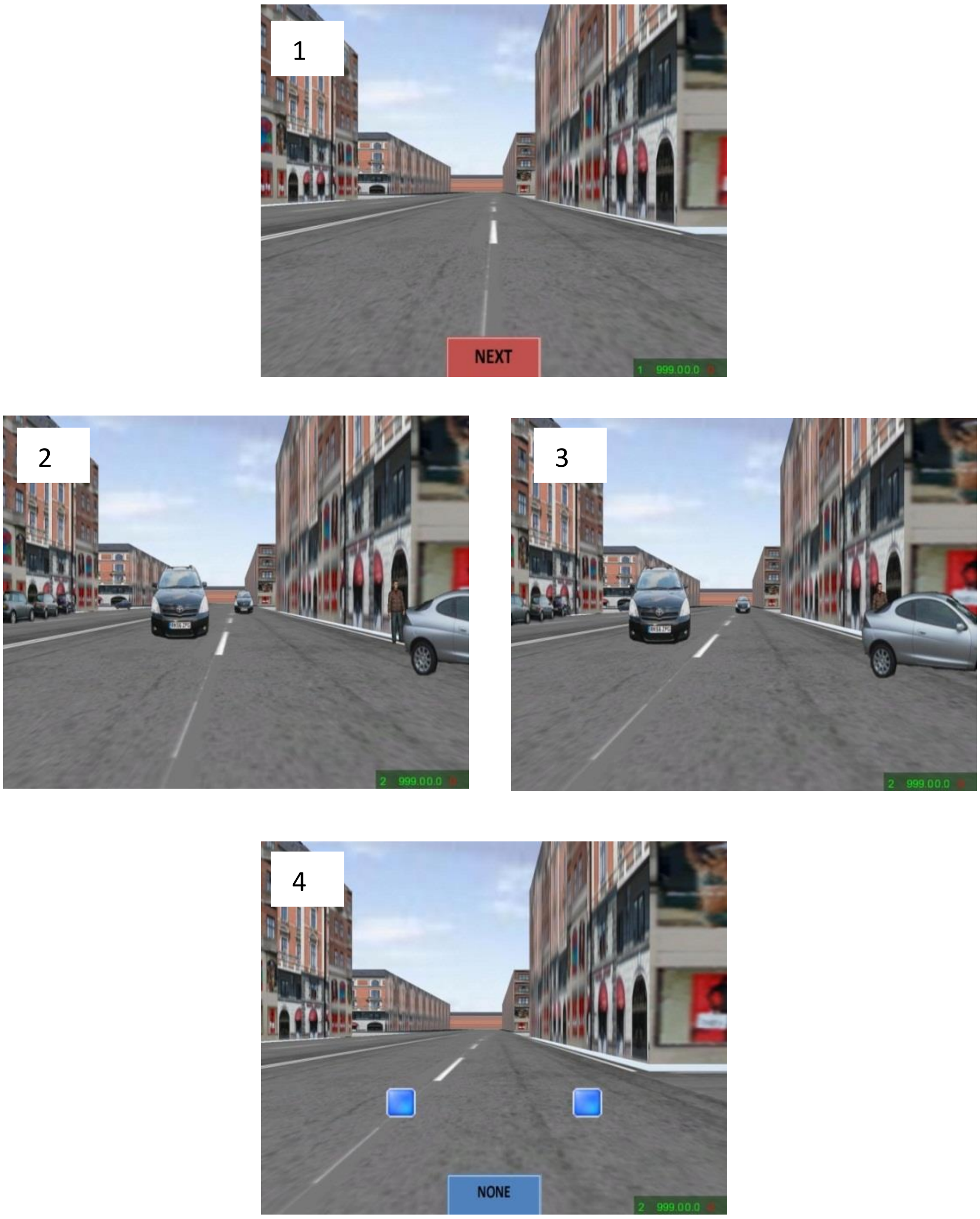


Figure 6.1: Visual display featuring (1) start screen, (2) start position for trial featuring a car stimulus, (3) final position for a trial featuring a car stimulus and (4) the decision screen

6.3 Results

A three-way repeated measures ANOVA was conducted with two levels of vehicle (motorcycle, car), two levels of motion (no self-motion, self-motion) and two levels of additional vehicle type (motorcycle, car). This revealed a significant main effect of vehicle type ($F(1, 11) = 18.10$, $p < .005$, MSe = .019, $\eta p^2 = .622$), where participants displayed higher thresholds for the detection of the motorcycle, compared with the car stimulus. The main effect of motion type ($F(1,11) = 11.82$, $p < .01$, MSe = .019, $\eta p^2 = .518$) was also significant, with participants recording higher thresholds for the detection of moving vehicles during simulated self-motion, compared with no self-motion. There was no significant effect of additional vehicle type ($F(1,11) = .66$, $p > .05$, MSe = .012, $\eta p^2 = .057$). There were no significant interactions.

Condition	Motion	Additional Vehicle	Mean Target Loom Level (rad/s)	Standard Deviation	Mean Target Speed (m/s)	Mean Target Speed (mph)
Motorcycle	None	Motorcycle	.0022	.0017	21.39	47.84
Motorcycle	None	Car	.0027	.0023	17.60	39.33
Motorcycle	Observer Motion	Motorcycle	.0047	.0033	10.00	22.38
Motorcycle	Observer Motion	Car	.0046	.0043	10.26	22.96
Car	None	Motorcycle	.0008	.0005	136.96	306.38
Car	None	Car	.0009	.0005	120.21	268.91
Car	Observer Motion	Motorcycle	.0016	.0021	68.32	152.83
Car	Observer Motion	Car	.0024	.0034	45.25	101.22

Table 6.1: Mean average loom level (degrees) and speed (mph) threshold judgements for target motorcycle and car stimuli

As stated in Chapter 5 (see Equations 5.3 & 5.4), the data displayed in Table 6.1 can also be expressed in terms of the TTP at which a vehicle would rise above the perceptual threshold for detection when travelling at different speeds (see Figure 6.2).

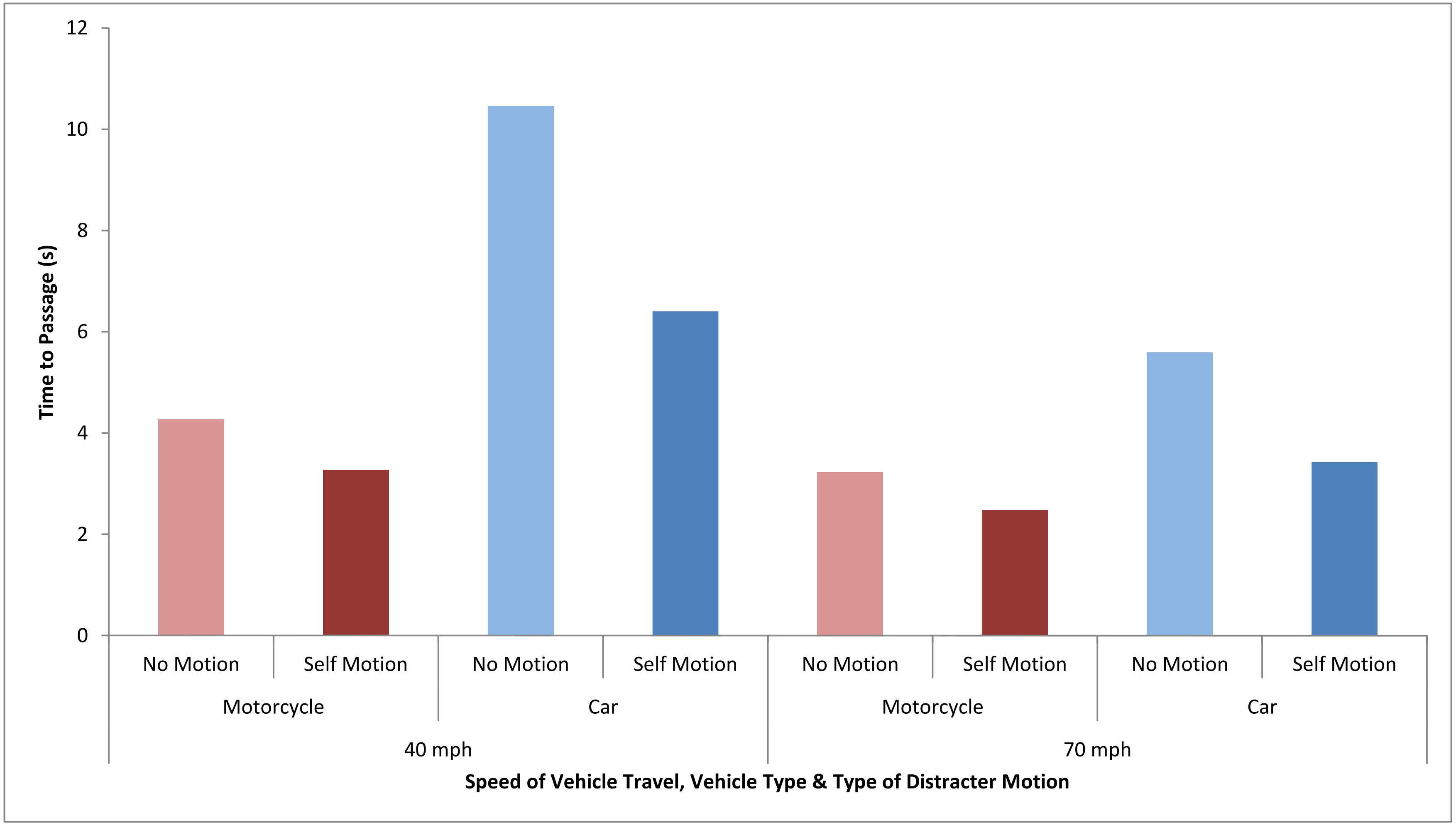
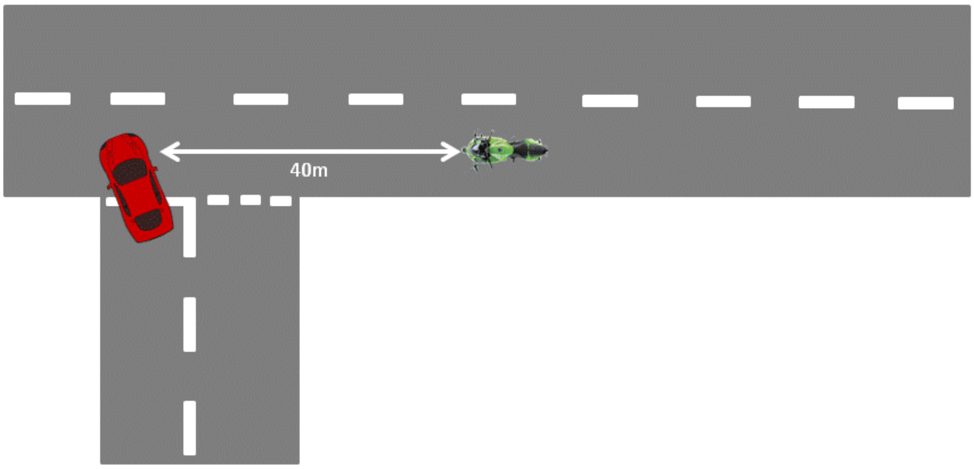


Figure 6.2: TTP at which vehicle would rise above perceptual threshold detection of approach at speeds of 40 mph and 70 mph.

6.4 Discussion

The present study examined how accurately individuals are able to detect the approach of moving motorcycles and cars during simulated lateral self-motion. The study supported the findings of Chapter 5, participants displayed higher thresholds for the detection of motorcycles compared with cars. The results also demonstrated that thresholds for the detection of approaching vehicles are higher in the presence of simulated observer motion, compared with no observer motion. This finding provides evidence that individuals are less sensitive to looming detection during simulated lateral self-motion.

The present study demonstrated that observer ability to detect the approach of both the motorcycle and car stimuli was adversely affected by simulated observer motion, regardless of the flanking vehicle type. In the worst case, for detection of the motorcycle when flanked by a car stimulus, the speed at which it could be detected was reduced from 39 mph without observer motion to just 22 mph in the presence of simulated observer motion. This means that if a driver was turning out of a junction without stopping they may fail to detect the approach of a motorcycle even if it was travelling under the speed limit and only 40-50m away. (see Figure 6.3). This finding might explain in part why drivers pull out into the paths of motorcycles when they are quite close to the junction (Gershon, Ben-Asher & Shinar, 2012).



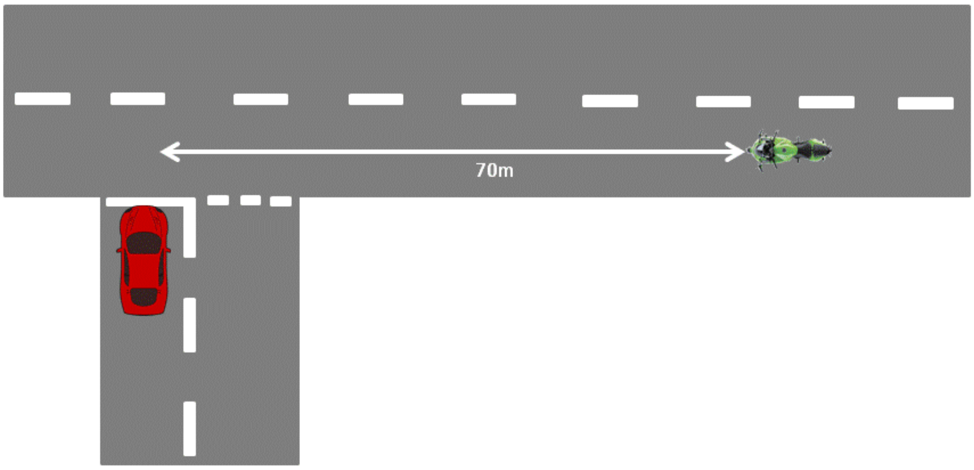


Figure 6.3: Roadside junction where a car is waiting to pull out into traffic. Upper: Motorcycle is approaching at 22 mph and located ~40m from the junction. Lower: Motorcycle is approaching at 39 mph and located ~70m from the junction. In both cases the TTP would be 4s, but the rate of expansion of the motorcycle, from the observer's viewpoint, would be lower than for the faster more distant motorcycle.

The experiment supported previous findings by Wann et al. (2011), who demonstrated that the additional lateral displacement of a looming vehicle can increase detection thresholds in adults. In the previous study, however, a single vehicle was placed within the scene and a fixed choice judgment was used; participants were asked to decided whether a vehicle approached their viewpoint or not. This experiment aimed to translate that finding to a naturalistic road scene, where the vehicle approached down a road alongside other vehicles and distracters. It is important to note, however, that to keep this experiment related to previous studies (e.g. Wann et al., 2011), only one moving vehicle was used and all others were static distracters. This is highly unlikely within a road scene, thus future research should focus on the effect of simulated observer motion on detection thresholds in the presence of a larger number of moving stimuli.

The findings in Chapter 6 have implications for design of road junctions. Whereas 'stop' signs that instruct individuals to stop before turning out of a junction are used globally, there is a tendency in some countries, including the UK, to only use them on junctions with severely reduced visibility. Our results clearly demonstrate that drivers' abilities to detect vehicle motion are impaired during lateral self-motion. As a preventative measure, 'stop' signs could be used at junctions where accidents involving a failure to give way to motorcyclists are particularly prevalent, even if visibility is apparently sufficient to preclude their use.

6.5 Summary

Chapter 6 has provided evidence that thresholds for the detection of a looming vehicle can be impaired by simulated lateral self-motion. The participant detection thresholds for vehicle approach were negatively affected by the simulated lateral self-motion, causing the speeds and distances at which vehicles would be detected as approaching in a real world scenario to become lower. The chapter suggested that these thresholds might be further negatively affected with the addition of further motion within the scene, such as an approaching vehicle in the adjacent lane. The designs for future road junctions and layout were discussed.

Chapter 7 – The effects of fluorescent garments on the detection motorcycle approach

7.1 Introduction

Chapters 3 and 4 have demonstrated that speed judgements for motorcycles can become dangerously inaccurate under diminished light levels. Chapters 5 and 6 demonstrated that detection thresholds for approaching motorcycles were significantly higher (poorer) compared with oncoming car stimuli. In addition, Chapter 5 demonstrated that the detection of the approach of motor vehicles can be affected by additional motion within the scene, particularly within foveal vision, and Chapter 6 showed that simulated lateral self-motion negatively impacted participant thresholds for the detection of oncoming vehicles. The chapters have proposed various interventions that may assist in the improvement of the above judgements or improve the knowledge of road users of their perceptual limitations. However, one issue that has not yet been addressed by this thesis in terms of detection and discrimination of vehicle approach is conspicuity, one of the most modifiable factors within the motorcycle accident literature (Lin & Kraus, 2009).

Sensory conspicuity refers to the degree to which an object can be distinguished from its environment (Hancock, Wulf, Thom & Fassnacht, 1990) and the properties of that object that attract attention (Connors, 1975 as cited in Cavallo & Pinto, 2011). Hurt, Oullet and Thorn (1981) assessed a sample of nearly 1000 motorcycle accident cases and noted that poor conspicuity was a causal factor in 46% of cases. Attempts to reduce automobile – motorcycle collisions have often led to a focus on modifying the physical characteristics of a motorcyclists and rider, thus altering their conspicuity (Hancock, Wulf, Thom & Fassnacht, 1990). However, while a vast amount of research has focused on this area, the results yielded have been mixed (Crundall et al., 2008).

Hole and colleagues (1995; 1996) conducted studies investigating the conspicuity of motorcycles within road scene environments. In their 1996 study, the authors showed participants still images of road scenarios and recorded their reaction time in identifying the motorcycle within the scene. The study featured a number of conspicuity factors, such as the operation of a headlight, the clothing worn by the motorcyclist, and the type of road environment utilised. While a number of statistically significant results were found, the authors emphasised the difficulty in drawing conclusions. In a specific example, the study found that the use of a headlight had the greatest effect on reaction time to identifying a motorcycle within a scene at the greatest viewing distance (distance of motorcycle from the front of the photograph). However, the study showed that participants identified the motorcyclist faster in scenes where the headlight was turned on regardless of clothing in the semi-rural environment, but in the urban environment, headlight use only enhanced conspicuity when the motorcyclist was wearing plain bright or patterned dark clothing (as opposed to plain dark or patterned bright clothing). The authors commented on the complex interactions between the road environment and motorcyclist, stating that a particular road scene that featured a flower bed may have silhouetted a motorcyclist wearing dark clothing, but camouflaged a motorcyclist wearing bright patterned clothing. While no solid conclusions were drawn, the authors warned that conspicuity aids should not be viewed as ubiquitous solutions to being seen in all road environments.

Some studies have noted significant benefits of conspicuity aids (e.g. Wells et al., 2004) and attempts to improve conspicuity have often focused on the use of fluorescent or reflective clothing (Hole et al., 1996). Turner, Simmons and Graham (1997) assessed the effects of fluorescent garments worn by road side workers in a field study and noted that vest colour had a significant effect on the distance at which participants detected their presence within a naturalistic scene. The authors noted that fluorescent red-orange was the most effective colour set, while yellow-green was also an effective combination, although the authors stressed that the colour used should be universal; creating some sort of visual 'signature' for the target (in this case road workers). However, in a naturalistic study on the daytime conspicuity of pedestrians, Sayer and Buonarosa (2008) demonstrated that the effect of fluorescent garments on identification time was affected by the complexity of the road scene. More specifically, the authors rated the road scene as either low or medium complexity. In the examples provided in the paper, low complexity scenes featured very little clutter and additional vehicles, while medium complexity scenes featured a high level of visual clutter, as well as traffic signals, and a large number of additional vehicles. The authors noted that on average, participants detected the presence of pedestrians 70 metres farther in low complexity scenes, compared with high complexity road scenes. Wells et al. (2004)

investigated 463 cases of motorcycle collision that resulted in hospitalisation or death and compared this sample with a control group of 1233 motorcycle riders in New Zealand. The control group were gathered by identifying motorcycle riders from 150 roadside survey sites on randomly assigned time of day, day of the week and direction of travel. The authors noted that riders who wore a reflective/fluorescent vest while riding had a 37% lower risk of being involved in a collision, while wearing a white helmet opposed to a black helmet was associated with a 19% lower risk of collision. As Hole et al. (1996) mentioned, these factors cannot be taken as solid evidence of the effectiveness of conspicuity aids, as often individuals who wear high visibility garments might be associated with lower risk driving groups (Rößger et al., 2012a). Hole et al. (1996) did note however that all other things being equal, the luminance contrast between the motorcyclist, the background and motorcycle might be a key determinant of the effectiveness of conspicuity aids.

The majority of experimental studies on motorcycle conspicuity have been carried out using static imagery (e.g. Hole et al., 1996). This generally involves participants being directed to search for a motorcycle within a photographic road scene while their reaction time is recorded. However, an acknowledged limitation of this study design is that individuals do not encounter static road scenes within a driving environment. Aspects such as clutter in the scene are important (Andersen & Enriquez, 2006) and included within static imagery studies, but dynamic scenes including motorcycle motion are rare within the literature on conspicuity, especially when considering laboratory studies rather than research in more naturalistic settings (see for example Donne & Fulton, 1985). In the study conducted by Hole et al. (1996), the authors noted that reaction time to the detection of motorcycles was shorter when the motorcycle was located at a closer distance and when at a further distance, participants sometimes failed to detect its presence altogether. Triesman (1996) added to this, citing that drivers may scan the traffic scene for a single feature of a potential hazard, but miss a faster approaching object that is placed further away. The role of motion capture in this could be crucial. The author is unaware of any experiments that have assessed the effects of conspicuity aids on the detection of motorcycle looming; such work might provide further information on the extent to which distance of the vehicle from the observer affects conspicuity.

Despite the absence of evidence for a ubiquitous conspicuity solution, many road safety organisations still encourage various conspicuity aids. High visibility garments for instance, are one of the most encouraged forms of conspicuity aid. Specifically, the Road Safety Authority (RSA) in Ireland seeks to improve the overall rate of motorcyclists wearing high visibility garments through its Motorcycle Safety Action Plan (RSA, 2010) and states that it wishes to introduce legislation to ensure this. The current study therefore aims to test whether the findings in Chapter 6, both in terms of the thresholds for motorcycle looming detection without simulated self-motion and with simulated self-motion, are affected by the introduction of a high visibility vest. The current study is exploratory. The visual looming equation should not be affected by the use of a high visibility vest as this will not affect the overall size of the motorcycle stimulus and thus should not affect detection thresholds. However, Crundall et al. (2008a) noted that the contrast between the motorcyclist and the background might be a key in the identification of a motorcycle with a scene. It might be hypothesised that a higher level of contrast might also lead to an improvement in the detection of the optical expansion of the contours of the motorcyclist as distance increases, thus improving thresholds for detection. The current study hypothesises that the detection thresholds for the motorcyclist stimulus in the high visibility vest will be lower (better) than for the motorcycle stimulus without the garment. Further, the study hypothesises that the detection thresholds for motorcyclists will be higher (poorer) than those for cars based on the findings in Chapters 5 and 6.

7.2 Method

7.2.1 Participants

A sample of 12 participants, 7 male and 5 female, with an average age of 23 years (S.D. 2.91) were recruited and paid £10 each for their time. The average number of years that drivers had held their licence was 4.9 years (SD 2.70).

7.2.2 Design

The design was the same as that used in Chapters 5 and 6 (see section 5.2.2 for further detail).

7.2.3 Experimental Conditions

The experiment comprised eight conditions. The conditions featured the photographic target vehicle stimulus (motorcycle, motorcycle with high visibility vest, car or yellow car – see Figure 7.1) approaching the observer in a simulated traffic scene containing static distracter objects (vehicles and a pedestrian), either in the presence of lateral self-motion or no self-motion for a duration of 500ms. The remainder of the experimental controls were the same as those used in Chapter 6. The type of static flanking vehicle however, was randomised between the car and yellow car stimuli for all target motorcycle trials and the motorcycle and motorcycle with high visibility vest for all target car trials. The study included a yellow high visibility vest on the motorcyclist in order to increase the luminance contrast between the motorcyclist and the background, because despite the finding by Turner et al. (1997) that red-orange vests were the most effective in terms of identification time, the virtual scene featured a number of red brick buildings. The yellow car was included in the experimental set up as a control. The flanking stationary distracter vehicle distance was adjusted in accordance with the target vehicle distance in order to prevent any occlusion during the simulated self-motion. This flanking distracter vehicle distance was varied so that it was either at a greater or lesser distance than the target vehicle. All of the other distracter vehicles were stationary in the same locations as in Chapters 5 and 6. As in Chapters 5 and 6, thresholds were converted into metres per second and presented in miles per hour in order that our findings might be related to everyday road speeds.

7.2.4 Procedure

Participants sat one metre from the computer monitor, with an eye height of 1.2 metres and viewed all of the presentations binocularly. Participants were given a small number of practice trials with verbal feedback provided by the experimenter. The initial screen presented to the participants featured the city scene background, with contextual information such as buildings and road markings. Participants were asked to click the “Next” button, which was displayed at the foot of the screen. The target stimulus (motorcycle, motorcycle with high visibility vest, car or yellow car), the additional distracter vehicles and a pedestrian were then displayed for 500ms with simulated self-motion or without simulated self-motion. On the disappearance of the vehicles and pedestrian, participants were asked to select the lane which had contained a vehicle approaching their viewpoint or to select the “None” button if they did not witness a vehicle approach them. Participants then clicked the “Next” button in order to continue with the next trial.

Figure 7.1: Motorcycle, High visibility motorcycle, Car and Yellow car stimuli

Figure 7.2: Visual display featuring (1) start screen, (2) start position for trial featuring a motorcycle with high visibility vest stimulus (yellow car is static), (3) final position for a trial featuring a motorcycle with high visibility vest stimulus and (4) the decision screen

7.3 Results

A three-way repeated measures ANOVA was conducted with two levels of motion (no self-motion, self-motion), two levels of vehicle (motorcycle, motorcycle with high visibility vest, car and yellow car) and two levels of conspicuity (low conspicuity, high conspicuity). This revealed a significant main effect of vehicle type ($F(1, 10) = 22.65$, $p < .005$, MSe = .000, $\eta p^2 = .694$), a significant main effect of motion type ($F(1,10) = 7.53$, $p < .005$, MSe = .000, $\eta p^2 = .429$) and a significant main effect of conspicuity ($F(1,10) = 5.15$, $p < .05$, MSe = .000, $\eta p^2 = .429$. There was a significant interaction between vehicle type and conspicuity ($F(1,10) = 8.16$, $p < .05$, MSe = .000, $\eta p^2 = .536$).

Bonferroni pairwise comparisons demonstrated that detection thresholds for the yellow car were far lower (leading to less safe pull out judgements) than for the black car ($p < .05$, 95% CI: .001-.003).

Table 7.1: Mean average loom level (rad/s) and speed (mph) threshold judgements for target vehicles.

Vehicle	**Motion**	**Mean Target Loom Level (rad/s)**	**Standard Deviation**	**Mean Target Speed (mph)**
Motorcycle	None	.0024	.0018	43.70
Motorcycle	Observer Motion	.0051	.0029	20.56
Motorcycle with High Visibility Vest	None	.0021	.0014	49.94
Motorcycle with High Visibility Vest	Observer Motion	.0042	.0024	24.97
Car	None	.0012	.0060	203.93
Car	Observer Motion	.0015	.0012	163.14
Yellow Car	None	.0021	.0011	116.53
Yellow Car	Observer Motion	.0045	.0041	55.62

7.4 Discussion

The purpose of the present study was to examine whether the inclusion of a high visibility vest on a motorcyclist improved thresholds for the detection of an approaching motorcycle stimulus. The study did not find a significant effect on improvement of detection thresholds for approaching motorcycles. The study once again provided evidence to support the findings of Chapters 5 and 6, demonstrating that participants displayed higher thresholds for the detection of the motorcycle stimuli compared with the car stimuli. Furthermore, the study supported the findings in Chapter 6 that simulated self-motion led to higher (poorer) thresholds for the detection of looming motor vehicles. The study did however note a significant effect of conspicuity and specifically showed that participants were significantly better at detecting the approach of the black car compared with the yellow car. This effect is likely to be artifactual or due to a confound in the car type used in the experiment. Two different cars (MG and Toyota) were used and the perspective angle at which the photographs were taken from were not controlled to a great enough extent. This is likely to explain the difference between the detection thresholds for the two vehicles.

As mentioned in the introduction to this chapter, the inclusion of a high visibility vest did not increase the overall size of the motorcycle and thus the equation proposed by Lee (1976) would not have predicted an improvement in detection thresholds. However, various authors (e.g. Crundall et al., 2008a; Hole et al., 1996) have intimated that luminance contrast could be a key aspect in terms of identifying motorcycles within a road scene. Thus, the present study hypothesized that while the physical size of the motorcycle was not increased, the change in contrast might assist individuals in detecting the optical expansion of the motorcyclist. However, while some studies have found high visibility garments to improve conspicuity (e.g. Wells et al., 2004) and others have found mixed results (e.g. Hole et al., 1996), the present study found these garments to have no significant effect on detection thresholds for looming.

It appears that while luminance contrast may sometimes be an important aspect of the identification of a motorcycle within a road scene, motion processing is more important in terms of looming detection. Furthermore, the complexity of road scenes means that the use of fluorescent garments in increasing the luminance contrast between riders and their background will vary in success between certain contexts. The situation included by Hole et al. (1996) whereby the motorcycle passed in front of a flower bed, which could cause camouflage if the motorcyclist was wearing bright colours is just one example of this. This type of conspicuity aid is also unlikely to significantly improve motorcycle appraisal in night-time and twilight conditions, unless there are street lamps or car headlights that shine directly on the rider.

7.5 Summary

The present chapter featured an exploratory study that aimed to investigate whether the inclusion of a high visibility vest could improve the detection thresholds for an approaching motorcycle. No evidence was found to suggest that these garments improve the detection of looming.

Chapter 8 - Discussion

8.1 Introduction

The aim of the thesis was to investigate the accuracy with which people can make perceptual judgements for approaching vehicles in terms of detection, and discriminating between looming rates of cars, motorcycles and motorcycles with adapted headlight configurations. The influence of different levels of ambient light on gauging vehicle approach speed was also explored in a number of experiments, as was how an adapted motorcycle headlight configuration might improve an observer's accuracy in gauging motorcycle approach under reduced lighting conditions.

The proficiency of drivers in making perceptual judgements can contribute to them safely pulling out from road junctions. Road traffic accidents account for approximately 1.2 million deaths every year worldwide (Rifaat et al., 2012). In the UK, motorcyclists, despite accounting for just 1% of traffic, account for 19% of all fatalities on the road (Department for Transport, 2010a). Official road casualty data compiled by the Department for Transport (2010a) has demonstrated that approximately 61% of all car and 75% of all motorcycle accidents (in which someone is injured) occur at roadside junctions; furthermore, the misperception of the speed and path of another vehicle has been highlighted as the second largest contributory factor recorded in vehicle collisions in which someone is injured

(Department for Transport, 2010a). The thesis focused on the perceptual components that allow a driver to safely negotiate out of a road junction and into the flow of traffic in the presence of oncoming motorcycles and cars.

Overall, the thesis has demonstrated that the human perceptual system has limitation in its thresholds for utilising information that contributes to accurate time to passage (TTP) judgements. It has been noted that motorcycles are at greater risk on the roads due to their smaller size relative to other vehicles. However, a simple intervention involving the introduction of additional headlights was found to improve the accuracy of motorcycle speed judgements, specifically under low levels of ambient lighting. Based on the results of the thesis, recommendations have been made regarding speed restrictions and road design. The overall results related to the perceptual processes investigated in each chapter are discussed below. More specifically, these processes have been broken down into three areas; relative speed judgements, detection of vehicle approach and conspicuity. The ability of individuals to judge the speed of oncoming motor vehicles is critical in order that they may make accurate TTP estimates about the immediacy of the threat posed by that vehicle. Further, the ability of drivers to detect a vehicle as approaching them within the road scene is necessary before they are even able to begin to judge its speed of approach. Lastly, while the issue of conspicuity has been heavily researched within the motorcycle accident literature, this has rarely occurred under strict psychophysical conditions. It is therefore important to understand whether conspicuity aids can affect participant thresholds within a controlled laboratory environment, as opposed to natural environments where often a number of complex interactions between conspicuity aids, search instructions, and contextual factors such as the background context may be taking place.

8.2 Relative Speed Judgements

The ability of individuals to judge the immediacy of the threat posed by approaching vehicles at road junctions relies on their ability to estimate the TTP of those vehicles. This ability involves the driver's sensitivity to the speed and therefore visual looming of the vehicles approaching. According to Lee (1976), individuals are able to judge the TTP of an object based on tau, the optical size of the object in time divided by its rate of expansion in time. Despite evidence supporting these claims (e.g. Lee & Reddish, 1981), a number of studies have demonstrated that additional visual cues can influence TTP judgements (e.g. DeLucia et al., 2003). Specifically, DeLucia and colleagues (1991a; 1991b) demonstrated the size arrival effect, whereby smaller objects were deemed to arrive at a later time than larger objects. This observation ties in with the rate of expansion or visual looming of an object, which is reliant on physical size as well as velocity and distance. Evidence has suggested that motorcycles are at a greater risk on the roads due to their smaller physical size (e.g. Horswill et al., 2005) and therefore it could be argued that this misperception leads to drivers not perceiving them as imminent threats at junctions. The first two experimental chapters

(Chapters 3 and 4) focused on the ability of individuals to make relative speed judgements for motorcycles and cars.

Chapter 3 assessed driver ability to make relative speed judgement decisions in night-time and day time conditions. In all conditions, participants viewed a reference car stimulus approaching the observer viewpoint at a speed of 30 mph, which was paired with a probe vehicle (solo headlight motorcycle, car, tri-headlight motorcycle). The speed of the probe vehicle was manipulated. On a methodological note, the chapter also investigated whether the accuracy of relative speed judgements was influenced by stimulus presentation; sequential or simultaneous. The day time condition demonstrated that participants were significantly less accurate at judging the speed of the motorcycles (solo and tri-headlight) compared with the car stimulus. This supported previous findings that smaller vehicles are deemed as arriving later than their larger counterparts (Caird & Hancock, 1994; Horswill et al., 2005), even when actual TTP remains constant. Theoretically, the findings supported the size arrival effect noted by DeLucia (1991a; 1991b). The finding did not however, fit with the tau theory (Lee, 1976), which claims that judgements would not be influenced by object size. The average speed difference to which participants were sensitive between the solo motorcycle and the reference car stimulus was 18 mph, while the difference was only 6 mph between the probe car and the reference car. While this difference may appear marginal, this error in perception may have a large bearing on whether an accident occurs. Specifically, when the reference car was travelling at 30 mph and the probe motorcycle at 48 mph, participants were unable to distinguish which was travelling at the greater speed. However, without physically increasing the physical size and therefore surface area of the motorcycle, this finding is difficult to reverse perceptually. A recommendation therefore, would be to raise awareness of this issue and highlight that even in optimal daylight conditions, drivers may see a motorcycle, but not necessarily be able to accurately judge the immediacy of the threat posed by it. Additionally, motorcyclists might be informed that they should stick to the speed limit for their own safety. Findings from observational studies (see e.g. Walton & Buchanan, 2012; Horswill & Helman, 2003) that motorcycles do travel faster on average than surrounding traffic when at junctions underline the importance of awareness raising in this regard.

Chapter 3 featured experiments that investigated the ability of drivers to judge the speed of motor vehicles when only the white headlights were visible on a black background. The chapter demonstrated that cars yielded the most accurate speed judgements, while solo headlight motorcycles yielded the least accurate. The results also demonstrated that the introduction of a tri-headlight configuration significantly improved speed judgements of the motorcycle. It appears that it is not only the physical surface areas of the headlights that individuals utilise when making speed judgements, but also the separation between the edges of those headlights. The findings once again supported the findings that object size influences speed judgements (e.g. Horswill et al., 2005). Theoretically, the findings supported the notion of “gap-tau” (Tresilian, 1991), whereby the TTP of an object could be calculated from the divergence of two features. This utilised the same equation proposed by Lee (1976), but the object size is defined by the optical gap between the two edges of the stimulus.

The improvement in speed judgements caused by the tri-headlight led to another experiment being conducted to assess the effectiveness of different formations. The study compared four different formations, all of which featured one main 20 cm diameter headlight and two flanking 10 cm diameter headlights, which were arranged either horizontally, vertically, in a triangle with the large light at the top, or in a triangle with the large light at the bottom. The study demonstrated that the triangular formations yielded the most accurate speed judgements, while there was no significant difference between the horizontal and vertical arrangements. It could therefore be argued that the combination of vertical and horizontal expansion provides a stronger percept of the looming of a vehicle than each in isolation. However, car headlights only separate along the horizontal axis, so it may be that there is a critical gap size that best suits human sensitivity to headlight separation. Further research should aim to investigate this, by comparing a range of headlight sizes and separation distances to find the optimum arrangement. It is important to note that while there was a significant difference between the triangular formations and the vertical and horizontal configurations, the experiment did not compare these with the original solo headlight. Thus, it is unknown whether these two formations may have improved on the solo headlight speed judgements. While the triangular configurations have been shown to assist speed judgements, they may also be useful in creating a “visual signature” for the motorcycle. A topic for debate in the motorcycle accident literature is the European legislation (ECE R48) that daytime running lights are mandatory for all cars produced post-2011. Cavallo and Pinto (2011) demonstrated that the use of car daytime running lights led to impairment in participant ability to detect the presence of a vulnerable road user (cyclist, motorcycle or pedestrian) within a road scene. To combat this detriment, Cavallo and Pinto (2011) have begun researching visual signatures for motorcycles, so that they are easily recognisable. This idea has also been utilised by Rößger et al. (2012a), who demonstrated that the use of a t-light on a motorcycle led to reduced identification times, particularly within a busy road scene. Further research should incorporate the tri-headlight formation into this visual signature research as it is a simple engineering intervention that could be fitted to a large number of motorcycles and may aid detection, identification, and detection of looming.

Lastly, Chapter 3 aimed to compare two presentation types; simultaneous and sequential. The studies demonstrated that overall, individuals displayed more accurate speed judgements in the sequential conditions than in the simultaneous conditions. This could be due to the short presentation duration, whereby participants viewed the stimuli for 500 ms. In the sequential condition, participants would have been able to view one stimulus for 500 ms and then another stimulus for 500 ms. Conversely, in the simultaneous condition, participants would have viewed both stimuli approaching them for just 500 ms. A limitation regarding participant eye fixation required acknowledgement here. Participants were not provided with any explicit instructions on where to focus their eyes on the screen. This may have led to a scenario where participants were attempting to look at each vehicle in turn and the time may not have been available, thus leading to less accurate judgements. In terms of theoretical application, one could argue that in relative discrimination paradigms using short presentation durations, researchers should use sequential presentation to yield the highest level of accuracy from participant judgements. However, future research could aim to increase the length of the presentation duration in order to assess whether simultaneous presentation performance reaches the same level as sequential presentation performance.

It is important to note that the displays featured in Chapter 3 were extremely sparse and did not feature a number of cues that might be used in everyday speed judgements (e.g. height in the scene). It was therefore necessary to investigate these findings within a more realistic virtual environment in Chapter 4. It was also important to understand that ambient light levels do not reduce from day to night in one step and that the point at which motorcycle speed perception sharply decreases in accuracy warranted further investigation. The results in Chapter 4 demonstrated that individuals were significantly less accurate at judging the speed of the solo headlight motorcycle compared with the car and the tri-headlight motorcycle when the ambient lighting level reduced to early night and night. In these two lighting levels, the contour of the motorcycle and motorcyclist was more difficult to detect against the background compared with the other lighting levels, meaning that the perceptual judgement became more reliant on the headlights. There was no difference in participant ability to judge the speed of the car across any of the lighting levels. These results once more support the assertions made by researchers that the size of the vehicle is critical in immediacy judgements (Horswill et al., 2005). In terms of real-world application, the study provided further evidence for the use of the tri-headlight formation. Additionally, the consideration of ensuring that accident “black spots” feature a sufficient number of street lamps may also reduce the magnitude of perceptual errors in speed judgement by allowing more of the motorcycle and motorcyclist to be visible. However, a limitation acknowledgement of Chapters 3 and 4 was that only the very basic nature of geometric headlight shapes was assessed. This was in order to ensure that a high level of control was achieved. One feature that was not included was the glare from the headlights, which could be problematic as it might render the gaps between the headlights to be less visible, an area that future research should assess. However, the findings of the decrease in speed judgement accuracy for the solo headlight motorcycle in the early night and night conditions might be exacerbated when the glare from the headlights is taken into consideration, as the contrast between the motorcyclist and rider might become less at an earlier time of day.

Hwang and Peli (2012) stated that many studies have avoided investigating headlight glare due to the difficulties associated with realistic simulation, mainly due to parallax and brightness. The authors devised a headlight glare simulator through the use of an LED display board and beamsplitter, which were superimposed over the driving simulator screen. The positions of the illuminated LEDs were spatially synchronised with the positions of the oncoming vehicles on the screen and programmed with the same light intensity as real life headlights. The simulator only featured glare that covered the central monitors of the display as the authors stated that glare from cars in the peripheral monitors of the simulator was inconsistent. There are problems associated with creating this type of simulator, including parallax, where the distance between the LED plane and the beamsplitter and the beamsplitter and the LCD monitor is different. This can cause an alignment error, which the authors state can be overcome by running a calibration for every driver. This calibration produces a set of spatial mapping coefficients between the driving simulator's onscreen surface and the LED grid surface. The simulator in question here featured 25 x 25 LED boards, all of which required calibration.

Headlight brightness can also be difficult to simulate accurately due to the differences in luminance available on an LCD screen compared to the real world (as indicated in Chapter 4). However, Hwang and Peli (2012) stated that the Angular Light Intensity Distribution Map (ALIDM) offered a method of simulating headlight glare. The pupil size of a human being is small (less than 5mm with headlight glare) compared to the distance between the oncoming vehicle and the driver (> 5m). Once the luminous intensity is known according to the ALIDM, the amount of light projected to the driver's eye can be calculated. This is done by locating the projection point on the ALIDM and scaling it by projection distance. However, a limitation is that the simulator would be unable to vary this based on pitch, which would render inclines and declines in the road difficult to simulate.

The ambient lighting levels within the scene were manipulated in Chapter 4. However, a trade off exists between virtual reality and naturalistic presentations, as it is not possible to reproduce real world luminance levels on a computer monitor. Relative adjustments were made by measuring lighting levels at different periods of the day and then creating similar percentage reductions in lighting level in the virtual display, relative to the daytime levels. However, the extent to which contrast can be manipulated within a virtual reality display is problematic and even the simulator proposed by Hwang and Peri (2012) above would find this simulation challenging. It is for this reason that the findings of Chapter 4 should be built on by future research and assessed within a naturalistic setting if possible.

8.3 Detection of Vehicle Approach

Before an observer is able to judge the speed of an approaching vehicle, they need to detect that the vehicle is moving towards them. Hoffman (1994) provided post-hoc values for observers' thresholds for detecting vehicle approach, while Wann et al. (2011) investigated these thresholds further within a laboratory setting, manipulating age and simulated self-motion as two variables. These studies were extended by Chapter 5 and 6 by addressing the effect of vehicle size and the influence of additional motion (both within the scene and simulated lateral self-motion) on detection thresholds. The study provided evidence that detection thresholds for motorcycle approach were significantly poorer than for an approaching car stimulus in the presence of other static vehicles and a pedestrian within a contextually rich road scene. Specifically, when the TTP of the vehicle was fixed at four seconds, individuals failed to detect the approach of the motorcycle when it was at a closer distance (99 metres) than the distance at which they detected the car approaching (521 metres). This finding supported the assertion that smaller vehicles loom less than larger vehicles and thus are more likely to be travelling below the threshold for detecting looming (see Equation 5.1). Awareness should be raised with road users that even if they see a motorcycle within a scene, they should not assume that they are able to judge accurately whether it is safe to pull out. While not tested in the thesis, further research could investigate whether the introduction of the tri-headlight configuration assists the detection of a looming motorcycle in night-time driving conditions. Based on the findings of Chapters 3 and 4, one might hypothesise that detection thresholds should be lower for the tri-headlight motorcycle than for its solo headlight counterpart.

Chapter 5 also assessed the effect of additional foveal and peripheral motion on thresholds for the detection of car and motorcycle looming. The experiment demonstrated that additional foveal motion in the form of a car travelling towards the observer viewpoint significantly impaired detection thresholds for the car stimulus. The reason for this impairment cannot be inferred from the experiment conducted. However, a possible explanation might be that when attempting to detect the approach of two vehicles, the optically larger vehicle might be perceived as more immediate, at the expense of an optically smaller, faster moving vehicle. A potential explanation coincides with the proposed explanation for the detriment in performance observed in the simultaneous presentation in Chapter 3. Specifically, the time pressure within the laboratory study might have meant that individuals were unable to fixate on each vehicle in turn and thus in this instance, opted for the optically larger. However, the time pressures within the experiment also exist in real world scenarios, where individuals are often motivated by reaching a destination in the shortest possible time. Additionally, the first experiment in Chapter 5 compared additional motion (without separating foveal and peripheral) with no additional motion and two different display durations were utilised; 500 ms and 750 ms. The experiment found no difference in participant performance between the two presentation durations; thus a simple time pressure explanation does not seem likely in this instance. The research could be furthered by introducing eye tracking technology in order to understand where individuals are fixating within the road scene, in order to assess whether they actually fixate on each vehicle or whether the optically larger vehicle simply draws their gaze at the expense of the optically smaller vehicle. In terms of application, the study demonstrated a significant impairment in detection thresholds for cars, but did not find that this impairment would be present at real world driving speeds. However, the introduction of more scenic motion requires further investigation. The study utilised the same additional motion in all trials in order to exercise a robust level of control, while also allowing for looming to be measured within an applied paradigm. The scene featured vehicles and a pedestrian that were moving in natural ways, to ensure that participants were not confused by the additional motion. In order to further this experiment, a number of different motion scenes should be programmed and utilised in order to reduce the predictable nature of the stimuli locations. This should also include receding vehicles, an area that was not included in the study featured in Chapter 5. As the cognitive demands of the task increase through unpredictable additional motion and a greater number of moving objects, the impairment observed here in a very basic display might also increase.

Chapter 6 featured a study where the aim was to assess the effect of simulated lateral self-motion on looming detection. Firstly, the study provided evidence to support the poorer detection thresholds for the motorcycle compared with the car stimulus in Chapter 5. Secondly, the study provided evidence that simulated lateral self-motion significantly impaired participant detection thresholds for the target vehicles. The ability to extract local looming information from a globally translating retinal image is not a straightforward process. In Chapter 5, while the experiment attempted to investigate observers' abilities to detect visual looming, it might be that they were simply detecting the edge motion of the vehicles being tested. However, in Chapter 6, this was no longer a reliable cue due to the translating display. This therefore requires observers to suppress the global information and extract the looming information. The experiment demonstrated that observers are significantly impaired when doing this. Specifically, participants were able to detect motorcycles that were approaching when they were ~70 metres away when the observer viewpoint was static compared with only ~40 metres away during simulated self-motion. There was however, no effect of the type of flanking static vehicle used, providing evidence that the size of this vehicle did not influence looming detection thresholds. A consideration of the above study however, was that the vehicles used were two dimensional, meaning that as the participant viewpoint translated laterally, the perspective of the vehicle did not change. The use of three dimensional stimuli is demanding in terms of technology and thus was not used in the thesis. While I am unaware of any research that has suggested that this might make a difference, this change in perspective and the angle at which the vehicles are observed might provide some form of additional cue and thus future research should assess this.

On the whole, the results of Chapter 6 supported the findings by Wann et al. (2011) that simulated self-motion can negatively affect detection thresholds for object approach, and have key implications for road design. In a number of countries, vehicles are required to give way, but not stop at road junctions. This can lead to a situation where an individual is detecting vehicle approach whilst in motion themselves. The results suggest that the introduction of 'stop' signs at road junctions where accidents are particularly prevalent might lead to fewer perceptual errors in the detection of vehicle approach. This could be particularly beneficial to driver groups who are deemed at higher risk of collisions at junctions. Specifically, IAM (2010) demonstrated that older driver crash involvement was higher at junctions compared with other road situations (e.g. roundabouts) where pull out judgements were less reliant on gauging vehicle approach speed.

Overall, the two chapters demonstrated that the perceptual ability of looming detection is negatively impacted by the smaller size of the motorcycle. This might provide partial explanation as to why individuals often scan a road scene and pull out in front of an approaching motorcycle, despite accounts often stating that the driver looked directly at the motorcyclist (Pai, 2011). Specifically, a vehicle that is above threshold for detection of motion will "pop out", while a vehicle that is below threshold will appear static. As thresholds for the detection of motorcycle approach were poorer than for cars, motorcycles will more often appear below threshold within a road scene. The finding that drivers were unable to detect a motorcycle as moving towards them during self-motion when it was travelling at 22mph with a fixed TTP of four seconds might provide partial explanation as to why motorcyclists are often hit by cars even when they are located quite close to the junction.

It should be noted that Chapters 5 and 6 did not feature any kind of control over participant eye movements. Participants were instructed to detect which vehicles were approaching their viewpoint and thus we believe that they will have attended to the two lanes present within the display. However, an extension to the present study could be to look at gaze patterns and observers fixate smaller objects such as a motorcycles when they are approaching threshold.

In terms of contribution to theory, Chapters 5 and 6 were designed to provide an additional step in TTP research. Models for the judgment of time to collision such as 'tau' (e.g. Lee, 1976) have been based on the assumption that individuals are always able to perceive the looming of an object. Previous research has demonstrated that some individuals, such as children or children with special needs may have significantly poorer ability to detect the looming of an object (Wann et al., 2011; Purcell et al, 2011, Purcell et al 2012). Chapters 5 and 6 have provided evidence that factors including vehicle size, the additional motion of other objects within the scene and simulated lateral self-motion can all negatively impact upon the abilities to detect looming. When the task to be undertaken allows for the object to be tracked across its trajectory and hit or intercepted close to the observer then in most circumstances the rate of expansion will have risen about the observer's threshold so that a tau estimate will be available. But some of the most critical and dangerous activities that we undertake in modern society, such as crossing a road in a busy city centre or pulling out from a junction into a stream of traffic require judgments when the vehicle is a considerable distance from the observer. In these cases we cannot assume that the rate of looming is above threshold. The ability to detect a vehicle approaching, and possibly TTP, will be dependent on the speed of approach, which the vehicle dropping below threshold with increasing speed (see equation 5.2), and also may be affected by distracters in the scene. Future work on collision processing should take into account the incidence of critical TTP judgments that have to be made well in advance of object arrival and the potential threshold for detection of image expansion in different scenarios.

The two perceptual processes of relative speed judgements and looming detection have both illustrated the limitations of the human perceptual system in terms of pull out judgements. However, the tri-headlight configuration has demonstrated how a small engineering intervention might significantly improve motorcycle speed judgements under low light level conditions. Several motorcycle manufacturers, including BMW, have already begun producing motorcycles fitted with a tri-headlight formation. The research presented in the thesis provides evidence that this design might well improve motorcycle safety and that future research should aim to find the optimum headlight arrangement. The final chapter aimed to assess the basic conspicuity aid of a high visibility vest as a potential cost-effective opportunity to enhance the detection of looming motorcycles.

8.4 Conspicuity

While conspicuity was not a theme that was central to the thesis, Chapter 7 aimed to assess whether conspicuity might affect detection thresholds for vehicle approach. The rationale for this study was that individuals are often advised to wear fluorescent garments when riding motorcycles by information sources (e.g. RSA, 2010). However, the research on the effects of conspicuity aids on motorcyclist safety has yielded mixed results (e.g. Hole et al., 1996; Wells et al., 2004). Specifically, research has noted that the effectiveness of conspicuity aids is affected by factors such as the type of road environment (e.g. rural or urban) and the distance at which the vehicle is placed within the scene (Hole et al., 1996). Research has highlighted that luminance contrast between the garments, motorcyclist, motorcycle and the background might be a key factor in the effectiveness of these conspicuity aids (Crundall et al, 2008). The study therefore opted to assess the effects of the inclusion of a yellow high visibility vest worn by an approaching motorcyclist on motion detection thresholds. The procedure of the study followed that of Chapter 6, where participants were either subjected to simulated lateral self-motion, or a stationary observer viewpoint, and asked to judge the location of an approaching vehicle in the presence of lateral distracter vehicles. The study found that the vest had no effect on detection thresholds when the observer viewpoint was static or during simulated lateral self-motion. As far as the present author is aware, this is the first study to investigate the effect of conspicuity aids on looming detection during self-motion. The majority of research in the conspicuity area has tended to utilise static displays (e.g. Hole et al., 1996; Cavallo and Pinto, 2011). While the experiment did not demonstrate any significant results, the paradigm of investigating conspicuity aids within a moving scene should be utilised in future research. The study did demonstrate a significant effect of conspicuity on the car stimulus however, where participants were poorer at detecting the yellow car compared with the black car. However, as mentioned in Chapter 7, this is likely to be due to a lack of control.

8.5 Concluding Remarks

It is likely that during situations where individuals are required to exert high levels of attentional demand, such as negotiating a road junction during peak times, individuals adopt a heuristic approach to pull out judgements. In these situations, it is entirely possible that individuals use the heuristic that "if a vehicle is small and not expanding very quickly, it is safe to pull out. If a vehicle is larger and expanding quickly, it is not safe to go". The recommendations that arise from the results of experiments in this thesis regarding motorcycle safety are, if this description is an accurate one, therefore of paramount importance. The most important intervention suggested by the current research is the introduction of tri-headlight configurations mounted on standard motorcycle frames, which were shown to dramatically improve relative speed judgements. This idea warrants further investigation and the notion that individuals seem to be more sensitive to the separation of contours on both the horizontal and vertical axes compared with horizontal or vertical in isolation should be attended to. However, as mentioned previously, future studies should focus on finding the optimal separation distance between the headlights. The current thesis is not implying that only lights that separate horizontally and vertically can be effective, thus configurations with horizontal and vertical separation in isolation could be investigated. For example, Cavallo and Pinto (2012) have conducted experiments featuring motorcyclists wearing a light on their helmet and the effects on recognition within a busy static scene. While the purpose of their investigation was not speed related, if there is indeed an optimum separation distance between headlights that can also be applied to the vertical axis, this might be a very cost effective engineering intervention that could improve speed judgements. In terms of motorcycle recognition, research has been investigating the effects of creating a visual signature for motorcycles through the use of a lighting arrangement (Rößger et al., 2012a; Rößger, 2012b). While Rößger et al. (2012a) utilised a t-shape lighting configuration as a method for increasing motorcycle recognition rates, the tri-headlight might also be an effective and more subtle visual signature, while also improving speed judgements.

The finding that detection thresholds for motorcycle approach were poorer than for cars poses a slightly harder problem and, as stated previously, one that is unlikely to change without increasing the physical size of the motorcycle. However, highlighting this issue in various awareness and educational campaigns might encourage individuals to exercise a greater amount of caution if they do notice a motorcycle within a road scene. The effect of additional vehicle motion within the scene and its negative impact on cars also warrants further investigation. While the speeds at which individuals were able to detect an approaching car far exceeded worldwide speed limits in Chapter 5, the scenes were reduced in their complexity. Research should therefore further these studies by featuring vehicles that are travelling away from the observer viewpoint as well as a greater degree of visual clutter within the scene in order to increase the realism of the experience, and therefore the external validity of the findings.

The finding that individuals are less able to detect an approaching motorcycle during self-motion is of particular concern. This implies that when in motion, individuals may be less susceptible to the motion pop-out effect caused by a moving object within a scene, and thus more likely to make an erroneous judgement regarding the immediacy of the threat posed by the motorcycle. A suggestion would be to introduce 'stop' signs at junctions where accident rates are particularly high. This would reduce the number of instances where individuals are making pull out judgements whilst in motion themselves. However, the studies featured in Chapter 6 and 7 featured two dimensional photographic images and as a result, simulated self-motion only resulted in a change in the location of the vehicle in the visual field and not a change in the angle of visibility. Future research should opt to assess the effects of self-motion on three dimensional objects, which would display at different angles and may provide additional cues of approach during self-motion.

The research presented in the thesis has highlighted some the limitations of the human perceptual system with regards to detecting visual looming and making relative speed judgements. The thesis has argued that these low level visual mechanisms may be important in understanding why motor vehicle accident involvement is so prevalent at road junctions and furthermore, why motorcycle accident involvement is so disproportionately high relative to the proportion of motorcycles present on the road.

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