Apparent Distance and Attention in Simulated Driving

The effect of apparent distance on visual spatial attention in simulated driving

By Jiali Song, B.Sc.

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AUTHOR: Jiali Song (McMaster University)
SUPERVISOR: Dr. Allison Sekuler & Dr. Hong Jin Sun
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Lay Abstract

Our visual world is complex and dynamic, and spatial attention enables us to focus on certain relevant locations of our world. However, much of what we know about spatial attention has been studied in the context of a two-dimensional plane, and less is known about how it varies in the third dimension: depth. This thesis aims to better understand how spatial attention is affected by depth in a virtual three-dimensional environment, particularly in a driving context. Generally, driving was simulated using a car-following task, spatial attention was measured in a task that required detecting targets appearing at different depths indicated by cues perceivable with one eye. The results of this work add to the literature that suggests that spatial attention is affected by depth and contributes to our understanding of how attention may be allocated in space. Additionally, this thesis may have implications for the design of in-car warning systems.

Abstract

Much about visual spatial attention has been learned from studying how observers respond to two-dimensional stimuli. Less is known about how attention varies along the depth axis. Most of the work on the effect of depth on spatial attention manipulated binocular disparity defined depth, and it is less clear how monocular depth cues affect spatial attention. This thesis investigates the effect of target distance on peripheral detection in a virtual three-dimensional environment that simulated distance using pictorial and motion cues. Participants followed a lead car at a constant distance actively or passively, while travelling along a straight trajectory. The horizontal distribution of attention was measured using a peripheral target detection task. Both car-following and peripheral detection were tested alone under focussed attention, and simultaneously under divided attention. Chapter 2 evaluated the effect of target distance and eccentricity on peripheral detection. Experiment 1 found an overall near advantage that increased at larger eccentricities. Experiment 2 examined the effect of anticipation on target detection and found that equating anticipation across distances drastically reduced the effect of distance in reaction time, but did not affect accuracy. Experiments 3 and 4 examined the relative contributions of pictorial cues on the effect of target distance and found that the background texture that surrounded the targets could explain the main effect of distance but could not fully account for the interaction between distance and eccentricity. Chapter 3 extended the findings of Chapter 2 and found that the effect of distance on peripheral detection in our conditions was non-monotonic and did not depend on fixation distance. Across chapters, dividing attention between the central car-following and peripheral target detection tasks consistently resulted in costs for car-following, but not for peripheral detection. This work has implications for understanding spatial attention and design of advanced driver assistance systems.

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Declaration of Academic Achievement

I, Jiali Song, declare that this thesis titled, "The effect of apparent distance on visual spatial attention in simulated driving" and the work presented in it are my own. I confirm that all chapters have been conceptualized, carried out, and written by me with the guidance and advice of my advisors and advisory committee, with assistance from multiple undergraduate students in collecting the data in Chapters 2 and 3.

Chapter 1

Introduction

Imagine you're driving on a country road and a moose is about to step onto the road ahead of you. Do you notice it? There are many aspects of this scenario that are involved in determining its outcome, such as the speed at which you are driving and the speed at which the moose crosses the road. Another important aspect is the distance between you and the moose. If the moose is near you, you must slow down or swerve to avoid hitting the moose. A lack of action or even a small delay in your response may endanger you and the moose. Therefore, it would be advantageous to notice the moose as quickly as possible in order to respond appropriately in time. However, if the moose is far enough away such that it can reach the other side of the road before you reach it, you may simply ignore it, or you may not even notice the moose, with no consequence to you. Depending on the distance between you and the moose, the behaviour required for safety differs dramatically.

The scenario above illustrates the topic of this thesis, specifically, how the distance of stimuli affects the ability to attend and respond to them. This chapter begins by describing one influential model of spatial attention, the spotlight model, and briefly reviews the existing literature on the effect of depth on spatial attention. Next, I discuss the utility of studying the effect of distance in a driving context, and the motivations for the methods used in this thesis. Finally, I describe the goal and rationale for each subsequent chapter in this thesis and summarize their main findings.

1.1 Visual spatial attention

Our visual world is complex and dynamic, and visual processing is limited. It is impossible to process all facets of a visual scene to the same extent and still react appropriately in time. Visual attention allows us to process and respond to some aspects of the world that are important and behaviourally relevant. An important aspect of attention that facilitates behaviour is spatial attention, which refers to the ability to differentially encode and respond to stimuli based on their location.

Much of what we know about spatial attention is based on experiments that require participants to respond to stimuli on a single two-dimensional (2D) plane. One common analogy for spatial attention is a moving spotlight (Posner, 1980): Responses to stimuli that fall within the attentional spotlight are faster and more accurate compared to stimuli that fall outside of the spotlight. The attentional spotlight can move within the visual field overtly with eye movements, or covertly without eye movements. It is thought that the movement of the attentional spotlight enables spatial selection. An extension of the spotlight metaphor is that the spatial extent of the spotlight can be increased or decreased according to task demand as the zoom lens model suggests (Eriksen and St. James, 1986). Although this metaphor is intuitively compelling, many aspects of the spotlight metaphor have been challenged. For example, recent evidence suggests that attention within the spotlight is not always on (VanRullen, 2018), and attention may be allocated to multiple, simultaneous spotlights (Cavanagh and Alvarez, 2005).

1.2 The effect of depth on spatial attention

One important limitation of the spotlight analogy is how attention is distributed along the depth axis, an aspect of spatial attention that is largely unaccounted for by the prevailing models (Chun and Wolfe, 2001). Yet the ability to perceive distance and modulate the response to a stimulus based on its distance – for example, deciding when to cross the road, or where to place the foot when walking up the stairs – is critical to survival. Consistent with the idea that survival requires distance perception, our visual system is able to use multiple redundant sources of visual information, or cues, to perceive 3D spatial relations (Cutting and Vishton, 1995). Less is known about how three-dimensional (3D) information affects attention. Given that humans live in an interactive 3D world, studying attention in the context of such a 3D world is imperative to construct a more complete understanding of the functions of attention.

1.2.1 Separating targets and distractors in depth

The attentional spotlight metaphor suggests that attention should be equal for all objects that fall within the spotlight regardless of their distance to the viewer. However, binocular disparity-defined depth information affects attention. For example, separating a stimulus array in depth decreases response time for visual search (Finlayson and

Grove, 2015; Chau and Yeh, 1995; Theeuwes et al., 1998) and enables participants to track more moving objects in multiple object tracking (Viswanathan and Mingolla, 2002) compared to when the array is located along a single fronto-parallel plane. Moreover, larger separations in depth between the target and flankers reduce the interference of flankers (Andersen, 1990; Andersen and Kramer, 1993 but see Funke et al., 2015). These results suggest that participants were able to segment the stimulus array based on depth information, but distractors in non-target depths could not be completely ignored.

However, more depth information is not always beneficial for spatial attention, suggesting that the use of depth information is sensitive to context. The facilitatory effect of depth separation on search time decreased when the search array was spread over more than two depth planes, when the total volume of the search space increased (Finlayson and Grove, 2015; Chau and Yeh, 1995), and during conjunction search when the depth of the target is not known ahead of time (Finlayson et al., 2013; Dent et al., 2012; Theeuwes et al., 1998). Moreover, separation in depth did not shorten search time when the targets and distractors were depicted as lying on the same plane that extended across depths (He and Nakayama, 1995).

1.2.2 Near-far asymmetry about the fixated depth

Another question is whether near and far stimuli affect attention differently. Intuitively, one may expect nearer stimuli be treated with more urgency than farther stimuli because they are more likely to require an immediate response, such as in the moose crossing scenario at the beginning of the chapter. One idea that may account for this pattern of behaviour is an asymmetry in attention where attention is most concentrated in the space between the viewer and the fixation point and less concentrated beyond the fixation point. For example, reaction times for near targets (defined by crossed disparity) were faster than far targets (defined by uncrossed disparity) in endogenous cueing paradigms (Gawryszewski et al., 1987; Miura et al., 2002; Xia and Doi, 2009). Furthermore, invalid cues slow response time for far targets more than near targets for both exogenous (Marrara and Moore, 2000; Bauer et al., 2012; Atchley et al., 1997) and endogenous cues (Gawryszewski et al., 1987; Xia and Doi, 2009). However, there were also studies that failed to find an effect of cueing in depth (Iavecchia and Folk, 1994; Ghirardelli and Folk, 1996). Such a near-far asymmetry has also been found in an attentional capture paradigm, where the effect of a single distractor is greater at a near depth than a far depth (Plewan and Rinkenauer, 2020).

The distribution of attention may also depend on the *attended* location rather than the fixated location. When participants were asked to indicate whether two sequentially presented shapes are identical, response time was faster if the second shape appeared at a nearer depth than the first shape regardless of the depth at which the first shape appeared Arnott and Shedden (2000). Importantly, all shapes appeared in stereoscopic depths that are between the viewer and the plane of fixation and had identical retinal characteristics. This result suggests that the attentional asymmetry in depth may be centred on the attended depth rather than the fixated depth. The results of cueing studies are consistent with this idea because it is thought that attention shifts to the cued location after cue onset. Given that near or far depth was defined by the direction of disparity (i.e. crossed disparity simulated near depths and un-crossed disparity simulated far depths), the evidence from the cueing studies reviewed above cannot distinguish between the two interpretations. Near and far distances must be defined independently from the fixation point to clarify which of the two interpretations is more accurate.

If the distribution of attention is asymmetrical about the fixation distance, one would expect that fixating at a depth in front of or beyond a stationary target should modulate the response to the target. Few studies have examined the effect of fixation distance on the distribution of attention, but the results of these studies are consistent with the idea that the distribution of attention depends on fixation distance (Kokubu et al., 2018; Roudaia et al., 2017). Detection for the same peripheral targets were faster when fixating at a a depth beyond the targets compared to when fixation at a depth nearer than the targets (Kokubu et al., 2018). Moreover, larger separations in depth decreased tracking performance only when some or all objects appeared beyond fixation but depth separation had virtually no effect on performance when all objects appeared between the viewer and fixation (Roudaia et al., 2017).

Conversely, fixation distance should not modulate the effect of depth if the relative location of the stimuli and fixation were kept constant. Consistent with this prediction, cueing studies that maintained the spatial relationship between stimuli and the fixation point did not find a significant effect of fixation distance (Couyoumdjian et al., 2003; Kimura et al., 2009). These results are consistent with the idea that there is an attentional asymmetry in depth about the *fixated* depth plane.

1.2.3 Viewing distance affects attention along fronto-parallel plane

The previous section discussed the effect of fixation distance on attention to a different depth. Some studies suggest that varying fixation distance also modulates the distribution of attention along the fixated depth plane. Pseudoneglect is a small but consistent spatial bias in neurologically healthy participants, typically measured along a single front-parallel plane by asking participants to indicate the midpoint of a horizontal line (see Bjoertomt et al., 2002, for review). In peripersonal space, the space approximately within arm's reach, participants show a small but robust leftward bias in the perceived midpoint of lines. However, in extrapersonal space, or space beyond arm's reach, spatial bias shifts rightwards, resulting in smaller leftward biases or rightward biases (Dellatolas et al., 1996; Varnava et al., 2002; Garza et al., 2008; Longo and Lourenco, 2007, e.g.). The effect of distance on spatial bias also was found when distance was manipulated with pictorial depth cues in natural images, even though the boundary between peripersonal and extrapersonal space was not obvious in these stimuli (Nicholls et al., 2011).

The different distributions of attention in near and far space may also play a role in visual exploration (Hartmann et al., 2019) and visually guided grasping (de Bruin et al., 2014). However, it is unclear whether these tasks tap into the same mechanisms as more conventional indices of pseudoneglect. Although the most common variations of the line bisection task show good test-retest reliability, the magnitude of pseudoneglect across tasks is only modest correlated (Learmonth et al., 2015). The work on improving the construct validity of pseudoneglect is ongoing (Chen et al., 2019), but these studies consistently find that the distribution of attention along the fixated depth plane differ in near and far space.

1.2.4 Monocular depth cues

All of the studies reviewed so far included binocular disparity as a depth cue. However, the visual system is also sensitive to many monocular depth cues, including static cues such as linear perspective and elevation, and motion cues such as motion parallax and expansion (Cutting and Vishton, 1995). Monocular depth cues have been found to modulate the effects of exogenous cueing in a similar way as binocular disparity defined depth (Parks and Corballis, 2006; Han et al., 2005) but did not modulate endogenous cueing (Han et al., 2005). Moreover, in change blindness paradigms where depth was indicated by linear perspective, near targets were detected faster than far targets (Ozkan and Braunstein, 2010; Ogawa and Macaluso, 2015), and the distance effect was larger when binocular disparity cues were also present (Ozkan and Braunstein, 2010). These results suggest that monocular depth cues affect the distribution of attention in a way that is similar to those of binocular disparity – there may be a near-far asymmetry in the distribution of attention. However, the magnitude of the effect of depth may be modulated by contextual factors such as the type of spatial cue used and whether binocular disparity information is present.

Overall, the literature on the effect of depth on spatial attention suggests that depth modulates spatial attention. In particular, separation in depth can facilitate the segregation of targets and distractors. In addition, the distribution of attention is likely asymmetrical about the fixated depth such that attention is more concentrated at depths between the viewer and the fixated depth compared to depths beyond the fixation point. Lastly, depth also affects the spatial distribution of attention along the fixated depth plane. However, these effects of depth may depend on many contextual factors. Moreover, given the relatively small number of studies that have investigated these effects, many of the findings that support these conclusions should be replicated and examined in more diverse contexts.

1.3 Driving as a naturalistic context

Given the evidence reviewed above, there are several reasons to believe that driving is a particularly suitable context for studying the distribution of attention in depth. First, distance information is highly relevant to driving, so participants are primed to process depth information. The moose crossing scenario at the beginning of the chapter is such an example. Although avoiding collision with an approaching object may be completed through use of another heuristic or optical variable such as time-to-collision (Cavallo and Laurent, 1988; Vogel, 2003; Yan et al., 2011) or rate of expansion (Terry et al., 2008; Wann et al., 2011; Krauss et al., 2012), the contribution of distance information to attention cannot be ruled out given the body of literature reviewed so far.

Moreover, eye-tracking data suggest that driving requires switching attention between near and far distances ahead (Falkmer and Gregersen, 2001; Mourant and Rockwell, 1972; Underwood et al., 2003; Konstantopoulos et al., 2010; Lehtonen et al., 2013; Cohen and Studach, 1977). However, attention can be directed covertly such that the attended location is not always at the fixated location. Therefore, eye movement patterns forms an incomplete picture of how drivers distribute visual attention in 3D space. Other indices are required to more fully understand how distance affects the spatial distribution of attention in a driving context.

Secondly, the familiarity of the driving environment facilitates participants' interpretation of depth cues in the experimental stimuli. Real world driving includes a plethora of familiar objects and including familiar objects in the experimental stimuli allow participants to use familiar size as an anchor to estimate absolute distance (Cutting and Vishton, 1995). Given the scarcity of studies examining the distribution of attention at far distances similar to those commonly encountered in driving, the ability to more clearly indicate a far spatial range is an important characteristic of the driving environment. This aspect of the driving context makes it possible to study the distribution of attention across a wide range of distances far beyond reach.

Thirdly, studying attention in a simulated driving context allows investigators to use naturalistic tasks that include the demands of driving with precisely controlled stimuli. In other words, this approach balances the need for ecological validity and rigorous experimental design. For these reasons, driving is an excellent context in which to study the distribution of attention in a 3D volume of space simulated by monocular depth cues at far distance ranges.

Another benefit of studying driving is that it provides insight into how drivers parse their environment. Despite recent advances in vision and cognitive sciences, much is still unknown about how current knowledge in experimental psychology applies to driving (Rosenholtz et al., 2017; Wolfe et al., 2017). Furthermore, human factors research on driving and driver safety also needs to consider human cognition, yet poor communication between the the fields of vision science and human factors has resulted in a large gaps between common theories of human cognition used in the two fields (Wolfe et al., 2020). Hence, studying attention in the driving context is beneficial for both psychological science and human factors alike. For these reasons, it is important to study attention in the context of driving, not only on the effect of distance on attention, but also on other questions related to perception and cognition.

In conlusion, driving is a naturalistic context that primes participants to attend to distance information, facilitates simulation of far distances, and balances ecological validity with experimental rigour. These characteristics make driving an excellent context in which to investigate how the distribution of attention is modulated by distance, and contributes to knowledge translation between the fields of vision science and human factors.

1.4 The Useful Field of View (UFOV)

Visual-spatial attention has many facets, and it would be impossible to study all of them in a single thesis. Therefore, it is imperative to choose a measure of attention that fits the objectives of the current work. One way to describe the 3D spatial distribution of attention that is relevant to driving is the useful field of view (UFOV). One aspect of vision that the attentional spotlight theory does not account for even along a single two-dimensional plane is scene gist processing, the ability to make judgments about stimuli in the visual periphery within 10 ms of onset (Rosenholtz, 2016). These findings directly contradict the idea that stimuli outside of the spotlight region are not processed or ignored. The UFOV is one way to account for these results because it is an index of the extent to which information can be extracted without eye or head movements from the visual field, a similar idea to the functional field of view (Ikeda and Takeuchi, 1975). Typically, the UFOV is assessed with a task that requires participants to locate a briefly flashed peripheral target under focussed attention, in which participants perform the peripheral target detection task alone, and under divided attention, in which participants detect the peripheral target while simultaneously identifying a central stimulus (Sekuler and Ball, 1986).

Dividing attention may affect the UFOV in two ways: a narrowing of the UFOV referred to as tunnel vision, such that the decrements in target detectability increase with increasing target eccentricity, and a reduction in target detectability that is approximately equal at all target eccentricities, referred to as general interference (Mackworth, 1965). Previous research using the UFOV paradigm to investigate the effects of dividing attention find large general interference effects: the decrement in detection performance in both accuracy and response time are similar across all eccentricities (typically between 5-30 degrees visual angle (dva); Sekuler and Ball, 1986; Sekuler et al., 2000; Owsley et al., 1998a).

The UFOV is particularly relevant in the context of driving because it taps into cognitive abilities that are correlated with driving performance. Driving accident risk is correlated with the magnitude of the divided attention cost in the UFOV task, particularly in older adults (Owsley et al., 1998b; Clay et al., 2005; Wood et al., 2012). Older adults tend to show larger divided attention costs and have more individual variation which enables correlating performance in the UFOV task and in driving, whereas young adults tend to show little between-subject variation in divided attention costs, making it difficult to correlate UFOV with driving performance (Richards et al., 2006; Allahyari et al., 2007). Some studies have extended the UFOV paradigm to driving using videos of travelling on real roads, and found reduced ability to detect peripheral targets when hazards are present in the video compared to when hazards were not present (Crundall et al., 1999, 2002).

1.4.1 The effect of distance on the UFOV

A few studies have examined how the UFOV varies along the depth axis and suggest that the UFOV varies with distance. When varying physical viewing distance while holding the retinal size of the targets constant, a far viewing distance (133 cm) reduced the extent of the UFOV compared to a near viewing distance (39 cm, Li et al., 2011. This result is consistent with the idea that the distribution of attention along the fixated depth plane may differ in peripersonal and extrapersonal space.

When distance was simulated by binocular disparity, the best detection performance for peripheral targets that appeared at the same depth plane as the central target (Plummer, 2019). Furthermore, the duration required to reliably detect the peripheral target was slightly longer when targets appeared at the far plane compared to the near plane when attention was divided. However, there was no significant correlation between UFOV performance across depth with hazard detection rates because the participant pool consisted of young adults who generally performed at ceiling on the UFOV task. These results suggest that depth separation between the central and peripheral targets may impair peripheral detection. Furthermore, this decrement in performance is slightly smaller for near targets compared to far targets, a result that is consistent with the idea that attention is better for near compared to far distances. However, it is unclear how the UFOV is affected by monocular depth cues, particularly in the case of driving.

Previous studies that used simulated driving tasks imply that the UFOV can be modulated by distance (Andersen et al., 2011; Pierce and Andersen, 2014). Participants were required to follow a lead car at a constant distance while also reporting the location of a target on an overhead traffic light array. Distance was simulated using optic flow and linear perspective cues. Target detection was slower and less accurate as the light's distance from the viewer increased (Andersen et al., 2011) even when the retinal size and location of the targets were controlled (Pierce and Andersen, 2014). However, the target durations used in those studies were very long and therefore participants may have used multiple fixations to extract information from the visual displays. Hence, the results of Andersen et al. and Pierce and Andersen cannot be easily compared to other UFOV studies (which used very brief targets). The current thesis attempts to address these issues and characterize how the UFOV varies at far apparent distances in a simulated driving task.

The topic of the current thesis is also a part of an ongoing growth in interest in understanding the contribution of vision and cognition in naturalistic, everyday tasks (Hayhoe and Ballard, 2005; Land, 2006), such as walking (Matthis et al., 2018), assembling parts (Mennie et al., 2007), and catching a ball (Fooken et al., 2021). The rising interest in understanding naturalistic tasks parallels technological innovations that allows the collection of more complex data and correspondingly computationally demanding analyses. A major goal of this approach is to better connect what we have learned about perceptual and cognitive processes studied in laboratory tasks to the role they play in naturalistic behaviour, including driving. This thesis is part of the effort to more fully characterize attention in the variety of contexts in which we live. A better understanding of the effect of depth on attention in a driving context allows us to better understand how vision and attention in generally, as well as how they serve to enable behaviour. Finally, the work presented in this thesis may have implications for the design of advanced driver assistance systems, such as in-car warning systems.

1.5 Thesis Overview

The current thesis examines whether the 2D extent of attention is modulated across distance simulated by forward motion and pictorial cues. There are two data chapters, and a final chapter to discuss the implications of this work as a whole in the broader context of attention and driving. Each data chapter is written with their own introduction and discussion sections and may include some overlap with the current chapter and the general discussion.

In most of the experiments presented in the current thesis, the virtual environment consisted of a ground plane that extended virtually infinitely in all directions. Pairs of walls covered in a checkerboard pattern were placed along the fronto-parallel plane at regular intervals along a straight path. Throughout most experiments, a lead car was shown in the centre of the screen travelling along the straight path while varying its speed continuously and unpredictably.

The horizontal extent of the UFOV was measured using a peripheral detection task. Participants were asked to indicate whether a circular peripheral target appeared on the left or right wall. A target could appear when a participant reached a certain distance from a pair of walls. Targets appeared briefly (67 ms) to make our task comparable with that of the traditional UFOV paradigm. Critically, throughout all experiments, the retinal size and eccentricity of all possible targets were kept constant across distances. This ensured that only the background differed across distance conditions, which we varied in Chapter 2 to examine the relative contributions of various pictorial depth cues.

To investigate the dynamics of allocating attention to a driving-like central task, participants also completed a car-following task. Participants kept a constant distance behind the central, lead car by pressing the up and down arrow keys on a standard computer keyboard with their right hand to accelerate and decelerate their own viewpoint. Each task was completed alone, under focussed attention, or the two tasks were completed simultaneously, under divided attention.

Chapter 2 asks whether target detection is affected by apparent distance in the paradigm described above. Experiment (Exp) 1 replicated the effect reported by Pierce and Andersen (2014) using the paradigm described above and two target distances. Detection was overall more accurate and faster for near targets than far targets. Furthermore, the effect of eccentricity was also larger for far targets than for near targets, suggesting a reduced UFOV for far distance. However, in Exp 1, anticipation of targets was confounded with distance. As participants approached a pair of walls, they always reached a far distance before a near distance. Because the target only appeared at one distance per pair of walls, the absence of a target at the far distance indicated that a near target was likely to appear. This may have enabled participants to better anticipate near targets than far targets. Exp 2 examines the effect of target distance while equating target onset uncertainty by ensuring that there was a 50% chance of a target appearing at the near and far distance independently.

Exp 3 and 4 examine the relative contributions of pictorial cues in the effect of distance on target detection. Exp 3 examines the effect of pictorial and motion depth cues in the absence of checkerboard patterns on the walls. Exp 4 varies the size of the checks comprising the checkerboard pattern on the wall, the overall size of the wall, and the presence of the textured ground plane orthogonally in a static display to determine their relative contributions to the effect of distance on target detection.

Chapter 3 further characterizes the effect of depth simulated by motion and pictorial cues on the horizontal extent of the UFOV. Exp 1 asks whether the effect of distance on detection is monotonic by measuring detection at three target distances. Exp 2 asks whether the effect of distance depends on the location of the lead car by varying the headway, defined by the distance from the viewer to the lead car.

This thesis also examines how attention was allocated between the central car following task and the peripheral detection task. Throughout the thesis experiments, there were consistent divided attention costs in the performance of the central car-following task but not the peripheral detection task. Exp 3 of Chapter 3 also examines how headway affects the allocation of attention across the car-following and peripheral detection tasks.

Chapter 4 integrates the results presented in previous chapters, discusses their implications for understanding visual attention and driving, and recommends future research directions that arise from the results of the current work.

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Chapter 2

The effect of apparent distance on peripheral target detection during simulated car-following

2.1 Abstract

Previous research suggests that peripheral target detection is modulated by viewing distance and distance simulated by pictorial cues and optic flow. In the latter case, it is unclear what cues contribute to the effect of distance. The current study evaluated the effect of distance on peripheral detection in a virtual three-dimensional environment. Experiments 1-3 used a continuous, dynamic central task that simulated observers travelling either actively or passively through a virtual environment following a car. Peripheral targets were flashed on checkerboard-covered walls to the left and right of the path of motion, at a near and a far distance from the observer. The retinal characteristics of the targets were identical across distances. Experiment 1 found more accurate and faster detection for near targets compared to far targets especially for larger eccentricities. Experiment 2 equated the predictability of target onset across distances and found the near advantage for larger eccentricities in accuracy but a much smaller effect in RT. Experiment 3 removed the checkerboard background implemented in Experiment 1 and 2, and Experiment 4 manipulated several static, monocular cues. Experiments 3 and 4 found that the variation in the density of the checkerboard backgrounds could explain the main effect of distance on accuracy but could not completely account for the interaction between target distance and eccentricity. These results suggest that attention is modulated by target distance, but the effect is small. Finally, there were consistent

divided attention costs in the central car-following task but not the peripheral detection task.

2.2 Introduction

The complexity of the visual world makes it difficult to process all visible information to the same extent, so visual spatial attention allows for the selective processing of some regions at the expense of others. Most research on the spatial distribution of visual attention has focussed on the fronto-parallel plane, and relatively little is known about how attention is modulated in three-dimensional (3D) space. Several studies of attention in 3D space simulated by binocular disparity suggest that it is easier to attend to targets and more difficult to ignore distractors that appear between the viewer and the plane of fixation (Andersen and Kramer, 1993; Finlayson and Grove, 2015; Roudaia et al., 2017, 2018). Furthermore, in the absence of distractors, it is also easier switch attention to a near plane compared to a far plane in both virtual (Arnott and Shedden, 2000) and real distance contexts (Gawryszewski et al., 1987; Miura et al., 2002).

2.2.1 The useful field of view

One way to describe the spatial distribution of attention in the fronto-parallel plane is the useful field of view (UFOV), which measures the extent to which information can be extracted without eye or head movements from the visual field [1]. Typically, the UFOV is assessed with a task that requires participants to locate a briefly flashed peripheral target under focussed attention, in which participants perform the peripheral target detection task alone, and under divided attention, in which participants detect the peripheral target while simultaneously identifying a central stimulus (Sekuler and Ball, 1986). Peripheral performance is measured by the ability to correctly locate the target.

Typically, dividing attention affects the UFOV in two ways that are referred to as tunnel vision and general interference (Mackworth, 1965). Tunnel vision is a narrowing of the UFOV, such that the decrements in target detectability increase with increasing target eccentricity. General interference, on the other hand, is a reduction in target detectability that is approximately equal at all target eccentricities. Previous research using the UFOV paradigm to investigate the effects of dividing attention find large general interference effects, where the decrement in detection performance in both accuracy

[1] In this paper we use the UFOV synonymously with the functional field of view (Ikeda and Takeuchi, 1975).

and RT are similar across all eccentricities (typically between 5-30 degrees visual angle (dva); Sekuler and Ball, 1986; Sekuler et al., 2000; Owsley et al., 1998a). Some studies also attempted to extend this 2D paradigm to more naturalistic contexts. For example, when watching pre-recorded dash-cam videos, videos with a higher number of hazards resulted in general interference for detecting peripheral targets (Crundall et al., 1999, 2002). Studies using peripheral discrimination or identification tasks rather than peripheral detection tasks also report divided attention decrements that are approximately equal across target eccentricities, although there may be small tunnel vision effects (e.g. Ringer et al., 2016; Gaspar et al., 2016; Williams, 1988). These studies suggest dividing attention typically reduces peripheral visual performance approximately equally across target eccentricities.

2.2.2 The effect of distance on the UFOV

Although the 2D extent of the UFOV has been studied extensively, few studies have examined how it varies along the depth axis. Li et al. (2011) measured the extent of the UFOV at two depths by displaying stimuli on screens placed at near (39 cm) and far (133 cm) viewing distances. Critically, even when the retinal size and eccentricity of stimuli were equated across the two distances, the effect of target eccentricity on detection accuracy was greater at the far distance than the near distance. This result is consistent with the idea that the UFOV is smaller at a far viewing distance.

Previous experiments examining the effect of distance on attention typically manipulate depth using binocular cues. Monocular cues such as linear perspective and motion parallax also contribute to the perception of depth in naturalistic contexts, but relatively little is known about how monocular cues modulate attention.

In a simulated driving task where distance was simulated by pictorial cues and forward motion, participants detected a target faster and more accurately if it appeared nearer the observer (Andersen et al., 2011), even when the retinal size and location of the targets were controlled (Pierce and Andersen, 2014, Experiment (Exp) 2). In this task, observers tried to maintain a constant distance behind a lead car that changed speed unpredictably and simultaneously detected a peripheral target that was presented among a horizontal array of green and red distractors located in the upper visual field. As a participant approached a light array, the peripheral target changed colour from red to green or from green to red at one of four possible virtual distances (24, 36, 48, and 60 virtual meters, or m_v).

However, three aspects were not addressed by pervious experiments. First, the results of Pierce and Andersen (2014) may not be directly comparable to traditional measures of the UFOV because the targets used in these studies were displayed until a response was made (i.e. 400-700 ms), resulting in stimulus durations that are much longer than the brief stimuli typically used in UFOV tasks (i.e. $\leq$100 ms). A long target duration may have allowed participants to make eye movements to search for the target and as a result does not measure the distribution of attention at a single glance.

Secondly, driving accident risk is correlated with the magnitude of the divided attention cost in the UFOV task particularly in older adults (Owsley et al., 1998b; Clay et al., 2005; Wood et al., 2012), so it is important to examine how dividing attention affects the UFOV in a driving context. However, Pierce and Andersen (2014) did not measure focussed attention conditions.

Thirdly, the distance effect in Pierce and Andersen (2014) may not have been due to distance *per se* as participants may have anticipated the probability of target onset better at near distances than far distances. Specifically, each distance condition was presented successively – from far to near – as the participant moved towards the array of lights. A target could appear at only one distance, so if a target did not appear at a far distance, then the probability that a target would appear at the next, closer distance increased. Hence, the uncertainty about the onset of the target decreased as participants approached the array of distractors, and this reduction in uncertainty may have contributed to better performance at near than far distances.

2.2.3 Current study

We examined the monocular depth information that affects the horizontal extent of the UFOV using a simulated driving paradigm. As illustrated in Figure 2.1, the virtual environment in our study included a textured ground plane situated below the participant's viewpoint extending virtually infinitely in all directions. Arrays of two identical fronto-parallel walls (one left and one right side) were arranged along the z-axis extending into the screen in front of the observer. Self-motion was also simulated, where the participant's viewpoint moved forward in a straight path through the middle of the gaps between walls.

In rendering the 3D environment, the on-screen size and elevation of any texture elements were made in accordance with the geometrical rules for 3D presentation (i.e., an inverse relation between on-screen size and distance-to-viewer and positive relation

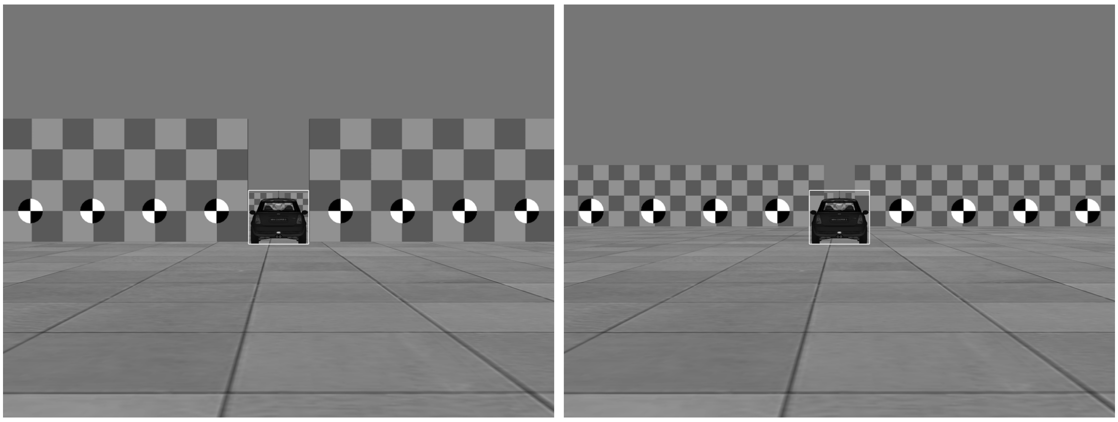

FIGURE 2.1: A schematic of all possible target locations in the near condition (left), and the far condition (right). Note that the retinal size of checks on the near and far walls differed, but the retinal position and size of the targets were identical at the two virtual distances. Target contrast was increased for illustration in this image and was lower in the experiment. On each trial, a target appeared at only one location. Finally, the lead car in the centre of the screen moved along a straight path at a speed that varied unpredictably over time.

between on-screen elevation and distance for objects on the ground). These texture elements on the ground plane and walls provided a source of distance information. Another source of information for the distance between the participant's viewpoint and target is provided through the spatial extent on the ground plane between participant and the bottom of the wall. In addition, optic flow due to simulated self-motion could also provide information about target distance.

The horizontal extent of the UFOV was measured using a peripheral detection task. The peripheral targets appeared on walls at a near ($18.5\,\mathrm{m_v}$) or far ($37\,\mathrm{m_v}$) distance from the viewer. We used a brief target duration (67 ms) to make our task comparable with that of the traditional UFOV paradigm. Critically, retinal size, eccentricity, and elevation of the targets were identical across distances. Simultaneously, participants kept a constant distance behind a lead car that varied in speed, either actively by changing their own speed, or passively where speed control was completed by the software.

To evaluate divided attention cost in both peripheral detection and car-following, we tested three blocks. Focussed attention was assessed using a peripheral detection alone block, in which car-following was passive, and a car-following alone block without target detection. The divided attention block, where both tasks were completed simultaneously, was tested last. Divided attention cost in peripheral detection is assessed by comparing detection performance in the focussed attention condition with that in the divided attention condition. Additionally, dividing attention may affect car-following performance, so divided attention cost in the car-following task is also assessed by comparing the car-following alone condition with the divided attention condition.

The goals of Exp 1 are to i) examine whether target detection is affected by the effect of apparent distance simulated by pictorial cues and optic flow; ii) provide a measure of peripheral attention comparable to the UFOV paradigm using a short target duration; iii) assess how performance on both peripheral detection and car-following tasks vary under focussed and divided attention. In Exp 1, the target always appeared in either near or far distance per a pair of walls. Exp 2 examines the effect of onset uncertainty on detection. Exp 3 and 4 examine the relative contributions of stimulus features to the distance effect. Throughout these experiments, we focussed our investigation on two aspects of the effect of distance: a near advantage averaged across all eccentricities, indicated by a significant main effect of Distance, and a greater effect of eccentricity at far distance, indicated by a significant Distance × Eccentricity interaction, and an effect of distance on the linear trend of performance across eccentricity.

2.3 Exp 1: Effect of target distance

2.3.1 Methods

Subjects

Twenty-eight undergraduate students at McMaster University who were naïve to the study's hypotheses participated in the experiment for partial course credit. Data from three participants were unusable due to programming errors. One additional participant was excluded due to a failure to respond in the car-following task. The final sample size was 24 participants (7 males) between 17 and 28 years of age (M = 18.9, SD = 2.2). Written informed consent was obtained before the start of the experiment following the Canadian Tri-Council Policy. The experimental procedure was approved by the McMaster Research Ethics Board.

Stimuli & Design

Stimuli were back-projected onto a white screen. A JVC DLA-sx21 projector was placed 2.85 m from the centre of the screen at a height of 0.90 m. The display area extended 51.2 dva horizontally and 39.3 dva vertically from the viewing distance of 1.5 m. All stimuli were in grayscale and were programmed in Vizard 4.0 and displayed using a

Dell XPS-27 All-in-One computer at 1366 × 1024 pixels resolution with a refresh-rate of 60 Hz.

An egocentric view of the virtual environment, illustrated in Fig. 2.1, was shown from an eye-height of one virtual metre (m_v). Participants travelled forward behind a lead car along a straight trajectory at an average speed of 60 km_v/h or 16.67 m_v/s. The lead car varied in speed throughout the experiment. Following the approach of Bian et al. (2010), the speed of the lead car was defined by the sum of 3 sine wave functions with frequencies of 0.033, 0.083, and, 0.117 Hz with respective amplitudes of 9.722, 3.889, and 2.778 km_v/h. At the beginning of each block, phases of the two highest frequency sine-wave components were generated randomly, and the phase of the lowest frequency component was set such that the starting speed of the car at the beginning of each trial was 60 km_v/h. These settings made it difficult to predict the lead car's speed and to present different variations in speed in each block.

Participants moved along a straight trajectory that passed through a 4 m_v gap centred on the screen in textured walls every 50 m_v. The walls were 4 m_v tall and 18 m_v wide, oriented perpendicular to the ground plane and along the fronto-parallel plane. The checkerboard pattern on the walls had a Michelson contrast of 0.36 and an average luminance of 8.40 cd/m^2. Each square in the checkerboard pattern extended 1 m_v^2, resulting in spatial frequencies of 0.17 cycles/dva and 0.33 cycles/dva at 18.5 and 37 m_v respectively. At an average speed of 16.67 m_v/s, the participant passed a pair of walls at an average time interval of approximately 3 s.

Peripheral Detection Task For each pair of walls, a circular target appeared at one of 8 possible positions at retinal eccentricities of 6, 12, 18, or 24 dva on the left and the right wall (Fig. 2.1). The target consisted of a checkerboard pattern with a spatial frequency of 0.41 cycles/dva that matched in phase with the wall. The target's contrast was vignetted with a circular window (diameter = 2.4 dva). A target appeared for a duration of 67 ms when the participant's viewpoint was 18.5 or 37 m_v from the wall. The texture of the target matched the texture of the wall behind it but had a higher Michelson contrast of 0.57 with an average luminance of 8.30 cd/m^2. Target retinal size and eccentricity were identical across distances. Targets were kept smaller than the total size of four checks on the wall to avoid the potential confound that might occur when the edges of more than four checks are broken by far targets but only four edges are broken by near targets. A 1658 Hz tone was presented simultaneously with the target for a duration of 67 ms. Participants were asked to identify the side on which the target appeared when they heard the tone even if they were unsure about the target's location, using their left hand to press the A (left) or D (right) key on a standard computer keyboard. Participants were asked to respond as quickly and as accurately as possible.

Car-Following Task As illustrated in Fig. 2.1, a 4×4 dva box drawn onto the screen surrounded the lead car. During the car-following task, participants were asked to stay at a constant, safe distance behind the lead car, such that the box appeared to be just surrounding the car. The box around the car served as feedback to encourage performance of the car-following task. Participants adjusted the speed of their own viewpoint, which was updated at 60 Hz, by using their right index finger to press the up arrow key to accelerate by $0.05\,\mathrm{m_v}$ per frame, or the down arrow key to decelerate by $0.1\,\mathrm{m_v}$ per frame.

Procedure

The experiment used a 2 (Attention: focussed vs. divided) $\times$ 4 (Eccentricity: 6, 12, 18, or 24 dva) $\times$ 2 (Distance: near and far) within-subject design. The experiment had three parts. Part one comprised 20 blocks of 16 trials each, where a trial is defined as the duration between the participant passing a pair of walls until the participant passes the next pair of walls. In part one, participants completed the peripheral detection task while their viewpoint moved forward passively behind the lead car at a constant distance of $18.5\,\mathrm{m_v}$, lasting approximately 25 minutes. In part two, participants completed one block of the central car-following task under focussed attention, in which no peripheral targets appeared. The second part lasted approximately two minutes. In part three, participants completed the peripheral detection and the car-following tasks concurrently for 20 blocks of 16 trials, lasting approximately 25 minutes. Verbal instructions were given at the beginning of each part of the experiment. In the divided attention condition, participants were given the instructions from the previous two focussed attention parts. Participants had opportunities to take breaks between blocks. All participants completed the three parts in the order described above. Using such a block order would mean that the cost due to divided attention and the improvement due to practise effect would have opposite effects on performance. Hence, any divided attention cost observed using this block order would be larger in magnitude than the practise effect. Previous studies using such a block order to examine the UFOV have found consistent divided attention costs for peripheral detection (Sekuler et al., 2000; Richards et al., 2006).

Data analyses

All statistical analyses were performed in R 3.3.2 (R Core Team, 2017). Where appropriate, association strength was measured using generalized eta squared (η^2_G Olejnik and Algina, 2003) and p values for F tests were adjusted using the Greenhouse-Geisser correction for deviations from sphericity ($\hat{\epsilon}$). To correct for deviations from normality, peripheral detection accuracy was arcsine transformed (McDonald, 2009).

For the car-following task, the speeds of the lead and following cars were recorded at a sampling rate of 60 Hz. The first three seconds of each block were excluded while participants adjusted to the task. The remaining data were transformed using the Fast Fourier Transform routine in NumPy 1.10.4 for Python (Oliphant, 2006; Walt et al., 2011). From each Fourier transform, we recorded the amplitudes and phases of the three sine wave components that defined the speed of the lead car. We calculated amplitude gain at each frequency by dividing the amplitude of the participant's response by the amplitude of the corresponding component from the lead car. Amplitude gains were calculated separately in each block and then averaged across blocks. Amplitude gains of one indicate that the range of speeds in the lead and following cars were well matched, whereas gains greater or less than one imply that the range of speeds in the following car were greater or less than the speed of the lead car respectively. We also calculated a phase shift at each frequency by subtracting the phase of the participant's response from the phase of the lead car. Phase shifts were calculated separately for each block and then averaged across blocks. A negative phase shift indicates that there was a delay between a change in speed of the lead and following cars, with more negative shifts corresponding to greater delays.

2.3.2 Results

Peripheral Detection Task

Fig. 2.2A shows arcsine transformed accuracy in the focussed and divided attention conditions plotted as a function of target eccentricity. The data were analyzed with a 2 (Attention) × 4 (Eccentricity) × 2 (Distance) ANOVA (see Table A1.2). There was a significant main effect of Eccentricity ($F(3, 69) = 276.5$, $p < 0.001$, $\eta^2_G = 0.68$), response accuracy for decreased with increasing target eccentricity. In addition, accuracy was overall higher for near targets than far targets ($F(1, 23) = 16.66$, $p < 0.001$, $\eta^2_G = 0.045$). There also was a Distance × Eccentricity interaction ($F(3, 69) = 4.83$, $p < 0.001$, $\eta^2_G = 0.021$, $\hat{\epsilon} = 0.001$), as the effect of eccentricity was larger for far compared for near distance. The effect of distance was in the same direction at all eccentricities, but it was statistically significant only at 18 and 24 dva. Detection also was slightly more accurate in the divided attention condition than in the focussed attention condition ($F(1, 23) = 4.40$, $p = 0.047$, $\eta^2_G = 0.013$).

To increase statistical power, we conducted a more focussed analysis of the effects of Attention and Distance on the linear trend of accuracy across eccentricity. Linear trend scores for each participant and condition were submitted to a 2 (Attention) × 2 (Distance) within-subjects ANOVA (see Table A1.3). There was a significant overall linear trend ($F(1, 23) = 505.4$, $p < 0.001$, $\eta^2_G = 0.92$), which is consistent with the significant main effect of eccentricity above. The Distance × Attention interaction ($F(1, 23) = 4.33$, $p = 0.049$, $\eta^2_G = 0.014$) was also significant. The linear trends for near and far targets differed significantly in the divided attention condition ($F(1, 23) = 8.07$, $p = 0.001$, $\eta^2_G = 0.11$), but not in the focussed attention condition ($F(1, 23) = 0.26$, $p = 0.61$, $\eta^2_G = 0.004$). No other effects were significant.

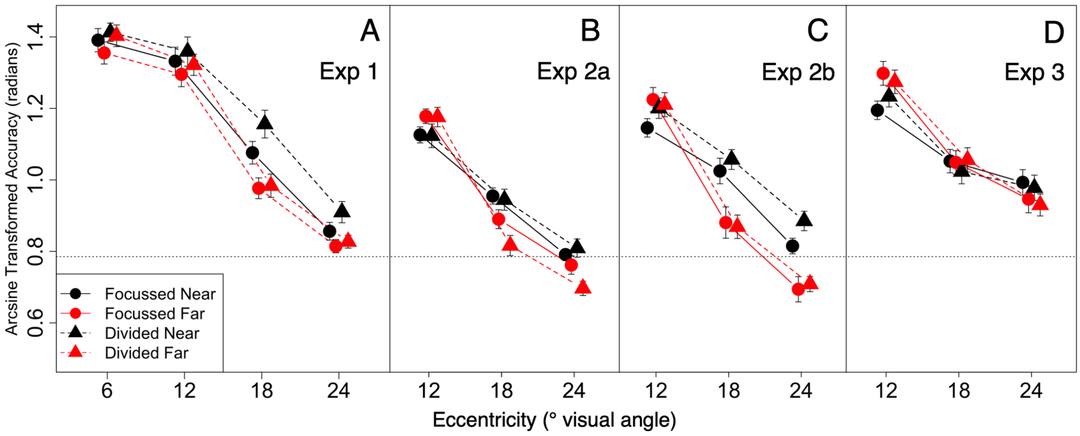

FIGURE 2.2: Arcsine transformed accuracy of peripheral target detection in Exp 1, 2a, 2b, and 3 plotted as a function of eccentricity. The horizontal dotted line indicates chance performance (50%). Higher values indicate better performance, with values of 0.8, 1.0, 1.2, 1.4 representing 51, 71, 87, 97%, respectively, and 1.57 represents 100%. Black and red symbols indicate performance in the near and far distance conditions, respectively. Circle and triangle symbols indicate performance in the single and dual task conditions, respectively. Error bars represent ± 1 standard error of the mean (SEM).

Log transformed RT in the peripheral detection task is plotted in Fig. 2.3A. We conducted a 2 (Attention) × 4 (Eccentricity) × 2 (Distance) ANOVA on these data (see Table A1.19 for full ANOVA table). Visual inspection of Fig. 2.3A shows that RTs were shorter for targets at small eccentricities than large eccentricities ($F(3, 69) = 186.86$,

$p < 0.001$, $\eta^2_G = 0.47$). RTs also were shorter in the divided attention condition than in the focussed attention condition ($F(1, 23) = 8.00$, $p = 0.009$, $\eta^2_G = 0.027$), and for near targets than far targets ($F(1, 23) = 79.87$, $p < 0.001$, $\eta^2_G = 0.03$). We also found a significant Distance × Eccentricity interaction ($F(3, 69) = 9.34$, $p < 0.001$, $\eta^2_G = 0.021$): RTs for near targets were significantly faster than far targets at all eccentricities ($F(1, 23) > 48.42$, $p < 0.001$), but the effect of target distance was larger at far eccentricities. No other effects were significant (see Table A1.19).

The linear trends of RT across eccentricity were also analyzed with a 2 (Attention) × 2(Distance) within-subjects ANOVA. Consistent with the main effect of eccentricity found in the ANOVA on RT, the grand mean of the linear trend scores differed significantly from zero ($F(1, 23) = 249.32$, $p < 0.01$, $\eta^2_G = 0.89$). There also was a significant main effect of Distance ($F(1, 23) = 16.85$, $p < 0.001$, $\eta^2_G = 0.063$), indicating that the linear effect of eccentricity was larger for far targets. No other effects were significant (see Table A1.20).

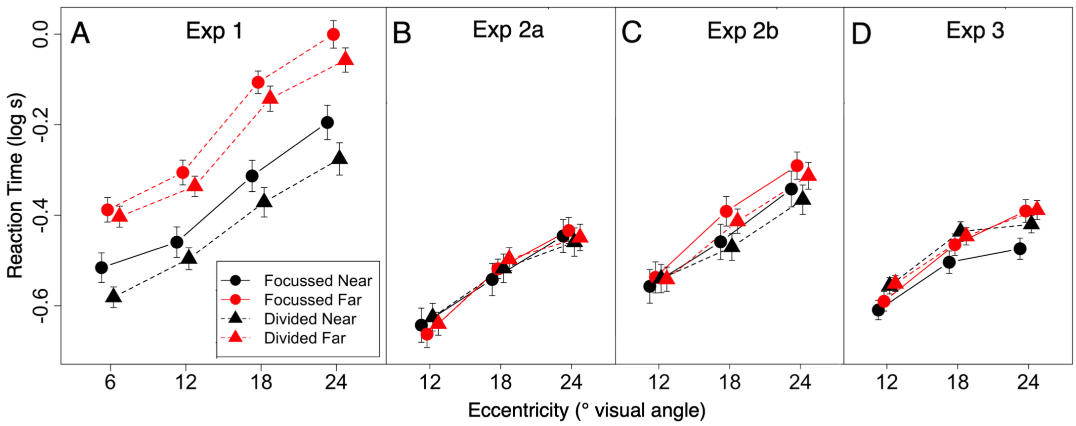

FIGURE 2.3: Log transformed RT of peripheral target detection in Exp 1, 2a, 2b, and 3 plotted as a function of eccentricity. Black and red symbols indicate performance in the near and far distance conditions, respectively. Circle and triangle symbols indicate performance in the focussed and divided attention conditions, respectively. Error bars represent ± 1 SEM.

Car-Following Task

Amplitude gains are shown in Fig. 2.4A and phase shifts are shown in Fig. 2.5A. Dividing attention appeared to have only small effects on response gain but increased phase lag at the highest two frequencies. To quantitatively evaluate these observations, amplitude gains and phase shifts were analyzed with separate 2 (Attention) × 3 (Frequency) within-subjects ANOVAs. The ANOVA on amplitude gain yielded a significant main effect of Frequency ($F(2, 46) = 13.18$, $p < 0.01$, $\eta^2_G = 0.09$), with no other significant effects. In contrast, the ANOVA on phase shift measures found significant main effects of Attention ($F(1, 23) = 15.45$, $p < 0.01$, $\eta^2_G = 0.06$) and Frequency ($F(2, 46) = 25.71$, $p < 0.01$, $\eta^2_G = 0.28$), which supports the observation that dividing attention resulted in longer delays. Although the effect of attention appears to increase with frequency, the two-way interaction was not significant ($F(2, 46) = 2.08$, $p = 0.15$, $\eta^2_G = 0.026$). Overall, our analyses suggest that dividing attention caused participants to respond more slowly to changes in the lead car's speed.

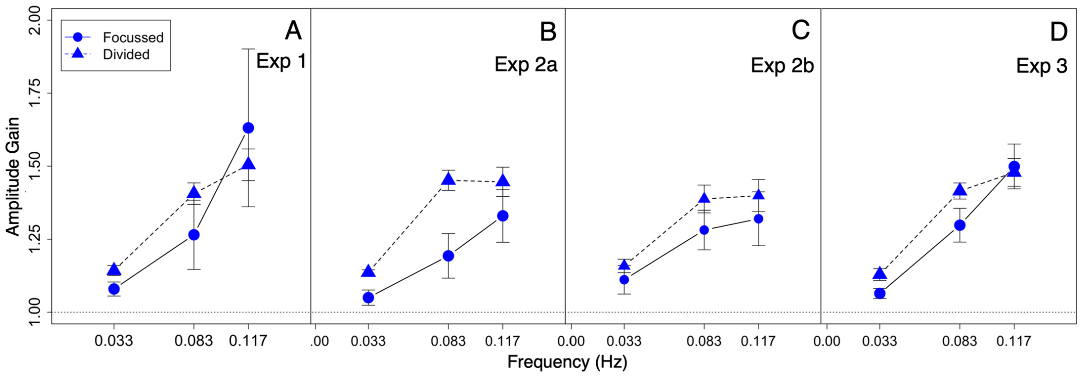

FIGURE 2.4: Amplitude gain of participants' following speed relative to that of the lead car as a function of frequency. Circle and triangle symbols indicate performance in the focussed and divided attention conditions, respectively. The horizontal dotted lines indicate perfect performance and deviations from the dotted lines indicate error. Deviations above the dotted line indicate overshooting the lead car's speed changes and deviations below indicate undershooting. Error bars represent ± 1 SEM.

Further analyses performed on the phase shift data showed that participants had longer delays for higher frequency components. If participants behaved like a linear delay system, then the function of phase shift over frequency should have a y-intercept at 0. However, the y-intercepts of phase shift over frequency functions were significantly below zero in all experiments where the car-following task was performed ($M < -0.28$, $t(1) < -0.43$, $p < 0.001$ in each case; see Supplementary Materials for more details), suggesting that participants' car-following behaviour could not be characterized by a linear delay system. Furthermore, participants showed imperfect entrainment to the frequencies of speed change in the lead car, another observation that would not be explained by a linear delay system.

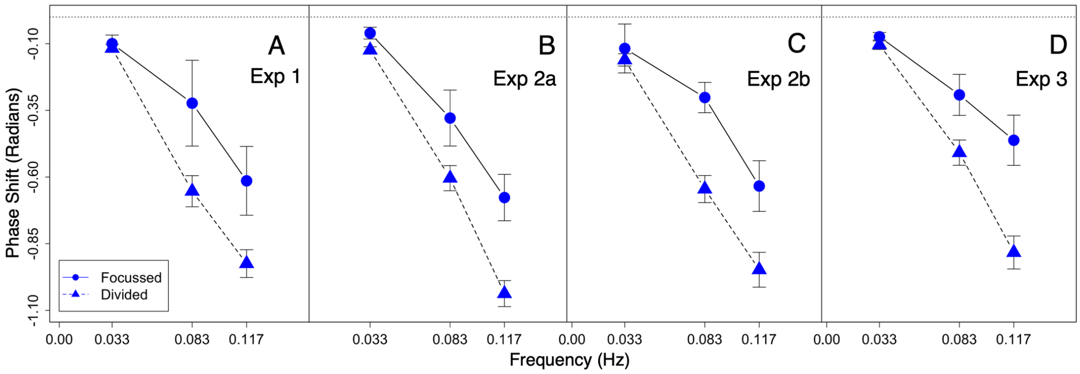

FIGURE 2.5: Phase shift of participants' following speed relative to that of the lead car as a function of frequency. Symbol conventions are same as 2.4. Deviations below the dotted horizontal line indicate response delay. In Exp 1 (far left), the focussed attention condition, average phase shifts correspond to delays of 0.48, 0.62, and 0.84 s at frequencies of 0.033, 0.083, and 0.117 Hz, respectively. In the divided attention condition, the phase shifts correspond to delays of 0.57, 1.25, and 1.26 s. Corresponding time delays for all experiments are shown in Table A1.1.

2.3.3 Discussion

Target distance affected detection performance even with short target durations and while controlling the retinal size and location of targets across distances. Specifically, responses were more accurate and faster overall for near targets than for far targets. In addition, there was evidence that attention was allocated less to the visual periphery because the effect of eccentricity is larger for far targets. The results of this experiment are consistent with previous studies (Andersen et al., 2011; Pierce and Andersen, 2014), which also found a main effect of distance and an increase in the effect of eccentricity as distance increased, particularly on RT.

We found divided attention costs for the car-following task but not for the target detection task. As we will see, this pattern of results was consistent across Exp 1, 2 and 3. Therefore, we will postpone our discussion of these results in the general discussion (see Supplementary Materials for full ANOVA tables).

2.4 Exp 2: Effect of anticipation of target onset

The distance effect found in Exp 1 may have been caused by reduced uncertainty about stimulus onset for near targets. In Exp 1, a target appeared on each pair of walls *either* at the far distance or the near distance. Therefore, while approach a pair of walls, if a target did not appear on a wall at the far distance, then the participant could be certain that the target would appear on the wall at the near distance. Hence, participants potentially were better able to anticipate onsets of near targets than far targets. This difference in the predictability of near and far targets may have contributed to the effect of distance we found in Exp 1 and in Pierce and Andersen (2014). Comparing our Exp 1 and 2 allows us to quantify the contribution of target predictability.

Exp 2 controlled for the predictability of target onset by ensuring that on each trial, there was an equal probability (25%) that the target was presented only at the near distance, only at the far distance, both distances, and neither distance. We added equal numbers of trials on which i) no target was presented at either distance; ii) the target was presented at both the near and far distances. This change in procedure ensured that the probability of target onset was 50% at the near distance regardless of whether a target appeared at the far distance. In addition, to ensure that differences between Exp 1 and 2 were not due to chance, we ran Exp 2b as a direct replication of Exp 2a using a separate sample of naïve participants recruited at a different time of year.

2.4.1 Methods

Subjects

For experiment 2a, a new sample of 25 students ($M = 21$ years, $SD = 2.67$ years; 5 males) were recruited in the same way as in Exp 1. Data from one participant were excluded due to a programming error, resulting in a final sample size of 24. For experiment 2b, a different set of 25 naïve participants was recruited at a different time of year in the same manner. One participant exhibited response accuracy that was near chance in all conditions and therefore was excluded from the data analyses, yielding a final sample size of 24 ($M = 19.44$ years, $SD = 1.6$ years, 7 males) individuals.

Stimuli & Design

The stimuli and procedure both Exp 2a and 2b were the same as Exp 1, except for the following changes. In addition to the target probability manipulation described above, We removed the 6 dva eccentricity condition to limit the total duration of the experiment to approximately one hour. The procedure was the same as Exp 1 except there were 16 blocks of 18 trials in the first and third parts. Finally, the data were analyzed in the same manner as in Exp 1, except using only three eccentricities rather than four.

2.4.2 Results

Peripheral Detection Task

Target detection accuracy in Exp 2a and 2b are shown in Fig. 2.2B and 2.2C, respectively. Because the two experiments were run separately, we report the analyses for each experiment separately in the appendix (Table A1.4 – A1.7 and Table A1.21 – A1.24). We summarize the results of analyzing the combined data from Experiments 2a and 2b here as the results were quite similar, especially for accuracy.

Overall, accuracy was similar to the accuracy obtained in Exp 1. The 2 (Experiment) x 2 (Attention) x 2 (Distance) x 3 (Eccentricity)ANOVA on accuracy found a significant main effect of Distance ($F(1,46) = 23.98$, $p < 0.001$, $\eta^2_G = 0.05$), accuracy was higher for near targets than far targets. There was a significant main effect of Eccentricity ($F(2,92) = 309.92$, $p < 0.001$, $\hat{\epsilon} = 0.84$, $\eta^2_G = 0.56$). Furthermore, there was a significant Distance × Eccentricity interaction ($F(2,46) = 22.25$, $p < 0.001$, $\eta^2_G = 0.05$) because effect of eccentricity was larger for far targets compared to near targets. We also note that the effect of distance at 12 dva was in the opposite direction as 18 and 24 dva. There also was an Attention × Distance interaction ($F(1,46) = 11.58$, $p = 0.001$, $\eta^2_G = 0.008$) because the effect of distance was larger under the divided attention than focussed attention condition. Notably, no effects involving Experiment, nor any other effects were significant ($F < 3.88$, $p > 0.05$, $\eta^2 < 0.008$ in each case; see Table A1.8). The results of the linear trend analysis were consistent with these observations (see Table A1.9).

Response time data are plotted in Fig. 2.3B (Exp 2a) and 2.3C (Exp 2b). Visual inspection of the figures indicates that the effect of target distance was much smaller in Exp 2a and 2b than Exp 1, although there was still a main effect of Distance ($F(1,46) = 7.68$, $p = 0.008$, $\eta^2_G = 0.006$) and of Eccentricity ($F(2,92) = 237.00$, $p < 0.001$, $\hat{\epsilon} = 0.69$, $\eta^2_G = 0.23$) across both experiments. However, RT results differed significantly between Exp 2a and 2b. First, although the effect was in the same direction in both experiments, the effect of Eccentricity was larger in Exp 2b than Exp 2a ($F(2,92) = 4.43$, $\hat{\epsilon} = 0.69$, $p = 0.027$, $\eta^2_G = 0.006$). The main effect of distance also was larger in Exp 2b than in Exp 2a ($F(1,46) = 4.90$, $p = 0.031$, $\eta^2_G = 0.004$): the main effect of distance was significant in Exp 2b ($F(1,23) = 13.28$, $p = 0.001$, $\eta^2_G = 0.017$), but not 2a ($F(1,23) = 0.15$, $p = 0.71$, $\eta^2_G =< 0.001$).

The ANOVA on RT also found a significant Eccentricity × Distance interaction ($F(2,92) = 9.74$, $p < 0.001$, $\eta^2_G = 0.004$). This result was corroborated by the 2

(Experiment) x 2 (Attention) x 2 (Distance) ANOVA on the linear trend of RT across eccentricity, which also found a main effect of Distance ($F(1, 46) = 10.52$, $p = 0.002$, $\eta_G^2 = 0.03$). These effects did not differ between Exp 2a and 2b.

Finally, the effect of eccentricity was larger in the focussed attention condition than the divided attention condition, as indicated by the significant Attention × Eccentricity interaction ($F(2, 92) = 5.15$, $\hat{\epsilon} = 0.88$, $p = 0.001$, $\eta_G^2 = 0.002$), and also by a larger linear trend in the focussed attention condition than the divided attention condition ($F(1, 46) = 8.28$, $p = 0.006$, $\eta_G^2 = 0.022$). No other effects were significant (see Table A1.25) & A1.26.

2.4.3 Discussion

Exp 2 measured the effects of target eccentricity, distance, and dividing attention in conditions that equated the uncertainty about target onsets in near and far conditions. Accuracy results were similar in Exp 1 and 2, where there was a small advantage for near targets averaged across eccentricities. Additionally, the effect of eccentricity was larger for far targets than for near targets. These results suggest that the extent of the UFOV was modulated by target distance such that less attention was allocated to larger eccentricities at the far distance. We also note that accuracy for far targets was slightly better than for near targets at 12 dva, which is the opposite of the main effect of distance, and the effect of distance at the other eccentricities. These effects were replicated in a second sample of participants in Exp 2b.

Notably, the main effect of distance in RT was much smaller in Exp 2 ($\eta_G^2 = 0.006$) than in Exp 1 ($\eta_G^2 = 0.30$), suggesting that anticipation contributed to the near advantage averaged across eccentricities. However, a Distance × Eccentricity interaction remained for RT in Exp 2 ($\eta_G^2 = 0.009$) and the magnitude of this effect was comparable to the effect obtained in Exp 1 ($\eta_G^2 = 0.01$), although this effect was more evident in Exp 2b than in 2a. Given the inconsistency of the RT results, we will be shifting the focus of our analyses to accuracy in Exp 3 and 4. We note here that RT results in Experiment 3 and 4 both show much smaller effects of distance compared to Exp 2, although there were some inconsistencies in their precise effects (see Supplementary Materials for full RT analyses).

2.5 Exp 3: Effect of distance in the absence of checkerboard background

Exp 2 suggest there was a distance effect even when target onset probability was constant across distances. It remains unclear what distance cues contributed to the differences in accuracy across distances. It is possible that some aspect of the visual display that co-varied with distance contributed to the effect. One potential contributing visual feature is the texture pattern on the wall which varied with distance. Although the visual angle of the target was held constant across near and far distances, the checks on the walls were not. The size of the checks on the walls may be an important source of distance information. In addition to the contribution to depth perception, the checks on the wall texture were larger relative to the target in the near condition than in the far condition (Figure 2.1). This difference in the relative sizes, or peak spatial frequencies, of the target and background textures may have made far targets more difficult to detect than near targets. If the difference in density contrast between the wall and target across depths is the only cue contributing to our depth effect found in Exp 2, removing this size or spatial frequency cue should eliminate the distance effect. Alternatively, if the effect of distance was due to the perception of 3D distance, removing one of many distance cues should not completely eliminate the impression of depth, and thus should not completely eliminate the distance effect.

In the current experiment, we investigated the effects of checkerboard pattern density on target detection by removing the checkerboard pattern but retaining optical flow and linear perspective cues. Comparisons of Exp 2 and 3 will reveal the contribution of the checkerboard backgrounds to the distance effect. If the distance effect is solely attributable to the checkerboard background, then there should not be an effect of target distance in Exp 3.

2.5.1 Methods

Participants

Twenty-eight undergraduate students from McMaster University were recruited in the same manner as in Exp 1. One participant was excluded due to failure to follow task instructions, resulting in a final sample size of 27 ($M = 18.67$ years, $SD = 3.15$ years, 5 males).

Stimuli & Design

We used the same stimuli, methods, and analyses as in Exp 2a and 2b except the checkerboard patterns on the walls were replaced by a uniform grey that had the same average luminance ($8.40\,cd/m^2$) as the walls used in Exp 1 and 2 (Fig. 2.6).

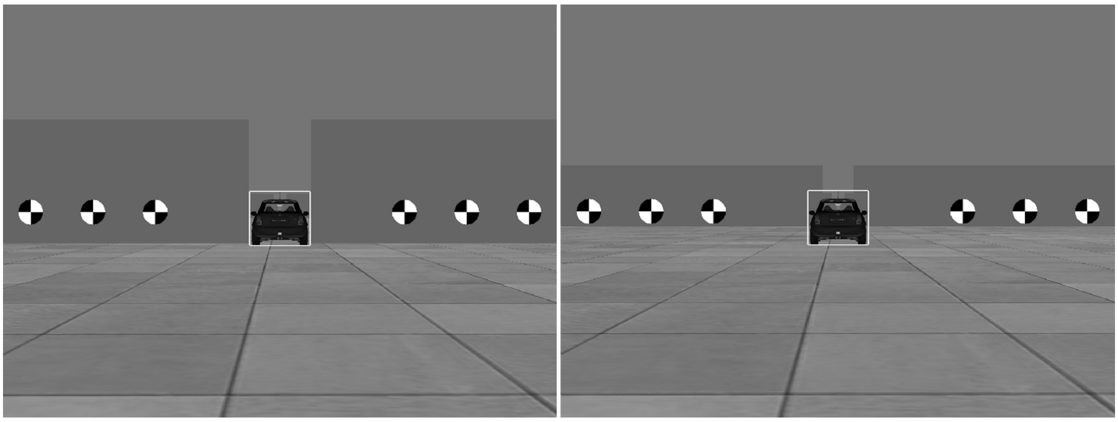

Figure 2.6: An illustration of all possible targets at the near (left), and far (right) distances in Exp 3. Target contrast was increased for illustration in this image. The stimuli and possible target locations were identical to Exp 2 except the walls were covered by a uniform grey.

Data analysis

The data of the current experiment were analyzed as in Exp 2.

Results

Fig. 2.2D plots detection accuracy as a function of attention, distance, and eccentricity. The main effect of distance was not significant when checkerboards were absent ($F(1, 26) = 1.61$, $p = 0.22$, $\eta^2_G = 0.015$). The effect of eccentricity was still larger for far targets than for near targets ($F(2, 52) = 15.34$, $p < 0.001$, $\eta^2_G = 0.02$). The fact that there was a benefit for far targets at 12 dva and a benefit for near targets at 24 dva also contributed to the interaction (see Table A1.10 for full ANOVA). The results of the linear trend analysis corroborated this interaction (Table A1.11).

Experiment 3 examined the distance effect in the absence of checkerboard patterns, whereas Experiment 2 examined the distance effect with checkerboard patterns present. Because both experiments used the exact same design, the differences in results between the two experiments would indicate variance accounted by checkerboard pattern, assuming the effect of checkerboard is additive and does not interact with other depth cues.

A 2(Checkerboard: Present vs. Absent) × 2(Distance) × 3 (Attention) × 3(Eccentricity) ANOVA was conducted on arcsine transformed accuracy scores in Experiment 2 and 3. The analysis suggest that the presence of the checkerboard had several effects on detection accuracy. There was a significant main effect of checkerboard presence ($F(1,73) = 22.32$, $p < 0.001$, $\eta^2_G = 0.13$) because accuracy was significantly higher overall when checkerboards were absent (Exp 3, $M = 1.08$) than when checkerboards were present (Exp 2, $M = 0.96$). There also was a significant main effect of Distance ($F(1,73) = 6.78$, $p = 0.011$, $\eta^2_G = 0.006$) and a significant Checkerboard × Distance interaction ($F(1,73) = 15.50$, $p < 0.001$, $\eta^2_G = 0.014$) because the effect of distance was significantly smaller when checkerboard was absent($\eta^2_G = 0.015$, $p = 0.22$) compared to when checkerboard was present ($\eta^2_G = 0.18$, $p < 0.001$).

There also was a significant Distance × Eccentricity interaction ($F(2,146) = 56.70$, $\hat{\epsilon} = 0.94$, $p < 0.001$, $\eta^2_G = 0.034$) but the presence of the checkerboard significantly affected the Distance× Eccentricity interaction ($F(2,146) = 9.82$, $\hat{\epsilon} = 0.94$, $p < 0.001$, $\eta^2_G = 0.006$). Specifically, the Distance × Eccentricity interaction was larger when the checkerboard pattern was present ($F(2,94) = 64.42$,$\hat{\epsilon} = 0.92$,$p < 0.001$, $\eta^2_G = 0.09$) than when the checkerboard pattern was absent ($F(2,52) = 15.34$,$\hat{\epsilon} = 0.92$, $p < 0.001$, $\eta^2_G = 0.02$). Additionally, the Distance × Eccentricity interactions were different in Exp 2 and Exp 3. Compared to Exp 2 (see Table A1.8), Exp 3 had a larger far advantage at 12 dva, and a smaller near advantage at 24 dva (see Table A1.10). Moreover, at 18 dva, there was a significant near advantage in Exp 2, but no significant effect of distance was observed in Exp 3. However, the interaction was significant and in the same direction regardless of checkerboard presence. Linear trend analyses found that the checkerboard presence did not significantly affect the the effect of distance on linear trend scores ($F(1,73) = 1.62$, $p = 0.21$, $\eta^2_G = 0.003$; see Table A1.12 and A1.14 for full ANOVA tables). These results suggest that removing the checkerboard pattern reduced, but did not eliminate the interaction.

2.5.2 Discussion

Exp 3 examined whether removing the checkerboard backgrounds on the walls would affect peripheral target detection at the near and far distances. As a result of this manipulation, the main effect of Distance differed between Exp 2 and 3 ($F(1,73) = 15.50$,

$p < 0.001$, $\eta^2_G = 0.014$). The effect of distance was non-significant in Exp 3 ($\eta^2_G = 0.015$) and much smaller in magnitude compared to Exp 2 ($\eta^2_G = 0.05$). These results suggest that the overall near advantage when averaged across eccentricities observed in Exp 2 was likely associated with the checkerboard background. Comparison across the two experiments suggests that only a small main effect of distance was left unexplained by the checkerboard background ($F(1, 73) = 6.78$, $p = 0.011$, $\eta^2_G = 0.006$).

The current experiment also found that the effect of eccentricity on accuracy was larger for far targets than near targets. Although this Distance × Eccentricity interaction was significantly smaller in Exp 3 ($\eta^2_G = 0.02$) than in Exp 2 ($\eta^2_G = 0.09$), the interaction was significant and in the same direction in both experiments. Furthermore, the effect of checkerboard on the Distance × Eccentricity interaction ($\eta^2_G = 0.006$) is much smaller in magnitude than that of the overall Distance × Eccentricity interaction found across Exp 2 and 3 ($\eta^2_G = 0.014$). These results suggest that although checkerboard size contributed to the overall decrease in accuracy for far targets, there was a statistically significant remaining component of the distance effect that modulated the distribution of attention in the visual periphery even when checkerboards were absent. We also note that the effect of distance was slightly different across eccentricities, a point that we discuss further in the discussion of Exp 4.

2.6 Exp 4: Effect of static pictorial cues

Exp 3 examined the target distance effect when checkerboard backgrounds were not present, but assumed that the effect of checkerboard pattern is additive. However, checkerboard pattern may have non-additive effects in the presence of other distance cues. For example, perceived depth may have been weakened by the exclusion of the checkerboard in Exp 3, which may also have changed the interpretation of the other depth cues present in the stimulus. Exp 4 systematically examines how the target distance effect was influenced by the retinal size of the checks making up the checkerboard patterns, the retinal size of the walls, and the presence of the ground plane to examine their combined effects on target detection by manipulating them orthogonally. To this end, we used a static display to more directly evaluate the effects of these pictorial depth cues. To identify the relative contributions of these depth cues, we factorially crossed on-screen check size, wall size, and ground presence in a 2 (large vs. small checks) × 2 (large vs. small wall) × 2 (ground plane present vs. absent) design. Note that this design differs from the one used in Exp 2, in which large walls were paired only with large checks for the near distance and small walls were paired only with small checks for the far distance. In addition, performance was only tested in a focussed attention condition because we were interested primarily in how these stimulus variables affected detection rather than how they interacted with divided attention.

2.6.1 Methods

Participants

Fifty-five naïve participants were recruited in the same manner as in Exp 1. Nine participants were excluded because they performed at chance level in all experimental conditions, leaving a total sample size of 46 participants ($M = 19$, $SD = 2.31$; 18 male).

Stimuli and Design

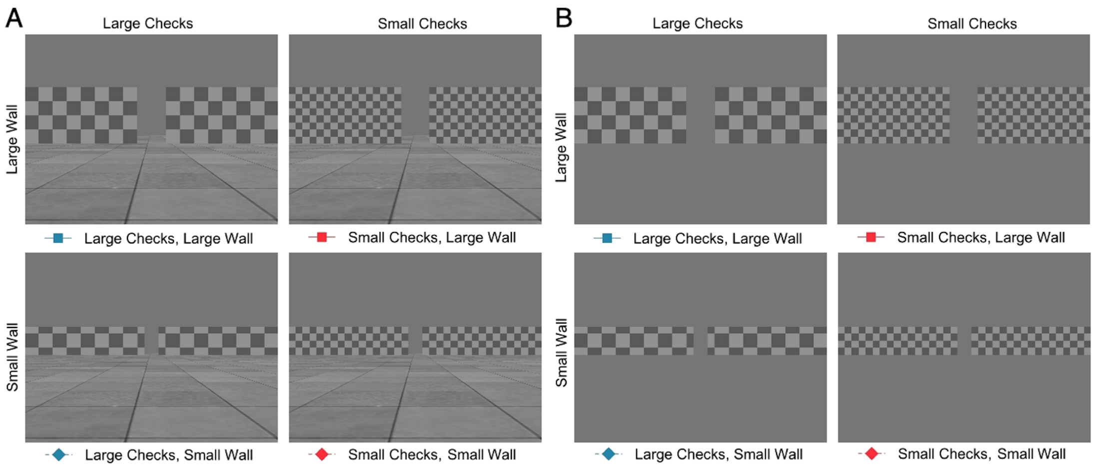

FIGURE 2.7: An illustration of all backgrounds used in Exp 4 in the ground present condition (A) and in the ground absent condition (B). Note that the targets are not displayed in the figure, but are the same as Exp 1. In all conditions, the retinal eccentricity and size of the targets were identical to Exp 1. On each trial, only one background and one target appeared.

The stimuli were the same as in Exp 1. However, rather than showing a simulated approach to the walls, only static images of the near and far distances were used to examine the effect of pictorial cues on the depth effect without optical flow. The lead car was also replaced with a white, square fixation point (0.5 × 0.5 dva). Checkerboards consisting of large (3 dva × 3 dva) or small (1.5 dva × 1.5 dva) checks were factorially crossed with large (12 dva tall × 24 dva wide) and small (6 dva tall × 25.5 dva wide) walls for a total of four different walls (see Fig. 2.7A). The combination of large checks and large wall area corresponded to the walls in the near condition in Exp 1, whereas the combination of small checks and small wall area corresponded to the walls in the far condition in Exp 1. Walls and target were presented with a textured ground plane (Fig. 2.7A), as in Exp 1, or in a uniform grey field with a luminance of 7.95 cd/m^2 (Fig. 2.7B). Wall and check size were manipulated within-subjects, whereas the presence or absence of the ground plane was manipulated between-subjects. Participants were randomly assigned to either the ground plane present or absent group ($n = 23$ in each group).

Each trial began with the text "Ready" in white Arial font with a height of 2 dva displayed in the centre of a uniform field with a luminance of 7.95 cd/m^2. Participants pressed the space key on a standard keyboard to start stimulus presentation, which made the fixation point appear in the centre of the screen and remained visible throughout the trial. The background appeared 1000 ms after the onset of the fixation point, and the target was presented after another 500 ms. Pilot experiments showed that performance was near ceiling with a target duration of 67 ms, which was used in previous experiments. Therefore, in the current experiment, the target was presented for a duration of 16.7 ms. The target and background disappeared at the same time, followed by a uniform grey field for 17 ms, after which the text "Where was the target?" was presented in the centre of the display. Participants indicated the location of the target by pressing one of two keys on a computer keyboard with their left hand, after which a new trial started. The entire procedure lasted approximately one hour.

2.6.2 Results

Target detection accuracy is plotted as a function of eccentricity in Fig. 2.8. Exp 4 included four levels of eccentricity (6, 12, 18, 24 dva) and Exp 2 included only three (12, 18, 24 dva). The results of Exp 4 including only three eccentricities were qualitatively similar to those obtained using all four eccentricity levels (see Table A1.17 and A1.18 for details of the analysis using four eccentricities). Analyses discussed below include only the eccentricities that were in both Experiment 2 and 4.

The effects involving ground and wall size were generally small and non-significant ($F < 1.62, p > 0.21, \eta^2_G < 0.022$ in each case), except for a small significant Ground × Eccentricity interaction ($F(2, 88) = 3.30$, $\hat{\epsilon} = 0.86$, $p = 0.049$, $\eta^2_G = 0.013$; see Table A1.15). This interaction is due to the fact that the effect of ground is larger and in the opposite direction at 18 dva than at other eccentricities, although the effect of the ground plane was not significant at any eccentricity ($F(1, 44) < 1.89$, $p > 0.18$, $\eta^2_G < 0.041$ in each case).

There was a main effect of Check Size ($F(1, 44) = 43.81$, $p < 0.001$, $\eta^2_G = 0.027$). There also was a significant Check Size × Eccentricity interaction ($F(2, 88) = 8.18$, $p < 0.001$, $\eta^2_G = 0.008$). The simple main effect of Check Size was in the same direction at all eccentricities, but was significant at 12 ($F(1, 45) = 10.22$, $p = 0.002$, $\eta^2_G = 0.018$) and 24 ($F(1, 45) = 70.86$, $p < 0.001$, $\eta^2_G = 0.012$), but not 18 dva ($F(1, 45) = 2.62$, $p = 0.11$, $\eta^2_G = 0.005$). No other effects were significant ($F < 1.62$,$p > 0.21$,$\eta^2_G < 0.022$ in each case; see Table A1.15 for details). The linear trend analysis corroborated the results of the omnibus ANOVA because only the main effect of Check Size was significant ($F(1, 44) = 7.16$, $p = 0.01$, $\eta^2_G = 0.02$, see Table A1.16).

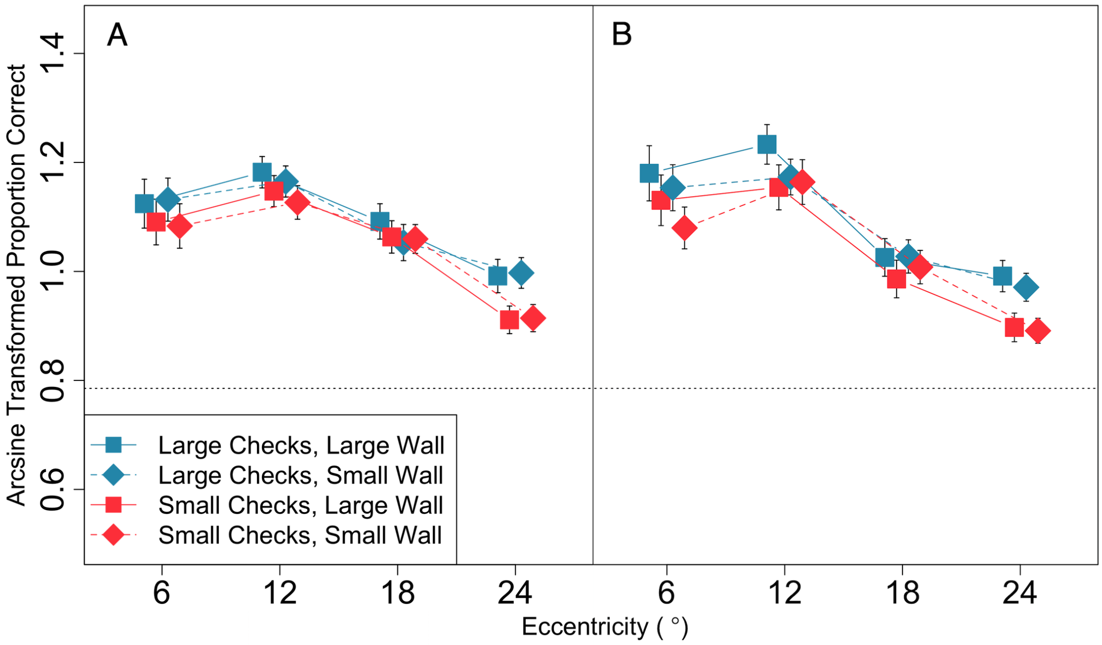

FIGURE 2.8: Peripheral target detection accuracy in Exp 4 plotted as a function of target eccentricity, check size, and wall size in the (A) ground plane present and (B) ground plane absent condition. Blue and red symbols indicate performance in the small and large check size conditions, respectively. Square and diamond symbols indicate performance in the small and large wall sizes, respectively. Error bars represent ± 1 SEM.

2.6.3 Discussion

Exp 4 investigated how peripheral target detection was affected by check size, wall size, and the presence of the ground plane. Across eccentricities, an overall advantage for detecting targets with a large checkerboard pattern was found in Exp 4, ($\eta^2_G = 0.027$). This result is consistent with the idea that check size contributed to the main effect of

Distance in Exp 2 ($\eta_G^2 = 0.05$).This result is consistent with the idea that the effect of distance found in Exp 2 ($\eta_G^2 = 0.05$) was largely the contribution of the checkerboard background. The effect of wall size ($\eta_G^2 = 0.001$) and ground plane ($\eta_G^2 = 0.003$) were non-significant and negligible in Exp 4.

The fact that we found a significant Check Size × Eccentricity interaction in Exp 4 is consistent with the idea that check size contributed to the Distance × Eccentricity interaction found in Exp 2. However, the magnitude of the Check Size × Eccentricity interaction in Exp 4 ($\eta_G^2 = 0.008$) was approximately nine times smaller than the Distance × Eccentricity interaction in Exp 2 ($\eta_G^2 = 0.07$). Furthermore, the Check size × Eccentricity interaction was qualitatively different than the Distance × Eccentricity interaction. Whereas Exp 4 found that the effect of Check Size was in the same direction at all eccentricities but smaller at 18 dva than the other eccentricities, Exp 2 found a near advantage at 18 and 24 dva and a far advantage at 12 dva. Together, these results suggest that the Distance × Eccentricity interaction found in Exp 2 was not due *solely* to variation in check size.

Wall size did not significantly impact detection accuracy. This may be because size in the current experiment is not a reliable cue for distance. Participants in Exp 4 had no prior exposure to the stimuli used in this experiment, and so could not use familiar size of the wall as a cue to judge distance. This result also excludes the possibility that the edges of the smaller walls, which were closer the targets than the larger walls, caused decrements in detection performance.

Ground plane presence affected detection accuracy: detection was better when the ground was present at 18 dva, but not at other eccentricities. There is a body of literature that suggests that the ground plane plays an important role in the inference of distance in 2D displays (e.g. Gibson, 1950; Mccarley and He, 2000; Ni et al., 2005; Bian et al., 2006; Bian and Andersen, 2006; Ozkan and Braunstein, 2010b; Gibson, 2014). For example, the location of the object's intersection with the ground plane may be used as a heuristic for perceived distance (Rand et al., 2011; Gardner et al., 2010; Ooi et al., 2001; Ozkan and Braunstein, 2010a). However, it is unclear how this explanation could account for the interaction observed. It is possible that in the current task, the wall's point of intersection with the ground plane may have been too similar across the two distances that participants could not use the intersection as a heuristic.

Optic flow was present in the stimuli used in Exp 2 and 3 but not Exp 4. In Exp 2 and 3, the peripheral targets were displaced on the retina as a result of simulated motion: On average, far targets at eccentricities of 6, 12,18, and 24 dva moved 2.76, 5.53, 8.26, 11.01 dva per second, and near targets moved 6.45, 12.87, 19.34, 25.8 dva per second, respectively. The fact that targets appeared briefly (i.e., 76 ms) and that the displacements were larger for more eccentric targets may have made target detection more difficult at larger eccentricities in Exp 2 and 3. In addition, target displacement may explain why Exp 2 and 3 found a slight far advantage at 12 dva, whereas Exp 4 found that the check size effect was in the same direction at every eccentricity. Specifically, on average, the far target at 12 dva had smaller retinal displacement (0.18 dva) compared to the the near target at the 12 dva (0.45 dva), which may have made the far target at 12 dva easier to detect.

However, the effect of retinal displacement during motion also cannot completely explain the effect of distance found in our study. In particular, in Exp 2 and 3, targets at all eccentricities underwent smaller retinal displacement in the far condition compared to the near condition. If faster motion made detection more difficult, then we would expect the general performance across eccentricity to be better for far targets than for near targets. In addition, although the proportional difference in displacement between eccentricity were equal across distances, the absolute difference in displacement between eccentricities were smaller for far targets than near targets, which should result in a smaller effect of eccentricity for far targets than near targets. In contrast, we did not find an overall far advantage, and the effect of eccentricity was larger for far targets than for near targets across Exp 1-3. Therefore our findings support the idea that the distance effect was robust despite the effect of target displacement. In addition, optic flow perhaps affected the distance effect by creating a more vivid impression of depth than static stimuli, so the reduced distance × eccentricity interaction in Exp 4 may be due to a reduced impression of depth.

2.7 General Discussion

The current study examined the effect of apparent distance on the accuracy and speed of detecting peripheral targets. Exp 1-3 simulated distance using linear perspective cues and optical flow, whereas Exp 4 examined the contribution of linear perspective cues in the absence of motion. Crucially, in all experiments, the targets were presented very briefly, and the retinal characteristics of the targets were identical across the two distances tested. We were interested in two aspects of the distance effect:

Exp 1 found that peripheral target detection depended on target distance and eccentricity. Detection was overall faster and more accurate for near targets than far targets across all eccentricities, and that the effect of eccentricity was larger for far targets than for near targets. However, participants may have been able to anticipate the onset of near targets better than far targets in Exp 1 due to differences in target onset uncertainty. Exp 2 controlled for anticipation and found a similar pattern of results in accuracy, but the effect of distance on RT was markedly reduced. The results of Exp 2 suggest that anticipation of target onset could explain the near advantage in RT but not accuracy.

Although targets were identical across near and far distances, the backgrounds differed. One such difference is the size of the checkerboard pattern on which the targets appeared. Exp 3 examined the effect of target distance in the absence of checkerboard backgrounds and found that detection for near targets was no longer significantly more accurate than far targets across all eccentricities. Instead, we found that the effect of eccentricity was larger for far targets than near targets. These results suggest that the different check sizes in the near and far conditions may account for the *overall* near advantage averaged across eccentricities, but probably do not account entirely for the interaction between target distance and eccentricity that was found in Exp 1 and 2.

In Exp 4, we assessed the interactive effects of multiple static depth cues by factorially crossing check size, wall size, and the presence of the ground plane on detection. In these static stimulus conditions, targets were detected more accurately when the background checkerboard consisted of large checks than small checks, but wall size and ground plane had minimal effects on accuracy. The interaction between target eccentricity and check size in Exp 4 was significant, although much smaller than the Eccentricity × Distance interaction found in Exp 2. Interestingly, the largest near advantage was seen at the largest eccentricity, and there was no far advantage at any eccentricity. These findings also are consistent with the idea that check size may account for the overall near advantage but cannot account entirely for the interaction between target distance and eccentricity.

Exp 3 examined the target distance effect after removing the checkerboard backgrounds from the dynamic stimuli used in Exp 2. In contrast, Experiment 4 examined the effect of checkerboard in the presence of other static distance cues. The ANOVA comparing Experiments 2 and 3 revealed that the effect size of the main effect of Checkerboard, and the effect size of the Checkerboard × Eccentricity interaction was 0.014 and 0.006, respectively. On the other hand, Experiment 4 found that the effect size of the main effect of Checkerboard and the Checkerboard × Eccentricity interaction was 0.027

and 0.008 (see Table 2.1). These results suggest that the effect of a textured background, like a checkerboard, on peripheral target detection may be larger in static than dynamic displays.

TABLE 2.1: Sizes of effects of interest on accuracy from all experiments

Effect	**Exp**	**Main Effect**	**Interaction with Eccentricity**	**12 dva[a]**	**18 dva[a]**	**24 dva[a]**	**Linear Trend**
Distance	1	0.045	0.021	0.014	0.18	0.08	0.03
Distance	2a	0.018	0.050	0.035[c]	0.138	0.01 [b]	0.12
Distance	2b	0.083	0.090	0.031[c]	0.230	0.31	0.24
Distance (full cue)	2 a&b	0.050	0.070	0.032[c]	0.180	0.22	0.18
Distance (no checker)	3	0.015[b]	0.020	0.070[c]	0.010[b]	0.02	0.13
Checker Presence	2 vs 3	0.014[d]	0.006[e]				0.003[b,d]
Check Size	4	0.027	0.008	0.180	0.005[b]	0.12	0.02

[a] Simple main effect of distance.
[b] Effect was non-significant.
[c] Far advantage, opposite of the main effect of distance.
[d] Checker × Distance interaction.
[e] Checker × Distance × Eccentricity interaction.

Our general conclusion that increasing target distance reduces peripheral target detectability at larger eccentricities is consistent with the findings of Pierce and Andersen (2014). However, the results of our experiments suggest that much of the near advantage was due to target anticipation and stimulus background, and that the effect of distance is small.

In a conventional UFOV task presented at two different viewing distance while matching retinal stimulus size, Li et al. (2011) also reported worse detection performance at a far viewing distance at large eccentricities, but performance at the far viewing distance was never better than at a near viewing distance. Furthermore, our estimated magnitude of the Distance × Eccentricity interaction is much smaller than the effect of varying physical viewing distance in that of a traditional UFOV task (Li et al., 2011). There may be a few reasons for this difference. First, the range of distances tested in the current study are much farther than that of (Li et al., 2011). The effect of distance may differ depending on distance from viewer, as far objects away from reach have relatively little behavioural relevance compared to near targets within reach. Future work may examine whether the effect of distance at far ranges is comparable to that of near ranges. Secondly, the current results may underestimate the effects of target distance on detection in naturalistic viewing conditions. The current experiments did not include binocular cues which are potent depth cues present in (Li et al., 2011). Interestingly, Li et al. (2011) found a distance effect only for a detection task, but not a letter discrimination task. Further investigation is required to determine whether the distance effect reported here will extend to a peripheral discrimination task.

The distance effect reported here may reflect learning from real-world driving. At any given retinal eccentricity, far objects lie at a greater distance than near objects from an observer's heading. Also, during driving, distant objects and events are less relevant to behaviour in the immediate future compared to near events. Hence, it may be more advantageous to attend to near distances to prepare for potential hazards during driving. Because driving is a daily task for many people, this pattern of preparing for hazards at near distances may become over-learned with practise, such that this pattern of behaviour is shown even when hazards are absent. However, it is worthwhile to note that in ideal driving conditions, objects of interest usually are at high, suprathreshold contrast, and therefore the results of the current study, which used low contrast targets, may not generalize to those situations. Instead, the results of the current study may be more applicable to suboptimal driving conditions, such as during night time when glare is likely, or during weather conditions such as rain or fog. It is important to study performance in adverse conditions as they are more common in some parts of the world, where driving is a central part of how people get around in daily life, particularly when environmental conditions are not ideal for alternative modes of transportation.

Exp 1-3 consistently found large divided attention costs for the central car-following task: In all three experiments, car-following responses had larger errors and were approximately 90 ms to 600 ms slower under divided attention than focussed attention. However, there were no divided attention costs in peripheral detection. In fact, detection performance was more accurate under divided attention only in Exp 1. This is likely due to a practise effect as the divided attention condition was always completed last.Typically, UFOV studies using 2D displays find divided attention costs in peripheral detection performance, but not central task performance (e.g. Sekuler and Ball, 1986; Sekuler et al., 2000; Owsley et al., 1998a). It is possible that a practise effect could have eliminated the divided attention cost for peripheral detection in our study because the divided attention condition was always performed last. However, previous studies on the UFOV presented the divided attention condition last consistently found a large divided attention cost in the peripheral task but a much smaller cost in the central task (e.g., Sekuler et al., 2000; Richards et al., 2006). Therefore, the order of tasks *per se* cannot explain our results, and it is unlikely that the failure of find a divided attention cost for our peripheral task was due to overall enhanced performance due to practice effects, particularly because we did find a divided attention task for the central task. Instead, it is more likely that the difference between the current findings and previous studies reflect differences in the way participants prioritized the central and peripheral tasks, given our particular stimuli and tasks. Specifically, we suggest that participants in the current experiments prioritized the peripheral task over the central task. Although the precise nature of what leads participants to prioritize central or peripheral tasks remains an empirical question for further consideration, it is important for researchers to recognize that the nature of the stimuli and tasks can impact the nature of divided attention, particularly as more tasks are adapted for real-world situations.

In the broader context of dual-task paradigms, it is not surprising that participants were able to maintain performance in one task when two tasks are completed concurrently. This pattern of results have been observed in a variety of dual-task paradigms in the laboratory (e.g. Schmidt et al., 1984; Newman et al., 2007; Morey et al., 2011; Farmer et al., 2018). Similar patterns of results have also been observed in more naturalistic contexts such as distracted lane-keeping (Janssen et al., 2012) and walking (Plummer et al., 2015; Yogev-Seligmann et al., 2010).

Some characteristics of our task may have encouraged prioritization of the peripheral task over the central task. First, the peripheral task used brief targets that appeared suddenly. These characteristics were not present in the car-following task, and therefore, may have made the peripheral task more demanding. Secondly, the focussed attention condition for the the peripheral detection task was much longer than the car following task, which may have emphasized the detection task over the car-following task. These aspects of the methods may have lead participants prioritize the peripheral task over the car-following task.

In addition, under divided attention, participants may have momentarily diverted attention away from the car following task and later, compensated for the diversion, resulting in less precise, but still acceptable, car-following performance. Such a margin of error in the car-following task may allow peripheral detection with high accuracy in our conditions, as the target car-following distance was large enough to allow some error without crashing. Previous studies reported similar patterns of results in simulated driving, where divided attention costs were observed in the central, vehicle-control task but not the peripheral task (Cooper et al., 2013; Wolfe et al., 2019). However, increasing the difficulty of the car-following task in a divided attention paradigm resulted statistically significant costs in peripheral detection in a driving context (Bian et al., 2010), and a similar effect was found for lane keeping (Gaspar et al., 2016; Ward et al., 2018).

Considering the demands of car-following in real driving, timely detection of possible obstacles ahead is critical for safe driving, particularly if the lead car were to suddenly brake. Although the delays in RT were quite small for target detection, we found that delays in car-following response slowed by 100 – 600ms in the divided attention condition compared to the focussed attention condition (except for at the highest frequencies which sometimes showed smaller delays in the divided attention condition, see Table A1.1). At an average speed of 60km/h, these delays correspond to travelling an extra 1.6 – 10m before a response is made. In real driving, even a small response delay may result in an accident, if, for example, a pedestrian suddenly steps into the road. Although responding quickly to an obstacle ahead is more critical than monitoring the environment away from the path of motion in real driving, keeping a large enough following distance from the car ahead is beneficial as it would allow for less precise control of the distance to the lead car. In our conditions, even in the event that the lead car suddenly stops, the observed delays would not result in a crash most of the time due to the target following distance of 18.5m. Furthermore, the lead car was always moving ahead, which would allow for a large enough margin of error to account for increased delays in the divided attention condition. For this reason, the observed pattern of divided attention cost in the current study may be applicable only in relatively safe car-following conditions, but not in situations where more immediate responses are required, such as when keeping shorter car-following distances, or when responding to hazards that are not moving along the viewer's path of motion. However, it is interesting to note that in our conditions, a following distance of 18.5m corresponded to a time-headway of 1.1s, which is well within the range of common time headways drivers choose in real driving (Treiterer and Nemeth, 1970; von Buseck et al., 1980; Ayres et al., 2001). Likely a reasonable choice as it allows for enough RT delay to respond to a sudden change in the vehicle ahead. Travelling at high speeds may also affect the prioritization of tasks, as at a higher speed of 100km/h, the same delays of 100 – 600ms corresponds to 2.7 – 16.7m, and drivers may be poorer at estimating car-following headways at faster speeds (Risto and Martens, 2013, 2014). Future work can examine whether varying parameters of the car-following task can modulate the impact of divided attention on vehicle control.

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Chapter 3

The effect of apparent distance on peripheral target detection is non-monotonic and does not depend on the distance of fixation

3.1 Abstract

Most of what we know about visual-spatial attention comes from studying responses to a 2D plane like a computer screen. Less is known about how the distribution of attention changes across distance. Previous studies suggest that attention to the visual periphery is affected by apparent distance simulated by pictorial cues and optical flow. However, it is unclear if this effect depends solely on the distance between the viewer and the target, or whether it is influenced by the distance between the target and the plane of fixation. The current study investigated these questions in two experiments that measured how performance in a peripheral target detection task is affected by target eccentricity and apparent distance when the peripheral task was performed alone or during a simultaneous, central car-following task. Experiment (Exp) 1 found that targets at a distance of 18.5 virtual meters (m_v) were detected faster and more accurately than targets at 9.25 and 37 m_v, but performance declined with eccentricity at all three distances. Exp 2 examined the effect of fixation location by varying the distance between the viewer and the lead car (i.e., the headway) on which participants were instructed to fixate, and presenting the target at three distances that were in front of, beyond, or at the same distance as the fixation plane. The results replicated the effects of target distance and eccentricity found in Exp 1, and the effect of target distance was not influenced by

the distance to the fixation plane. The current experiments suggest that target detection depends non-monotonically on the distance between the viewer and the target, and is not affected by the distance between the target and fixation plane.

3.2 Introduction

Visuo-spatial attention is typically tested in the lab on a computer screen, and is relatively well characterized on the fronto-parallel plane. However, less is known about how visual ability varies in three-dimensional (3D) space. Extending our investigations to 3D space allows us to build a more complete picture of how we parse our complex visual environment in naturalistic settings.

A body of literature suggests that the distribution of visual-spatial attention varies in 3D space, particularly when attention is unguided (i.e. un-cued). One demonstration of viewing distance modulating attention is spatial neglect. Spatial neglect typically is caused by right hemispheric lesions resulting in an inability to attend, orient, and respond to stimuli presented in the contralesional left space, despite intact motor and sensory functioning (Adair and Barrett, 2008; Hillis, 2006; Parton et al., 2004; Heilman and Valenstein, 1979). However, spatial neglect may vary with egocentric distance (Aimola et al., 2012; Adair and Barrett, 2008; Butler et al., 2004; Kerkhoff, 2001). For example, neglect may be worse in reachable, peri-personal space in some individuals (Halligan and Marshall, 1991; Guariglia and Antonucci, 1992), and worse in out-of-reach, extrapersonal space in others (Cowey et al., 1994; Vuilleumier et al., 1998). These behavioural findings and subsequent neuro-imaging studies suggest that attention in near and far spaces have different neural substrates and underlying processes (Butler et al., 2004; Aimola et al., 2012; Halligan et al., 2003; Kerkhoff, 2001see Hillis, 2006, for review).

Consistent with these ideas, neurologically healthy participants also show a small but consistent spatial bias, called pseudoneglect, that vary with distance (see Bjoertomt et al., 2002, for review). Typically, at within-reach distances in near space, participants show a small but robust leftward bias in the perceived midpoint of lines. However, when stimuli are presented out of participants reach, the small leftward bias typical of pseudoneglect shifts rightwards and results in smaller leftward biases or even rightward biases (Dellatolas et al., 1996; Varnava et al., 2002; Garza et al., 2008, e.g.).

The differential patterns of attention distribution in near and far space may also play a role in other tasks requiring visual attention. For example, the selection of fixation locations during free visual exploration of natural images as participants made more fixations to the left side of an image at a near viewing distance, but made more fixations to the right at a far viewing distance (Hartmann et al., 2019). And in a visually guided grasping task where both left- and right-handed participants constructed a 3D object using an array of blocks. Participants' fixations and visually guided grasps tended towards the right side of the array in far space, where a change in posture was required to reach objects, but not in near space (de Bruin et al., 2014). Moreover, viewing distance also affected the sensitivity to a peripheral target that appeared simultaneously with a central identification target. Specifically, detection performance was better at the near viewing distance especially in the visual periphery, even when retinal size and location were equated across distances (Li et al., 2011). Together these studies suggest that spatial attention may differ in near and far space defined by egocentric distance.

Studies reviewed above compared the distribution of attention in different spatial ranges defined by egocentric distance. However other research suggests that distance affects attention even when the spatial range is unclear due to the use of binocular disparity as the sole depth cue. For example, in a response compatibility paradigm, participants responded to a target surrounded by two identical flankers that were either compatible, suggesting the same response as the target, or incompatible, suggesting the opposite response as the target (Andersen, 1990; Andersen and Kramer, 1993). Participants were asked to respond only to the central target and ignore the flanking distractors which varied in location along the horizontal and depth axes (Andersen, 1990), or along the vertical, horizontal, and depth axes (Andersen and Kramer, 1993). Both response compatibility studies found that there is an asymmetry in the distribution of attention about the fixation along the depth-axis, but the precise effects differed between the two studies. Andersen (1990) found a bigger effect of flanker compatibility for far than near targets, whereas Andersen and Kramer (1993) found a bigger flanker compatibility effect for near targets. It was suggested that the larger flanker compatibility effect found in Andersen (1990) was due to the larger perceived size of far targets due to the very short viewing distance used in Andersen (1990) (Andersen and Kramer, 1993).

One interpretation of these results is that the distribution of attention may differ depending on the distance of the target relative to the plane of fixation. That is, in both Andersen (1990) and Andersen and Kramer (1993), the depth of the flankers was defined relative to the target, which were always on the target presented at a single distance. Furthermore, the interference effect of flankers were always largest when they appear at the same depth of the target. Consistent with this idea, a singleton distractor that appears between the viewer and the fixation point capture attention more than one that appears beyond fixation (Plewan and Rinkenauer, 2020). These results are in line with the idea that attention is concentrated between the viewer and the fixation point, and decreases rapidly beyond.

However, another interpretation of these results is that the relationship between egocentric distance and attention may not be monotonic. Attention may increase up to some intermediate distance, then decrease again for farther distances. Manipulation of fixation distance would be required to examine whether the pattern of results depends on fixation distance.

A few studies that manipulated fixation distance suggest that the distribution of attention depends on the location of fixation. In a peripheral target detection paradigm under binocular viewing, peripheral targets at a single, fixed physical dpeth in front of the participant were detected faster when fixating far beyond the targets than when fixating between the viewer and the target (Kokubu et al., 2018). Furthermore, in a multiple object tracking task, eight objects moved randomly within a virtual 3D space with depth simulated by binocular disparity and relative size (Roudaia et al., 2017). When participants fixated at a near depth such that objects were at or farther than fixation, tracking decreased when there is greater separation of the objects. However, when participants fixated at a far depth such that all objects were between the viewer and fixation, no decrements in tracking related to depth separation was found. This result suggests that attention was mainly deployed between the viewer and fixation. Taken together, these studies suggest that the spatial distribution of attention along the depth-axis depends on the distance of fixation.

In the studies discussed above, binocular disparity always contributed to perceived distance. However, distance may affect performance even when it is simulated by only monocular depth cues. In a change-blindness paradigm, changes in a complex scene were detected faster when they occurred in the foreground (in relative near space) compared to the background (in relative far space). But the effect of location when only monocular depth cues were present was smaller compared to when both binocular and monocular depth cues were present (Ogawa and Macaluso, 2015).

Monocular depth cues also were used in driving simulation studies, which found a near advantage. In a driving paradigm where distance was simulated by linear perspective and optic flow, participants were asked to follow a lead car at a constant distance while also reporting the location of a target on an overhead traffic light array. Target detection was slower and less accurate as the light's distance from the viewer increased (Andersen et al., 2011), even when the retinal size and location of the targets were controlled (Pierce and Andersen, 2014). However, in this paradigm, a target appeared only at one distance per light array, allowing participants to anticipate the onset the near targets more easily than far targets.

Chapter 2 of this thesis (Exp 2 and 3) controlled for anticipation in addition to retinal size and eccentricity of targets using a different simulated driving paradigm. Participants kept a constant distance of 18.5 virtual meters (m_v) behind a lead car on a straight trajectory that changed speed unpredictably in a car-following task. In these conditions, the apparent distance between the lead car and the participant's viewpoint determined the virtual fixation distance. The car-following task was completed either passively (accomplished by the computer) or actively by participants via accelerating or decelerating their own viewpoint. Simultaneously, they were asked to detect brief peripheral targets that appeared on walls that were parallel to the participant's trajectory on the left and right side. Peripheral targets appeared on the walls at a near distance ($18.5m_v$), or a far distance ($37m_v$). Although detection accuracy decreased for larger eccentricities, the effect of eccentricity was larger for far targets, indicating tunnel vision that occurs at the far distance in both active and passive driving conditions. In other words, detectability for near targets at large eccentricities were more accurate than far targets. However, Chapter 2 tested only two distances and near targets were always presented at the same distance as the lead car which participants were told to fixate. Therefore, it is unclear whether participants were able to detect near peripheral targets better because the targets were nearer to the viewer, or because targets were nearer to the fixation.

The aim of the current study is to examine whether the effect of distance on detectability found in Chapter 2 depends on the location of fixation. We anticipated three possibilities: 1) Performance may depend on the egocentric distance of the target to the viewer. 2) Performance may depend on the relative distance between the target and the distance of fixation. 3) A combination of both 1) and 2). The two experiments presented here attempt to determine which of the three possibilities best describe the allocation visual-spatial attention in simulated 3D space.

Before we examined the effect of fixation distance, Exp 1 aimed to further characterize the effect of distance on detection by testing targets that appear between the viewer and lead car. The results of Exp 1 provides a baseline condition for subsequent investigation of the effect of fixation in Exp 2.

3.3 Experiment 1

Only two distances (18.5 and 37m_v) were tested in Chapter 2, so it is unclear whether performance decreases monotonically (Andersen et al., 2011; Pierce and Andersen, 2014) or non-monotonically (Andersen, 1990; Andersen and Kramer, 1993) with distance. Given that the design of the current study is more similar to Andersen et al.; Pierce and Andersen than Andersen; Andersen and Kramer, we expect the results to more likely be in-line with the former. However, in Andersen et al.; Pierce and Andersen, distances between the viewer and the fixation distance were never tested. To more fully investigate the spatial distribution of attention, Exp 1 used a paradigm that was similar to the one used in Chapter 2 with the addition of a third target distance (9.25m_v). Using these three distances (9.25, 18.5, and 37m_v) allowed us to measure the characterization of performance at target distances that are less than, equal to, and greater than the distance to the plane of fixation (i.e., the headway).

3.3.1 Methods

Subjects

Of the 27 participants recruited, 22 (13 female; 17-24 years old, $M = 19.5$, $SD = 1.90$) completed the experiment. Of the five excluded participants, two ended the task early due to motion sickness, two were excluded due to inattention during the experiment, and one was excluded due to a programming error. All participants had self-reported normal or corrected-to-normal visual acuity at 1.5 m. Written informed consent was obtained in accordance with the Canadian Tri-council Policy, and the experimental procedure was approved by the McMaster Research Ethics Board. Participants received $15 or partial course credit for their participation in this study.

Stimuli and Design

The display apparatus was identical as Chapter 2. Figure 3.1 illustrates the virtual environment used in the experiment. An egocentric view of the virtual environment was shown from an eye-height of one virtual metre (m_v). Participants travelled forward along a straight trajectory at an average speed of 40 km_v/h or 11.11 m_v/s behind a lead car that varied in speed throughout the experiment. The speed of the lead car was defined by the sum of 3 sine wave functions with frequencies of 0.033, 0.083, and, 0.117 Hz with respective amplitudes of 9.722, 3.889, and 2.778 km_v/h. At the beginning of each block, phases of the two highest frequency sine-wave components were generated randomly, and the phase of the lowest frequency component was set such that the starting speed of the car at the beginning of each trial was 40 km_v/h.

The virtual environment was in greyscale and included a ground plane with a tile pattern extending virtually infinitely in all directions. Every 50 m_v, participants passed through a a 4m_v gap centered on the screen between pair of walls oriented perpendicular to the ground plane and along the fronto-parallel plane. Each wall was 4m_v tall, 18 m_v wide, and 0.1m_v thick, placed in the left and right side of the display area. Walls were covered by a checkerboard pattern consisting of alternating light and dark grey squares measuring 1 m_v^2 with a Michelson contrast of 0.36 and an average luminance of 8.40 cd/m^2. Each square in the checkerboard pattern extended 1m_v resulting in spatial frequencies of 0.08, 0.17, and 0.33 cycles/dva at distances of 9.5, 18.5 and 37 m_v respectively.

Peripheral detection task Figure 3.1 illustrates all possible target positions in this experiment. The circular target consisted of a checkerboard pattern with a spatial frequency of 0.41 cycles/dva that matched in phase with the wall. The target's contrast was vignetted with a circular window (diameter = 2.4 dva). A target appeared for a duration of 67 ms. An auditory beep at 1658 Hz was played at the same time as the onset of a target. The texture of the target matched the texture of the wall behind it, but had a higher Michelson contrast of 0.57. Targets were presented at three distances (9.25, 18.5, and 37m_v) and two eccentricities (12 and 24 dva). Whenever the participant reached one of these three distances from a wall, there was a 50% chance that a single target would be displayed at one location on the corresponding wall. When travelling towards a pair of walls, a target could appear at zero, one, two, or all three distances. Thus, the appearance of a target at each distance was independent from targets at the other distances, and therefore, the temporal uncertainty about target onset was the same at all target distances. Participants indicated as quickly and accurately as possible whether the target appeared on the left or right wall by pressing 'A' (left) or 'D' (right) on a standard computer keyboard with their left hand.

Car following task As illustrated in Figure 3.1, a white box measuring 4 × 4 dva was drawn onto the screen surrounded the lead car to serve as feedback to encourage accurate performance of the car-following task. Participants were asked to stay at a constant, safe distance hind the lead car such that the box appeared to be just surround the car. They accelerated and decelerated their own viewpoint by using their right hand to press the up and down arrow keys, respectively, on a standard computer keyboard. The viewpoint accelerated at 3 m_v/s (0.05m_v per frame), and decelerated at 6 m_v/s (0.1m_v per frame).

Procedure

The experiment used a 2 (Attention: focussed and divided) × 2 (Eccentricity: 12 and 24 dva) × 3 (Distance: 9.25, 18.5, 37m_v) within-subject design and had three parts. In the first part, participants were asked to detect the onset of peripheral targets in the peripheral detection task while the computer kept a constant headway of 18.5m_v. The first part lasted 16 blocks, each with 32 pairs of walls. In part two, participants were asked to follow the lead car actively by matching the size of the lead car with the on-screen box, and no peripheral target appeared. Part two consisted of one continuous block lasting approximately 3.5 min. In part three, participants were asked to follow the lead car and detect peripheral targets at the same time. Like part one, part three also consisted of 16 blocks with 32 pairs of walls in each block. Verbal instructions were given at the beginning of each part of the experiment. In the divided attention condition, participants were given the instructions from the previous two focussed attention parts. Participants had opportunities to take breaks between blocks. In total, the experiment lasted approximately 1.5 h.

Data Analysis

We measured accuracy and reaction time (RT) of target detection. Only trials on which target onset occurred at a single distance per wall pair were used, resulting in 32 trials per condition. For RT, only correct responses were included. Untransformed data were analyzed as transformation did not improve the sphericity of the data and to preserve the ease of interpretation of the results. Furthermore, the pattern of results of the transformed and untransformed data were similar.

To quantitatively evaluate the effect of attention, eccentricity, and target distance on target detection, we ran separate 3(Distance) × 2(Eccentricity) × 2(Attention) within-subject ANOVAs on accuracy and RT. Furthermore, to examine whether the effect of distance has linear and quadratic components, we compared the linear and quadratic trends of the main effect of distance for accuracy and RT as well.

Car-following performance was analyzed using the same procedure as in Chapter 2. The speed of the participant's viewpoint was recorded and compared to the speed of the lead car. Speeds were transformed into the frequency domain using the fast Fourier transform routine in numpy in Python 3.8. The amplitude gain and phase shift of the participant's viewpoint relative to the lead car were calculated and analyzed with separate 2(Attention) × 3(Frequency) ANOVAs.

All statistical analyses were performance in R 3.3.2 (R Core Team, 2017). Where appropriate, p values for F tests were adjusted using the Greenhouse-Geisser correction for deviations from sphericity ($\hat{\epsilon}$). For estimates of effect size, the generalized eta squared (η_G^2) is reported. For estimates of effect size, the generalized eta squared (η_G^2) is reported to allow for comparisons across between- and within-subject designs (Olejnik and Algina, 2003).

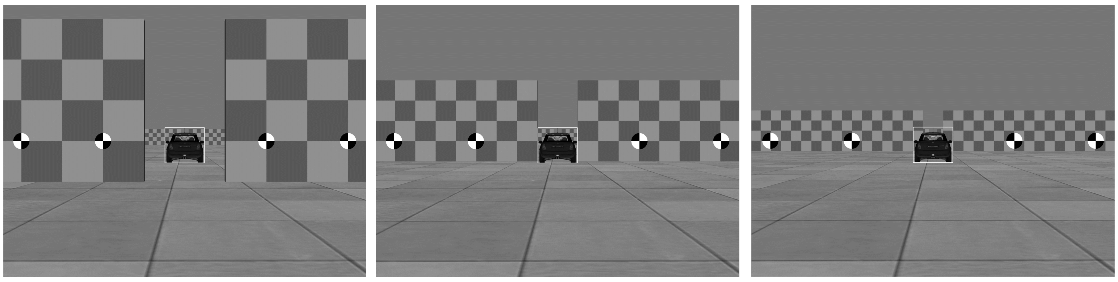
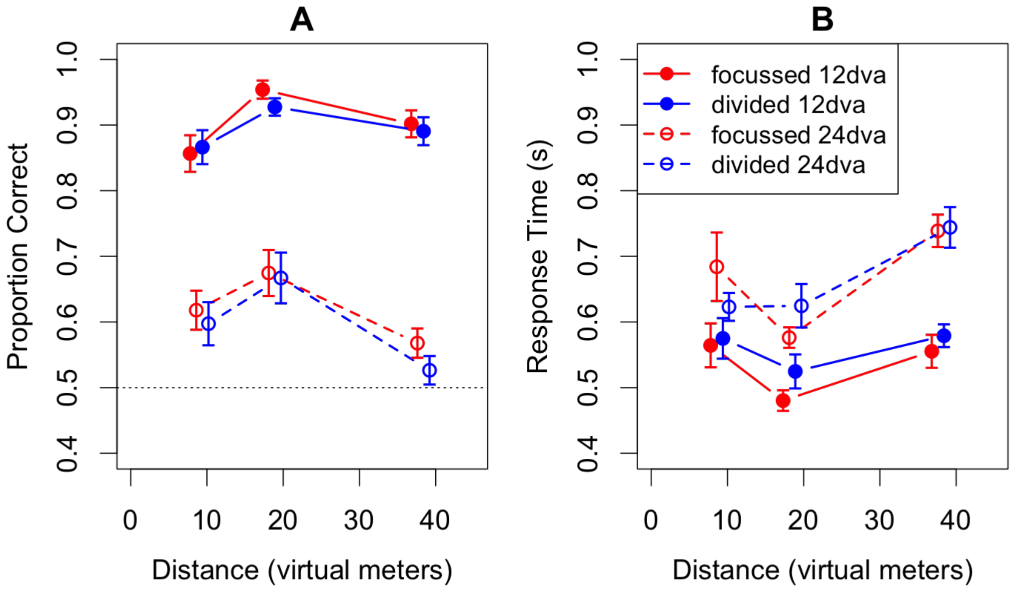


FIGURE 3.1: A schematic of all possible target locations in the 9.25 (left), 18.5 (middle), and 37m_v (right) target distance conditions. Note that across the three distances, the retinal eccentricity and size of the circular targets were equated. Target contrasts were increased for illustration and were lower in the experiment. On each trial, only one of the four targets shown appeared.



(A) Exp 1 - Peripheral detection performance

FIGURE 3.2: Peripheral target detection accuracy (A), and RT (B) plotted as a function of target distance. Red and blue indicates focused and divided attention conditions, and solid and dashed lines indicates eccentricities of 12 and 24 dva, respectively. The dotted horizontal line in (A) indicates chance performance. Error bars indicate ± 1 standard error of the mean (SEM).

3.3.2 Results

Peripheral Detection Accuracy

Figure 3.2A shows response accuracy in the peripheral detection task as a function of distance, eccentricity, and attention. Accuracy was analyzed with a 3(Distance) × 2(Eccentricity) × 2(Attention) within-subject ANOVA was conducted to quantitatively evaluate the data. Accuracy was worse at 24 dva compared to 12 dva, indicated by a significant main effect of eccentricity ($F(1, 21) = 463.20$, $p < 0.001$, $\eta^2_G = 0.59$). The main effect of distance also was significant, ($F(2, 42) = 21.11$, $p < 0.001$, $\eta^2_G = 0.06$). Pair-wise tests indicated that accuracy was significantly higher at 18.5 m_v ($M = 0.81$) than 9.25 m_v ($M = 0.73$; $F(1, 21) = 35.49$, $p < 0.001$, $\eta^2_G = 0.11$) and 37 m ($M = 0.72$; $F(1, 21) = 41.24$, $p < 0.001$, $\eta^2_G = 0.21$), but that accuracy at 9.25 and 37 m_v did not differ significantly ($F(1, 21) = 0.62$, $p = 0.44$, $\eta^2_G = 0.005$). There also was a significant Eccentricity × Distance interaction ($F(2, 42) = 5.11$, $p = 0.01$, $\eta^2_G = 0.03$), because the effect of eccentricity at 37m_v ($D = 0.34$) was was significantly larger than at 18.5 ($D = 0.27$; $F(1, 21) = 4.64$, $p = 0.04$, $\eta^2_G = 0.04$) and 9.25 $\mathrm{m_v}$ ($D = 0.25$; $F(1, 21) = 14.56$, $p < 0.001$,$\eta^2_G = 0.05$). The effects of eccentricity at 9.35 and 18.5 $\mathrm{m_v}$ were not significantly different ($F(1, 21) = 0.24$, $p = 0.63$, $\eta^2_G = 0.001$). The simple main effect of eccentricity was significant at every distance ($F(1, 21) \geq 90.65$, $p < 0.001$, $\eta^2_G \geq 0.53$). No other effects in the omnibus ANOVA were significant ($F \leq 1.37$, $p \geq 0.25$, $\eta^2_G \leq 0.004$ in each case; see Table A2.1).

The polynomial trend analysis of the main effect of Distance found a significant quadratic trend ($\psi = 0.06$, $F(1, 42) = 41.37$, $p < 0.01$, $\eta^2_G = 0.08$), which is consistent with the observation that accuracy was slightly higher for the 18.5$\mathrm{m_v}$ compared 9.25 and 37$\mathrm{m_v}$ conditions. The linear trend was non-significant ($\psi = 0.01$, $F(1, 2) = 0.856$, $p = 0.036$, $\eta^2_G = 0.002$).

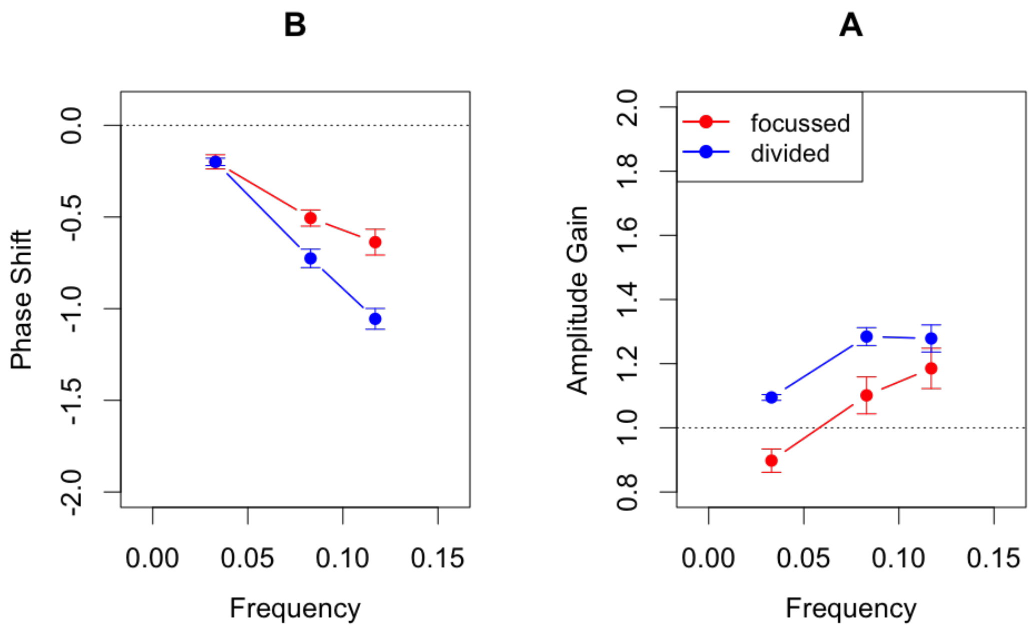
Peripheral Detection RT

Figure 3.2B shows RT as a function of distance, eccentricity, and attention. In many respects, the results obtained with RT were similar to those obtained with accuracy. These observations were evaluated quantitatively with A 3(Distance) × 2(Eccentricity) × 2(Attention) within-subject ANOVA. As expected, reaction time was slower overall for 24 dva than 12 dva ($F(1, 21) = 159.06$, $p < 0.001$, $\eta^2_G = 0.17$). The main effect of distance was significant ($F(2, 42) = 20.25$, $\hat{\epsilon} = 0.79$, $p_{adj} < 0.001$, $\eta^2_G = 0.09$), where RT at 18.5 $\mathrm{m_v}$ ($M = 0.551$) was significantly faster than 9.25 ($M = 0.61$; $F(1, 21) = 9.04$, $p = 0.006$, $\eta^2_G = 0.07$) and 37 $\mathrm{m_v}$ ($M = 0.654$; $F(1, 21) = 52.35$, $p < 0.001$, $\eta^2_G = 0.23$). However, RT at 9.25 $\mathrm{m_v}$ was also significantly faster than 37 $\mathrm{m_v}$ ($F(1, 21) = 9.66$, $p = 0.005$, $\eta^2_G = 0.03$).

The Eccentricity × Distance interaction was significant ($F(2, 42) = 10.63$, $\hat{\epsilon} = 0.77$, $p < 0.001$, $\eta^2_G = 0.022$). As was found with response accuracy, the effect of eccentricity at 37 $\mathrm{m_v}$ ($D = 0.17$) was significantly larger than at 18.5 ($D = 0.10$; $F(1, 21) = 28.18$, $p < 0.01$, $\eta^2_G = 0.04$) and 9.25$\mathrm{m_v}$ ($D = 0.08$; $F(1, 21) = 15.11$, $p < 0.001$, $\eta^2_G = 0.03$), and 9.25 and 18.5$\mathrm{m_v}$ were not significantly different ($F(1, 21) = 0.34$, $p = 0.56$, $\eta^2_G =< 0.001$). The simple main effects of eccentricity were significant at each distance ($F > 17.14$, $p < 0.001$, $\eta^2_G \geq 0.08$ in each case).

The Distance × Attention interaction also was significant ($F(2, 42) = 3.30$, $p = 0.05$, $\eta^2_G = 0.01$). The effect of attention differed significantly only between 9.25 and 18.5$\mathrm{m_v}$ conditions ($F(1, 21) = 2.87$, $p = 0.04$, $\eta^2_G = 0.02$) because there was a slight divided attention benefit at 9.25$\mathrm{m_v}$ ($D = 0.025$), but a slight divided attention cost in at 18.5$\mathrm{m_v}$ ($D = -0.046$). Visual inspection of Figure 3.2B indicate that the divided attention benefit at 9.25 m_v only occurred at 24 dva. However, the simple main effect of attention was not significant for any target distance ($F \leq 3.31$, $p \geq 0.08$, $\eta^2_G \leq 0.05$), and no other effects were significant ($F \leq 3.30$, $p \geq 0.05$, $\eta^2_G \leq 0.004$ in each case; see Table A2.2).

As was done for accuracy, we examined the main effect of distance by evaluating the linear and quadratic trends of response times across the three target distances. Both the linear ($F(1, 42) = 6.93$, $p = 0.01$, $\eta^2_G = 0.02$) and quadratic ($F(1, 42) = 33.58$, $p < 0.001$, $\eta^2_G = 0.08$) trends were significant. However, the magnitude of the quadratic trend ($\psi = 0.07$) was more than twice that of the linear trend ($\psi = 0.03$), suggesting again that the relationship between target distance and performance is non-monotonic.



(A) Exp 1 - Phase shift of car-following

FIGURE 3.3: Phase shift (A) and Amplitude (B) of car-following responses at each frequency after fast Fourier transformation. Dotted horizontal line represent perfect performance, and deviations indicate error. Focussed attention condition is represented by solid grey circles, and the divided attention condition is represented by open black circles. Error bars represent ± 1 standard error of the mean (SEM).

Car-following Performance

Figure 3.3A and B show the phase shift and amplitude gain of car-following responses in each frequency component in both focussed and divided attention conditions. Overall, a divided attention cost for car-following was evident in both measures. The 2 Attention × 3 Frequency ANOVA on phase shift found a main effect of Attention ($F(1, 21) = 13.1$, $p < 0.001$, $\eta^2_G = 0.18$), with larger lags in the divided than the focussed attention condition. There also was a main effect of Frequency ($F(2, 42) = 118.11$, $p < 0.001$, $\eta^2_G = 0.59$) indicating that phase lag increased as a function of frequency. The Attention × Frequency interaction also was significant ($F(2, 42) = 21.63$, $p < 0.001$,$\eta^2_G = 0.13$), consistent with the observation that the effect of attention on phase lag increased as frequency increased. To further examine the two-way interaction, we evaluated the effect of Attention at each frequency with one-way within-subject ANOVAs. The effect of Attention was significant at the two higher frequencies (0.083 Hz: $F(1, 21) = 8.42$, $p < 0.001$, $\eta^2_G = 0.20$,$D = 0.22$; 0.117 Hz: $F(1, 21) = 25.52$, $p < 0.001$, $\eta^2_G = 0.34$, $D = 0.42$), but not at 0.033 Hz ($F(1, 21) < 0.01$, $p = 0.99$, $\eta^2_G < 0.001$, $D < 0.001$).

Amplitude gain was higher in the divided attention condition than the focussed attention condition. The ANOVA on amplitude gain found significant main effects of Attention ($F(1, 21) = 11.86$, $p = 0.02$, $\eta^2_G = 0.14$), where divided attention condition showed higher amplitudes than the focussed attention condition $D = 0.20$) and Frequency ($F(2, 42) = 38.31$, $p < 0.001$, $\eta^2_G = 0.21$). The two way interaction was not significant ($F(2, 42) = 2.05$, $p = 0.14$, $\eta^2_G = 0.01$).

3.3.3 Discussion

The results of the current experiment suggests that the effect of distance on attention is a non-monotonic function of ego-centric distance: targets at an intermediate distance (defined by monocular depth cues) were more detectable than targets at nearer or farther distances. These results are consistent with the idea that the effect of target distance on detection is non-linear. The results of the current experiment suggest that the detectability of peripheral targets is a non-monotonic function of target distance: targets at an intermediate distance (defined by monocular depth cues) were more detectable than targets at nearer or farther distances. In the current experiment, the intermediate distance coincided with the distance to the lead car. Therefore, our results are consistent with the hypothesis that targets are most detectable when they are presented at a distance that is close to the plane of fixation. Exp 2 tests this hypothesis.

Numerous aspects of the results of the current study replicated the results in Chapter 2. For one, the effects of eccentricity, distance, and attention at distances of 18.5 and 37 m_v were comparable to that of Chapter 2. Furthermore, dividing attention negatively impacted car-following performance, but had little effect on target detection, suggesting that participants prioritized peripheral detection over car-following. These results will be discussed further in the general discussion.

3.4 Experiment 2

The aim of Exp 2 is to determine if the effect of distance on the detectability of peripheral targets is influenced by the plane of fixation. If target detectability is affected by the relative distance between the target and the plane of fixation, then varying the fixation distance should modulate the effect of distance on detection.

In Exp 1, the fixation distance was always 18.5 m_v which coincided with the distance at which detection performance was the highest. In the current experiment, fixation distance was manipulated by varying distance to the lead car on which participants were instructed to fixate (i.e. the headway). If the detectability depends the relative distance between target and fixation, then performance should be best for targets at the same distance as the lead car, leading to different effects of distance for each headway condition. The effect of target distance and fixation location were examined independently by factorially combining the three target distances used in Exp 1 with three car-following headways that are equal to the three target distances.

Lastly, varying headway may alter the difficulty of the car-following task. A short headway has a smaller margin for error as participants are more likely to crash into the lead vehicle if an error is made. A long headway has a much larger margin for error, as participants are very unlikely to hit the lead vehicle even when errors are made. To cope with these characteristics of the car-following task, participants may use different strategies in different headway conditions. To exclude the effect of car-following task difficulty on peripheral detection performance, we assessed baseline performance of the car-following task alone and peripheral detection alone, under focussed attention, and then simultaneously, under divided attention. By comparing the effect of divided attention for both tasks, we can determine whether the headway distance manipulation affected either or both of the tasks participants were asked to complete.

3.4.1 Methods

The methods were identical as Exp 1 except for several changes that are described below.

Subjects

Seventy-eight participants were recruited. Data from nine participants were excluded due to a software error. One participant who did not complete the experiment and three participants who performed at or below chance level in all conditions also were excluded. The final sample size was 65 participants aged 17-23 ($M = 18.18$, $SD = 0.827$), of whom 42 were female.

Design

We varied car following distance by varying the following distance or headway to the lead car as a between-subject factor. There were three headways, 9.25, 18.5, and 37m_v, with 25, 21, and 19 participants in each headway group respectively. Note that the three headways coincide with the three target distances. A participant only experienced one headway condition, but experienced all three target distances. This resulted in a 3(Headway) × 3(Distance) × 2(Eccentricity) × 2(Attention) mixed factorial design.

3.4.2 Results

Peripheral Detection Accuracy

Figure 3.4 shows target detection accuracy as a function of eccentricity, target distance, and headway. At each headway, effects of eccentricity and target distance appear to be similar to the ones obtained in Exp 1. To examine whether detection was influenced by car-following headway, the same analyses as in Exp 1 were conducted with an additional between-subject, three-level factor, Headway. A 3 (Headway: 9.25, 18.5, & 37 m_v) × 2 (Eccentricity: 12 & 24 dva) × 3 Target Distance (9.25, 18.5 & 37 m_v) × 2 (Attention: Focussed vs. Divided) ANOVA was conducted (see Table A2.5). Accuracy was lower for targets at 24 dva than at 12 dva, indicated by a significant main effect of eccentricity ($F(1, 62) = 853.01$, < 0.001, $\eta_G^2 = 0.0.58$). There was a significant main effect of target distance ($F(2, 124) = 15.14$, $\hat{\epsilon} = 0.83$, $p < 0.001$, $\eta_G^2 = 0.03$): pairwise comparisons found that target detection was more accurate at 18.5 m_v ($M = 0.71$) than 9.25 ($M = 0.67$; $F(1, 64) = 39.29$, $p < 0.001$, $\eta_G^2 = 0.04$) and 37 m_v ($M = 0.67$; $F(1, 64) = 20.55$, $p < 0.01$, $\eta_G^2 = 0.05$), but the 9.25 and 37 m_v conditions did not differ significantly ($F(1, 64) = 0.22$, $p = 0.64$, $\eta_G^2 = 0.001$). The main effect of attention also was significant

($F(1, 62) = 6.78$, $p = 0.01$, $\eta^2_G = 0.01$), indicating that there was a divided attention cost.

The Eccentricity × Distance interaction was significant ($F(2, 124) = 30.87$, $p < 0.001$, $\eta^2_G = 0.03$) because the effect of eccentricity was significantly larger at 37m_v ($M_{ecc} = 0.35$) than at 18.5 ($M_{ecc} = 0.31$; $F(1, 64) = 5.17$, $p < 0.03$, $\eta^2_G = 0.01$) and 9.25m_v ($M_{ecc} = 0.24$; $F(1, 64 = 51.73$, $p < 0.001$, $\eta^2_G = 0.06$), and the effect of eccentricity at 18.5m_v was significantly larger than at 9.25m_v ($F(1, 64) = 36.21$, $p < 0.001$, $\eta^2_G = 0.02$). However, detection accuracy at 12 dva was higher than 24 dva at all three target distances ($F(1, 64) \geq 333.86$, $p < 0.001$, $\eta^2_G \geq 0.46$ in each case.) Importantly, the results were consistent across all three headways: the main effect of car-following headway was small and not significant ($F(2, 62) = 0.42$, $p = 0.66$, $\eta^2_G = 0.01$)as were all of the effects ($F \leq 3.11$, $p \geq 0.19$, $\eta^2_G \leq 0.01$ in each case; see Table A2.5). Thus, the ANOVA found no evidence that accuracy was affected by headway distance.

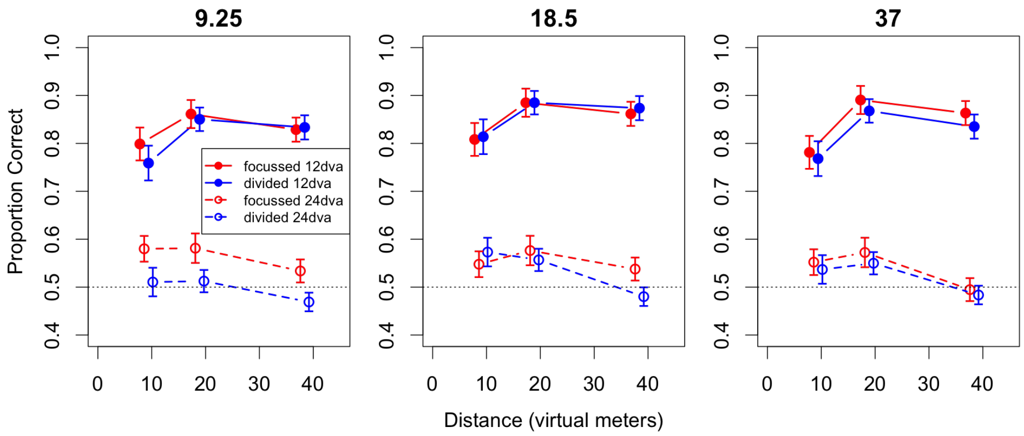


FIGURE 3.4: Peripheral target detection accuracy as a function of target distance. The left, middle and right panels represent headways of 9.25, 18.5, and 37m_v respectively. The dotted horizontal line represents chance performance (50% accuracy), and perfect accuracy is represented at 1.58. Focussed attention condition is represented by red, and the divided attention condition is represented by blue. Finally, eccentricities of 12 and 24 dva are represented by solid and dashed lines respectively. Error bars represent ± 1 standard error of the mean (SEM).

Peripheral Detection RT

Peripheral target detection RTs on correct trials are shown in Figure 3.5. RTs were analyzed with a 3 (Headway: 9.25, 18.5, & 37 m_v) × 2 (Eccentricity: 12 & 24 dva) × 3 Target Distance (9.25, 18.5 & 37 m_v) × 2 (Attention: Focussed vs. Divided) ANOVA (see

Table A2.6). RTs were slower at an eccentricity of 24 dva compared to 12 dva, as indicated by a significant main effect of eccentricity ($F(1, 62) = 331.75$, $p < 0.001$, $\eta^2_G = 0.29$). There was a significant main effect of target distance ($F(1, 124) = 64.73$, $\hat{\epsilon} = 0.84$, $p_{adj} < 0.001$, $\eta^2_G = 0.09$). Pairwise comparisons found that RT at 18.5m_v ($M = 0.68$) was significantly faster than 37m_v ($M = 0.75$; $F(1, 64) = 153.37$, $p < 0.001$, $\eta^2_G = 0.18$), but the difference between 9.25m_v ($M = 0.69$) and 18.5m_v ($F(1, 64) = 2.95$, $p = 0.09$, $\eta^2_G = 0.003$) and between 9.25m_v and 37 m_v ($F(1, 64) = 0.225$, $p = 0.64$, $\eta^2_G = 0.001$) were not. The main effect of Attention also was significant ($F(1, 62) = 15.11$, $p < 0.001$, $\eta^2_G = 0.02$), indicating that RTs in the focussed attention ($M = 0.688$) were faster than in the divided attention condition ($M = 0.719$).

The ANOVA also found a significant Eccentricity × Distance interaction ($F(2, 124) = 45.11$, $p < 0.001$, $\eta^2_G = 0.03$). Although RT at 12 dva was always faster than at 24 dva ($F(1, 64) \geq 102.51$, $p < 0.001$, $\eta^2_G \geq 0.15$ in each case), the effect of eccentricity increased with increasing distance. The effect of eccentricity at 37m_v ($M_{ecc} = 0.175$) was significantly larger than 18.5 ($M_{ecc} = 0.12$; $F(1, 64) = 29.68$, $p < 0.001$, $\eta^2_G = 0.02$) and 9.25m_v ($M_{ecc} = 0.09$; $F(1, 64) = 71.11$, $p < 0.001$, $\eta^2_G = 0.05$), and the effect of eccentricity at 18.5 and 9.25m_v also differed significantly ($F(1, 64) = 24.28$, $p < 0.001$, $\eta^2_G = 0.01$). Lastly, RTs in the focussed attention were faster than in the divided attention condition, indicated by a significant main effect of attention ($F(1, 62) = 15.11$, $p < 0.001$, $\eta^2_G = 0.02$).

The main effect of headway ($F(2, 62) = 2.42$, $p = 0.10$, $\eta^2_G = 0.04$), the Distance × Headway interaction ($F(4, 124) = 0.09$, $p = 0.99$, $\eta^2_G < 0.001$), and all of the remaining effects ($F \leq 1.51$, $p \geq .20$, $\eta^2_G \leq 0.002$) were not significant. Thus, as was found with response accuracy, the results were consistent across the three headway distances, and we found no evidence that the effect of target distance depended on headway.

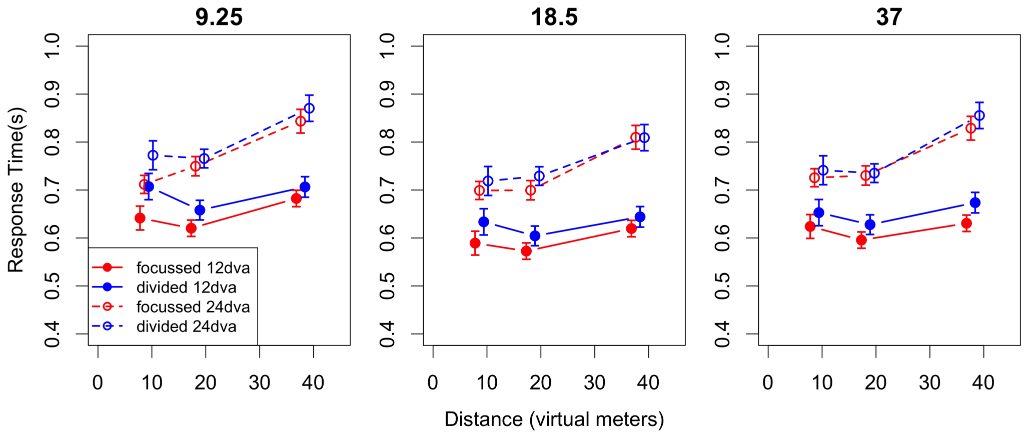


FIGURE 3.5: Peripheral target detection reaction time as a function of target distance, eccentricity, and attention. Symbol conventions are the same as Figure 3.4. Error bars represent ± 1 SEM.

Car-following task

Data from the central car-following task are shown in Figures 3.6 and 3.7. Phase lag and amplitude gain were analyzed with separate 2 (Attention: Focussed vs. Divided) × 3 (Headway) × 3 (Frequency) ANOVAs. For phase lag, there was a significant main effect of attention ($F(1, 62) = 30.77$, $p < 0.001$, $\eta^2_G = 0.11$), indicating that phase lag was (on average) greater in the divided attention condition. However, there also was a three-way interaction between Headway, Frequency, and Attention ($F(4, 124) = 12.27$, $p < 0.00$, $\eta^2_G = 0.075$). At Headways of 9.25 and 18.5 m_v, phase lags were greater in the divided attention condition and the effect of attention increased with increasing frequency. However, in the 37 m_v headway condition, phase lag was *shorter* under divided attention at the highest frequency, although the difference was not statistically significant ($F(1, 17) = 4.42$, $p = 0.051$, $\eta^2_G = 0.13$). [1] The ANOVA on amplitude gain in the 37 m_v Headway condition differed from the other Headways, as indicated by a significant Headway × Attention interaction ($F(2, 62) = 5.45$, $p = 0.007$, $\eta^2_G = 0.027$). The interaction reflects the fact that dividing attention had a significant effect in the 37 m_v Headway condition ($F(1, 17) = 9.35$, $p = 0.007$, $\eta^2_G = 0.12$) but not in the other conditions (see Table A2.8).

In summary, we found that dividing attention and headway affected performance in the central car-following task, and that car-following performance at the largest headway (i.e., 37 m_v) was slightly different than the other headways.

[1] Delays in units of seconds, which are listed in Table A2.9, show the same patterns.

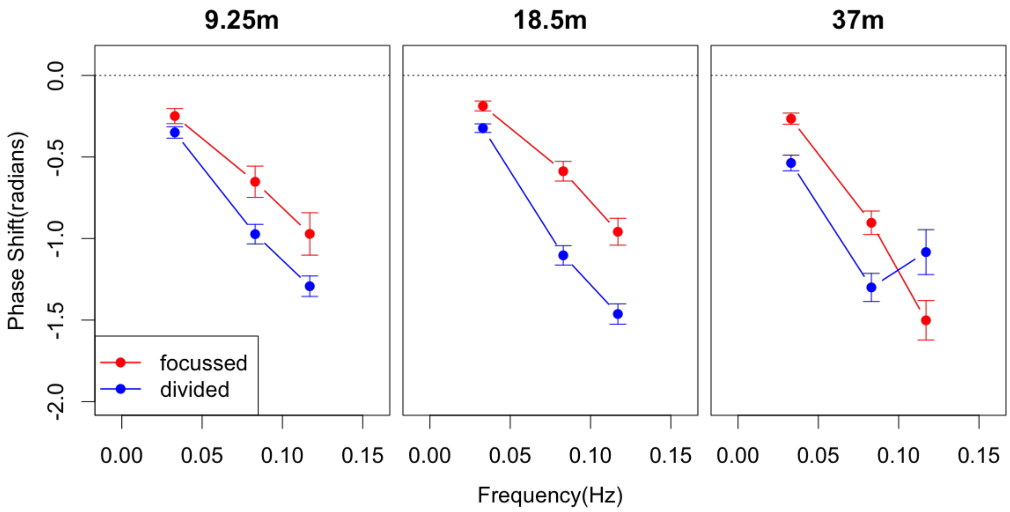


FIGURE 3.6: Phase shift of participant car-following responses as a function of the frequency component of speech change in the lead car. Empty circles represent focussed attention condition, and filled circles represent divided attention condition. Error bars represent ± 1 SEM.

To examine whether participants had a constant delay in following the lead car, we fit mixed effect linear regression to the phase shift data. If participants exhibited constant delay, we would expect intercepts to not differ significantly from zero and the slope of the phase shift by frequency function would approximate the time delay. However, the intercepts differed from zero in each case, suggesting that participants may not have responded to the lead car like a linear system with a simple time delay (see Table A2.10).

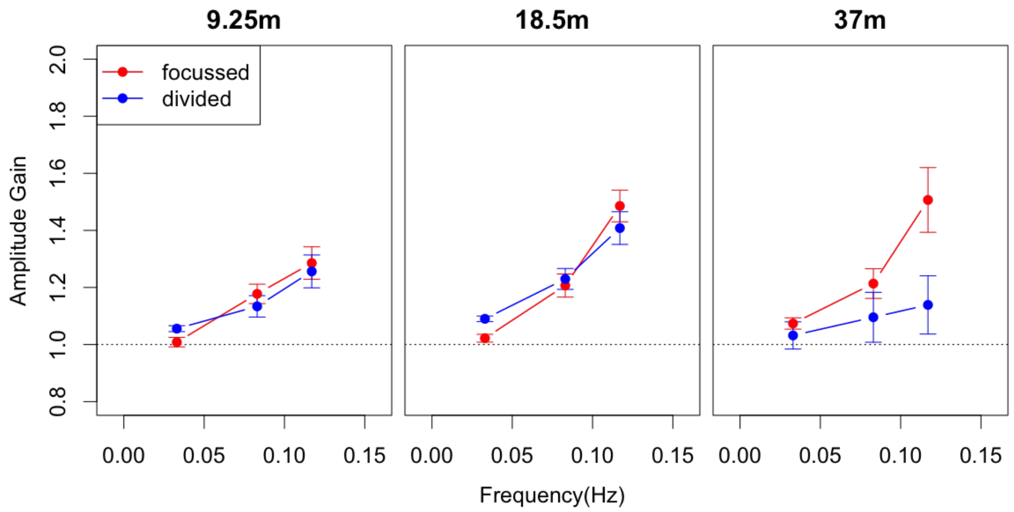


FIGURE 3.7: Amplitude gain of participant car-following responses as a function of the frequency component of speech change in the lead car. Symbol conventions are the same as Figure 3.7.

Visual inspection of Figures 3.6 and 3.7 shows that the standard error of the mean are much larger in the 37 m_v headway condition, suggesting that the variation in performance was larger in that headway condition. To quantitatively test the idea that car-following performance was more variable in the 37 m_v condition, standard deviation of the distance between the viewpoint and the lead car was calculated for each block of 16 trials then averaged for each participant and condition. The average standard deviation of following distance was submitted to a 2 Attention(within-subjects) $\times$ 2 Headway (between-subjects) mixed ANOVA. There was a significant main effect of Headway ($F(1,63) = 10.42$, $p = 0.002$, $eta^2_G = 0.095$), where standard deviation was significantly higher in the 37 m ($M = 6.59$) than the 18.5 m ($M = 3.59$; $F(1,40) = 7.86$,$p = 0.007$,$eta^2_G = 0.16$) and 9.25 m headway condition ($M = 4.14$; $F(1,39) = 16.12$, $p < 0.001$, $eta^2_G = 0.29$). Standard deviation of 18.5 m and 9.25 m headway conditions were not significantly different ($F(1,45) = 0.57$, $p = 0.45$, $eta^2_G = 0.01$). The main effect of Attention was not significant ($F(1,63) = 0.33$, $p = 0.57$, $eta^2_G = 0.002$), but there was a significant Attention $\times$ Headway ($F(1,63) = 7.87$, $p = 0.007$, $eta^2_G = 0.04$). The effect of Attention at the 37 m_v headway condition was significantly larger than at 9.25 ($F(1,40) = 5.03$, $p = 0.03$, $eta^2_G = 0.11$) and 18.5 m_v ($F(1,39) = 10.53$, $p = 0.002$, $eta^2_G = 0.21$) conditions. Pairwise comparisons indicate that the effect of attention at 9.25 and 18.5 m_v did not significantly differ from each other ($F(1,45) = 0.06$, $p = 0.81$, $eta^2_G = 0.001$). The simple main effect of attention was significant in 37 ($F(1,17) = 32.29$, $p < 0.001$,

$eta_G^2 = 0.41$) and 18.5 m_v ($F(1,22) = 38.37$, $p < 0.001$, $eta_G^2 = 0.22$) headway conditions, but not in the 9.25 m_v condition ($F(1,23) = 3.77$, $p = 0.06$, $eta_G^2 = 0.07$), though standard deviations in the divided attention condition were larger than the focussed attention condition for all Headways, a result that is consistent with the divided attention cost found in phase and amplitude measures.

3.5 General Discussion

The experiments described in Chapter 2 found that performance in a peripheral target detection task depended on the virtual distance to the target, even when the visual angle of the target was held constant across distances. The first goal of the current chapter is to examine whether target detectability varied monotonically with distance. In Exp 1, we found that performance was best – accuracy was highest and RT was lowest – at an intermediate distance (18.5 m_v) compared to a near (9.25 m_v) and far (37 m_v) distance. Exp 2 examined whether that effect of target distance depended on the distance to the fixation plane by orthogonally manipulating target distance and fixation distance (i.e. car-following headway). Participants detected peripheral targets presented at the same three distances while they followed a lead car at headway distances of 9.25, 18.5, or 37 m_v. We found that target distance again influenced performance non-monotonically in the same pattern as in Exp 1 – detection was best at an intermediate target distance. We also found in both experiments that peripheral task performance declined with increasing eccentricity, and that the effect of eccentricity increased monotonically with distance. The effect of eccentricity was also greater for far targets than near targets.

More importantly, the goal of Exp 2 was to investigate the effect of car-following headway on the effect of target distance. Headway distance had small, non-significant effects on performance. Thus, in these experiments the effects of distance most likely depends only on the distance between the target and the viewer, and not on the distance between the target and the plane of fixation.

The results of the current study are consistent with the findings in Chapter 2. Target detection was slightly faster and more accurate at 18.5m_v than 37m_v, and the effect of eccentricity was larger at 37m_v. As in Chapter 2, we also found consistent dual task cost in the car following task. The divided attention cost was less evidence in the peripheral detection task, although there was a small divided attention cost in Exp 2. We observed some modulation in car following performance when car-following headway was increased, suggesting that the far car-following distance altered the way participants performed the car-following task, but not the peripheral detection task.

The results of chapter 2 and 3 at target distance of 18 and 37 m_v distances are consistent. There were large performance decrements at larger eccentricities, and targets at 18 m_v were detected more accurately and faster than 37 m_v, although the effect was small. These distance effects were replicated across 5 different samples, and approximately 177 participants. Although the effects of distance were small, they were consistent across multiple independent samples.

Results of Exp 3 and 4 of Chapter 2 suggest that checkerboard patterns contributed to the main effect of distance. The effect of the checkerboard pattern may have two mechanisms. First, texture can be a depth cue (Cutting and Vishton, 1995). The removal of the checkerboard texture in Exp 3, and the orthogonal combination of check size with other depth cues may have reduced the perceived distance of targets. However, the difference in peak spatial frequency between the checkerboard texture and the target also varied with distance. This contrast in peak spatial frequency was smaller at the far distance (37 m_v) compared to the near distance (18.5 m_v), and may have made targets more difficult to detect. However, Chapter 3 added an additional nearer target distance (9.25 m_v), in which the difference in peak spatial frequency was even greater than that of the near condition in Chapter 2. If peak spatial frequency was the *sole* cause of the depth effect, we would expect detection for targets at 9.25 m_v to be the same or better than that at 18.5 m_v. However, Chapter 3 found that detection performance for targets at 9.25 m_v was less accurate than at 18.5 m_v. This results is inconsistent with the idea that the distance effect was *solely* due to the difference in peak spatial frequency between checkerboard background and the target. The more likely explanation is that the checkerboard pattern contributed to distance perception which affected the detectability of targets.

Although the conclusion of the current study, that nearer is not always better, differs from that of Pierce and Andersen (2014), target detection performance slows linearly with distance, these results are not necessarily contradictory. The distances tested in the current study, 9.25, 18.5 and 37m_v, were much closer to the driver than those tested by Pierce and Andersen (2014) (30, 45, and 60m_v). Given that the current study used the same car-following speed parameters as that of Pierce and Andersen (2014), our results suggest that attention to near is better than far only starting at some distance ahead of the driver. Secondly, the result that performance decrements associated with eccentricity increases monotonically with distance is consistent with previous findings.

In addition, the current study extended prior findings by suggesting that attention distributed over the depth axis does not depend on fixation location. One intuitive reason why this may be the case comes from considering the demands of driving. An object that is some distance ahead still has a chance for behavioural intervention to change its interaction with the viewer, whereas an object that the viewer is about to pass is not, and so has no behavioural relevance. In both real world and simulated driving, drivers often make fixations across near and far distances during real driving (Falkmer and Gregersen, 2001; Mourant and Rockwell, 1972; Underwood et al., 2003; Konstantopoulos et al., 2010). It has been observed in curve driving that drivers look ahead on their travel path with a lead time of 1-2s, a behaviour thought to play a role in motor planning and the control of the vehicle (Lehtonen et al., 2013; Cohen and Studach, 1977), analogous to guiding fixations observed when humans perform a variety of other active tasks (Mennie et al., 2007; Land, 2006). In contrast, visual information at nearer distances ahead are thought to be involved mainly in the fine control of the car's heading (Morrison et al., 2021; Cohen and Studach, 1977). Fine heading control was not required in our task, which may explain why middle targets are detect with better accuracy than near targets.

Furthermore, it is interesting to note that drivers typically choose to keep following distance at a constant time headway of 1-2 seconds (Treiterer and Nemeth, 1970; von Buseck et al., 1980; Ayres et al., 2001, i.e. if the preceding car suddenly stops moving, it would 1-2 seconds for the driver to crash into it). It is thought that this distance is kept in anticipation of possible hazards in the lead car. Drivers are able to maintain a certain time headway comparably in both simulated and real driving, although they may be less accurate at high speeds (Risto and Martens, 2013, 2014). Further research is needed to examine the relationship between time-headway, speed, and how attention is distributed ahead.

Besides driving, the body of literature on the distribution of attention across depths suggest that that it is easier to distribute attention across the space between the viewer and fixation than beyond fixation (Andersen and Kramer, 1993; Andersen, 1990; Arnott and Shedden, 2000; Roudaia et al., 2017). Our results are mixed regarding this idea. The fact that the effect of eccentricity increased with distance monotonically is consistent with the idea as it indicates that participants ability to use more peripheral areas of their vision worsens with increasing distance. However, it is unclear what the effect of eccentricity is in prior results as it was not always explicitly tested (Andersen and Kramer, 1993, although see). Similarly, reaction time for nearer targets was faster than for far targets, but accuracy for the nearest targets did not significantly different from the far targets. This may reflect the fact that accuracy and reaction time may reflect different aspects of visual and attentional processing. Furthermore, the difference between our results and those from other paradigms suggest that the effect of distance on attention may depend on the task at hand, and that there may be no single frame of reference that prevails across all tasks. Hence, it may be important to use a variety of other paradigms to investigate the influence of task goals on the distribution of attention in 3D space.

The current experiments also assessed the effect of dividing attention on both the peripheral detection and car-following tasks. There was a small, significant divided attention cost for detection in Exp 2 but not in Exp 1. However, both experiments found large, consistent divided attention costs in car-following task. These results are consistent with results in Chapter 2 which also found consistent divided attention costs for car-following but not for target detection.

The precise effect of divided attention on target detection were small and inconsistent in the current chapter and Chapter 2. Exp 2 of the current Chapter found a divided attention cost, whereas Exp 2, and 3 of Chapter 2, and Exp 1 in the current Chapter found no divided attention costs, and Exp 1 of Chapter 2 found a divided attention benefit. These results suggest that the effect of dividing attention on peripheral detection is very small or non-existent.

The divided attention costs for car-following is more consistent across experiments. Phase lag was consistently larger under divided attention than focussed attention, indicating a longer delay in response. Across chapters, amplitude gains in the divided attention condition were larger than the focussed attention conditions, except for Exp 2 in the current chapter which did not find a divided attention cost in amplitude gain measures. Furthermore, the results of Exp 2 suggests a far headway affects car-following performance. First, amplitude gains were smaller in the divided attention for the 37 m_v headway condition. This may suggest that performance was better under divided attention in a far headway condition, but there was an overall divided attention cost in phase shift. Moreover, the standard deviation of follow distance under divided attention was higher than in the focussed attention condition, particularly for a far headway. These results suggests that dividing attention has a larger effect on car-following than on peripheral detection, and that headway affected performance in the car-following task, but not the detection task. Taken together, these results suggest that participant prioritized the peripheral target detection task over the central car-following task.

Given that headway only affected car-following but not target detection, one potential interpretation of the results of Exp 2 is that the allocation of attention across distances was not affected by headway. This result suggest that participants may be able to follow a lead car at a safe distance while attending elsewhere. One possibility is that participants may be able to attend multiple locations depths simultaneously, an idea that has been used to explain multiple-object tracking performance (Cavanagh and Alvarez, 2005). Alternatively, because targets always appeared on the walls, participants may have shifted attention away from the lead car to the walls in anticipation of target onset. The latter interpretation is consistent with the finding that dividing attention decreased car-following performance but not target detection. Because previous studies suggests that shifting attention from far to near is faster than shifting attention from near to far (Gawryszewski et al., 1987; Arnott and Shedden, 2000; Theeuwes and Pratt, 2003), headway may affect the peripheral detection task if participants prioritized the central car-following task instead. This idea suggests that the allocation of attention in depth, like attention in a 2D context, can be flexibly allocated depending on task demands. Further research is needed to empirically examine these ideas.

To conclude, the current study found that peripheral detection performance depended on egocentric distance of the target and not the headway nor the relative distance between the target and fixation, and the relationship between target distance and detection performance was not monotonic across all distances. However, the decrements in detection performance associated with eccentricity increased monotonically as a function of target distance.

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Chapter 4

General Discussion

This thesis investigated the effect of distance on the distribution of attention in a simulated driving context. The work presented here expanded upon prior findings by measuring performance in a UFOV-like peripheral detection task at various apparent distances in a simulated driving context. The main paradigm used in the current thesis adapted a peripheral detection task into a virtual, 3D environment where distance was simulated by pictorial cues and optic flow. Participants travelled on a straight trajectory through the gaps of fronto-parallel walls while following a lead car at a constant distance, either passively, or actively by accelerating or decelerating their viewpoint. The distribution of attention was measured using a peripheral target detection task. When participants reached particular distances from a pair of walls, a target appeared on one of the walls and participants were asked to indicate whether the target appeared on the left or right wall.

4.1 Summary of key findings

Chapter 2 investigated the effect of apparent distance on target detection. Using two target distances, Experiment (Exp) 1 found more accurate and faster detection for near targets than far targets across all eccentricities. Detection was less accurate and slower as eccentricity increased, and this effect of eccentricity was larger for far targets than near targets. This result was consistent with the findings of Pierce and Andersen (2014). Exp 2 examined the effect of distance on target detection while equating target onset probability at both distances, and found similar effects of distance on accuracy as those found in Exp 1, but found drastically reduced effects of distance on reaction time (RT). These results suggest that the distance effect on RT in Exp 1 was mainly due to target anticipation. , Next, I investigated the effect of the checkerboard pattern backgrounds on detection. Exp 3 removed the checkerboard pattern covering the walls and found no overall near advantage for detection accuracy when performance was averaged across eccentricities, but there was still a distance × eccentricity interaction. Exp 4 varied check size of the checkerboard pattern, wall size, and the presence of the texture ground plane orthogonally in a static display to examine interactions between pictorial depth cues. Exp 4 found that check size, but not wall size or the presence of the ground plane affected target detectability. Averaged across all eccentricities, detection accuracy was lower in the small check condition compared to the large check condition, an effect that is consistent with the main effect of distance found in Exp 2. The results of Exp 3 and 4 suggest that the effect of the checkerboard pattern could account for the main effect of distance found in Exp 2 but not the distance × eccentricity interaction. In summary, the results of Chapter 2 suggest that distance modulates the horizontal extent of the UFOV, although the effect is small.

Chapter 3 investigated whether the effect of apparent distance on detection is monotonic and whether detection is affected by fixation distance. Exp 1 examined detection at three apparent distances and found that detection was most accurate and fastest at a middle distance, indicating that target distance modulated detection non-monotonically. However, the performance decrements at a larger eccentricity increased with distance monotonically. Exp 2 examined whether the effect of distance depended on the location of fixation by varying the headway, the distance between the viewer and the lead car. Headway did *not* modulate detection performance: the results were virtually identical to those obtained in Exp 1 regardless of headway. However, car-following performance was affected by headway, particularly in the far headway condition.

The experiments presented in Chapters 2 and 3 suggest that the detectability of briefly flashed, peripheral targets is affected by target distance, specified by linear perspective and optic flow, even when the retinal characteristics of the target are matched across distances. Furthermore, the effect of distance is non-monotonic and independent of fixation location. More generally, these results are consistent with the idea that the distribution of attention is affected by depth.

Given that the central car-following task was chosen because it has a continuous demand on attention similar to real driving, the current thesis also investigated the effect of dividing attention among the central car-following and peripheral detection tasks. Across Chapters 2 and 3, experiments that examined the effect of dividing attention consistently found large divided attention costs for the car-following task, but small and inconsistent divided attention costs on peripheral detection. These results suggest that participants prioritized the peripheral detection task over the car-following task. The implications of this idea in the context of driving will be further discussed below.

4.2 Implications and future directions

4.2.1 The effect of distance

The general conclusion of the current thesis, namely that apparent distance affects attention, is consistent with previous work examining the effect of both binocular and monocular depth information on attention. However, the precise pattern of the distance effect found here differs from that of prior studies. Chapters 2 and 3 found better performance at 18.5m_v than at 37m_v, and increased effect of eccentricity at far distances. These results are consistent with the results of previous studies that examined the effect apparent distance on detection in a simulated driving context (Andersen et al., 2011; Pierce and Andersen, 2014). However, whereas previous studies found that detection slowed monotonically as apparent distance increased, Chapter 3 found a non-monotonic relationship between distance and detection: detection was less accurate and slower at 9.5m_v compared to 18.5m_v. This discrepancy may be due to the fact that Chapter 3 tested a much nearer distance (9.25 m_v) than in Andersen et al. (2011) and Pierce and Andersen (2014) (minimum 24 m_v). These results suggest that there may be a near advantage only beyond a certain distance ahead of the viewer, but detection performance may decrease at nearer distances.

The results of Chapter 3 is inconsistent with the idea that distribution of attention is asymmetrical about the fixation point. Chapter 3 found that fixation distance did not modulate the effect of distance on detection, a result that is consistent with studies that found that the effects of cueing in depth are not affected by fixation distance (Couyoumdjian et al., 2003; Kimura et al., 2009). However, whereas the cueing studies maintained the same spatial relationship between the fixation point and the targets across fixation distances, Chapter 3 varied the fixation distance while keeping the same target distances. The design of Chapter 3 is more similar to the studies that found an effect of fixation distance on performance (Kokubu et al., 2018; Roudaia et al., 2017), but the results are inconsistent with the idea that the distribution of attention depends on fixation distance.

It is worthwhile to note that the studies that manipulated fixation location used binocular disparity to indicate depth whereas the current study used monocular depth cues. This difference may be one reason why the effects of fixation distance were different between the current work and previous studies. When the relative location of the target and fixation point is varied, the magnitude of binocular disparity also varies: Binocular disparity increases as the distance between the target and the fixation depth increases. Therefore, the effect of fixation found in previous studies may be an effect of the magnitude of binocular disparity. In a monocular display used in this thesis, fixation distance was manipulated using simulated apparent distance while all stimuli were displayed on a 2D screen at a constant physical viewing distance. Therefore, there were no differences in disparity across target distances regardless of fixation distance in the conditions tested in this thesis, which may contribute to the lack of effect of fixation distance on performance.

An alternative interpretation of the finding that fixation distance did not modulate the distance effect is that the distance effect depends on the *attended* location rather than the fixated location. Given that attention can be directed to a location covertly without eye movements, the attended location may vary independently from the fixated location. Yet, most prior evidence is equivocal about whether attention is asymmetrically distributed about the attended location or the fixated location because the attended and fixated locations were the same in some studies (Plummer, 2019; Andersen, 1990; Andersen and Kramer, 1993), and because near and far distances were defined based on crossed and uncrossed disparity which is necessarily centred about the fixation point in others (Couyoumdjian et al., 2003; Kimura et al., 2009; Gawryszewski et al., 1987, e.g.). In fact, some authors interpret the near-far asymmetry found in prior studies as an asymmetry about the *attended* depth, rather than the fixated depth (Gawryszewski et al., 1987; Andersen and Kramer, 1993).

Similarly, this alternative interpretation may be applied to the work presented in this thesis. It is possible that participants fixated the lead car while attending a different depth. The results of most prior studies are consistent with the idea that attention is most concentrated along the the attended depth plane (Andersen, 1990; Andersen and Kramer, 1993; Arnott and Shedden, 2000; Finlayson et al., 2013; Dent et al., 2012; Theeuwes et al., 1998, but see Funke et al., 2015; Kokubu et al., 2018). Chapter 3 found that detection was always fastest and most accurate for targets at 18.5 m_v, which suggests that the attended distance may have been approximately 18.5 m_v ahead.

Why would participants be biased to attend to 18.5 m_v ahead? The answer may be related to driving behaviour. When traversing curves, drivers look ahead on their travel path with a lead time of 1-2 s, a behaviour that is thought to play a role in motor planning and vehicle control (Lehtonen et al., 2013; Cohen and Studach, 1977). Furthermore, during real driving, drivers typically choose to adjust following distance to maintain a constant *time* headway between 1-2 s (Treiterer and Nemeth, 1970; von Buseck et al., 1980; Ayres et al., 2001). These observations suggest that drivers tend to attend a certain *time* ahead rather than a certain distance, presumably to account for their reaction time in the event of a sudden hazard. Interestingly, this 1-2 s window corresponds to the conditions used in the current studies: a distance of 18.5 m_v corresponds to 1.11 s at a speed of 60 km/hr (as in Chapter 2) and 1.66s at a speed of 40km/hr (as in Chapter 3). Thus, the bias to attend to a distance of 18.5 m_v in our experiments may reflect a tendency to attend to 1-2 s ahead while driving. If this idea is correct, then the speed of travel should modulate the distance at which detection performance is best because a constant time headway corresponds to longer distances as speed increases.

One caveat to these conclusions is the potential contribution of the magnitude of perceived depth. One assumption of the work presented here is that all participants can perceive depth simulated by pictorial cues and motion. This assumption seems reasonable given that infants as young as 3-6 months (see Kavšek et al., 2012, for a recent review), and congenitally blind adults immediately after sight onset (Gandhi et al., 2015), are sensitive to pictorial depth cues. Infants as young as one month are sensitive to looming or expansion, a motion cue that indicates an approaching object (Ball and Tronick, 1971; Bower et al., 1971; Náñez, 1988; Shirai et al., 2004). These results suggest that humans are sensitive to pictorial and motion depth cues even without extensive visual experience, and therefore that participants were likely able to use the depth cues present in these studies.

Nevertheless, there may be individual differences in the magnitude of the perceived depth. If the distance effects were due to perceived depth, then the magnitude of perceived depth should be correlated with the magnitude of the distance effect on detection. However, the methods of the current thesis are not suited to such a correlational study because the distance effects were small. If such a correlation exists, it would be easier to find it if there were large individual variations in both the magnitude of perceived depth and the magnitude of the distance effect on detection. A different paradigm from the one used in this thesis is required to address this issue empirically.

Most of the ideas discussed above are based on accuracy results because they showed the most reliable effect of distance across experiments. One reason to focus on accuracy rather than RT is that the most consistent effect of distance was found in accuracy rather than RT. Another reason is that low accuracy affects the interpretation of RT.

Although only RT of correct trials were included in the analysis, not all correct trials are the same. For example, near chance-level performance in a condition indicates that participants were guessing and could not actually locate the target. This suggests that, in that particular condition, correct responses were not a response to seeing the target, rather, participants pressed the correct key by chance. Therefore, RT in a condition in which accuracy was near chance is not necessarily a measure of detection, but how long it took the participant to press a key. This issue is particularly apparent in Exp 2a and 2b of Chapter 3 when accuracy was near chance levels at the 24 degree visual angle (dva) eccentricity condition. It is also possible that participants guessed a proportion of the time at every eccentricity, making some correct trials also possibly correct guesses rather than correct detection. Therefore, RT should be interpreted with caution, particularly when accuracy was near chance.

Finally, attention is a multifaceted construct and requires a plethora of paradigms to characterize fully. The methods used in this thesis, which focus on the detection of brief, peripheral visual targets, undoubtedly are not sensitive to all facets of attention. As reviewed in Chapter 1, depth affects performance in many tasks that measure attention, but it is unclear how these tasks are related to the effects measured in the current thesis and to each other. Relatedly, other visual abilities are also affected by depth. For example, separation in depth affects crowding (Astle et al., 2014), visual working memory (Chunharas et al., 2019), eye movement patterns during viewing of natural images (Jansen et al., 2009), and object recognition (Caziot and Backus, 2015). It would be interesting to examine whether the underlying mechanisms of the effect of depth on spatial attention and other visual abilities are similar, because such a comparison may shed insight on whether the effects of depth are based on a single spatial representation of the world.

4.2.2 Effect of dividing attention in the driving context

Chapters 2 and 3 consistently found large divided attention costs in car-following performance, but no such costs were found in peripheral detection performance. These results suggest that participants prioritized completing the peripheral detection task at the expense of the car-following task. As discussed in Chapter 2, the prioritization of the central task observed in this thesis differs from the results obtained with the traditional 2D UFOV task, which typically find divided attention costs in the peripheral detection task but not the central task (Sekuler and Ball, 1986; Owsley et al., 1998), and sometimes costs are observed in both the peripheral and central tasks (Sekuler et al., 2000;

Richards et al., 2006). Although the findings of this thesis differ from that of the conventional UFOV paradigm, it is not surprising that participants can choose to maintain performance in one task over the other in a dual-task paradigm (Schmidt et al., 1984; Newman et al., 2007; Morey et al., 2011; Farmer et al., 2018). Moreover, other simulated driving studies have reported divided attention results like those in the current thesis (Cooper et al., 2013; Wolfe et al., 2019).

An important difference between the car-following task and the central identification task of the traditional UFOV paradigm is that the car-following task proceeds continuously in time, whereas central identification and peripheral detection tasks are momentary. The parameters of the car-following task may have allowed participants to delay response and compensate for the delay later. In contrast, a discrete, momentary task like the peripheral detection task provides no later opportunity to compensate for not responding in time. The car-following task's continuous nature maybe have enabled participants to prioritize the peripheral detection task rather than the car-following task.

Moreover, the car-following headways used in Chapters 2 and 3 are well within the range of headways that drivers commonly choose during car-following in real driving (Treiterer and Nemeth, 1970; von Buseck et al., 1980; Ayres et al., 2001). These headways are chosen presumably because they give drivers enough time to respond safely to the lead car suddenly stopping. Such a margin of error would allow participants to momentarily divert attention away from the car-following task without crashing. The finding in Chapter 3 that the divided attention cost in car-following performance was affected by headway may be the result of such a compensatory strategy. Headway may affect peripheral detection in conditions that made it difficult for participants to compensate for the increased task demand of dividing attention in the car-following task.

As pointed out in Chapter 2, several other aspects of the methods used in the thesis may have emphasized the peripheral detection task over the central car-following task despite participants receiving no instructions about how to allocate attention between the two tasks. First, an auditory tone accompanied target onset to indicate to participants that they should respond. This auditory tone, which was absent in the car-following task, may have drawn attention towards peripheral detection rather than car-following. Secondly, the peripheral detection task was always tested first, under focussed attention, and this condition was longer in duration (lasting approximately 25 min) than the car-following task under the focussed attention condition (lasting approximately 3 min). This difference in order and duration may have contributed to emphasizing the peripheral detection task over the central car-following task.

Finding that participants maintained peripheral detection performance at the expense of the central car-following task has interesting implications for real driving. These results are consistent with the idea that drivers can extract information from peripheral vision, particularly under safe driving conditions. Although this is well known in vision sciences, human factors research on driver attention often uses eye movement patterns as a proxy for attention. For example, novice and experienced drivers show different scan patterns of their environment during real (Falkmer and Gregersen, 2001; Cohen and Studach, 1977; Mourant and Rockwell, 1972) and simulated driving (Konstantopoulos et al., 2010), and while viewing video-recordings taken from cars driving in real traffic (Underwood et al., 2003). Environmental complexity also novice and experienced driver's scan patterns are differently affected by to environmental complexity (Huestegge and Böckler, 2016; Nabatilan et al., 2012; Underwood et al., 2002; Underwood, 2007; Crundall and Underwood, 1998). However, eye tracking is not a perfectly reliable measure of the *attended* location because it cannot account for the fact that drivers can shift attention covertly without eye movements. Furthermore, the ability to use and extract information from peripheral vision plays an important role in selecting the next fixation location (Kowler, 2011), so understanding attention can help explain and predict the observed fixation patterns. For this reason, more specific studies of how well drivers can respond to information in the visual periphery using driving-like tasks are required to understand the contribution of attention to safe driving.

4.2.3 Generalizability to real driving

Research that aims to bridge psychological theory and daily functioning must always balance ecological validity and rigorous experimental control. In the current thesis, it is important to control for the visual characteristics of the target to ensure that the effects measured are related to target *distance* rather than other visual characteristics of the target. Further, part of Chapter 2 was concerned with the relative contribution of particular depth cues, which required the orthogonal combination of each cue of interest. Using complex, naturalistic stimuli would have made it much more difficult to exclude visual or statistical confounds in the experimental design. Given these constraints, the conditions tested in the current study are only directly comparable to a limited subset of the conditions commonly encountered during driving.

Real driving is dynamic and complex and always involves multitasking to some degree. The cognitive demand of driving depends on the road environment, the in-car environment, and human factors such as a driver's personality or health. Several aspects of the work in the current thesis limit its implications and need to be addressed in future research. First, the targets in the peripheral detection task used in the experiment were low in contrast. In optimal driving conditions during the day and clear weather conditions, low contrast stimuli are relatively uncommon. However, glare during night driving and adverse weather conditions such as rain and fog reduce the contrast of otherwise suprathreshold, high contrast stimuli. The results of the current study are more comparable to suboptimal driving conditions. Although these suboptimal conditions are relatively less common, they are still common enough to impact daily life, particularly in Canada. Furthermore, these adverse conditions are more dangerous to road users than optimal driving conditions (Theofilatos and Yannis, 2014; Qiu and Nixon, 2008, e.g.). This fact alone warrants further study of how drivers cope with adverse road conditions and find potential areas in which driver behaviour should be altered to promote safety.

Secondly, this thesis did not investigate targets in motion. All peripheral targets were stationary in the virtual environment, but hazards in the real world are often in motion. A jay-walking moose and a car merging lanes without signalling are both examples of moving hazards. Moving hazards unfold over time, which may result in different dynamics of attention allocation than stationary targets. For example, a moving target may draw attention compared to a non-moving target, which would make moving targets easier to detect. Conversely, in a complex urban environment where there are many moving stimuli, a stationary target may be masked by the moving surroundings. It would be of interest to investigate how motion information affects attention as well. Finally, the context of the situation may matter, as a cross-walk may cue drivers to look for pedestrians crossing the road, making it easier to detect a pedestrian. All of these factors that were not investigated in the current thesis need to be considered to understand the role of attention in real driving.

Finally, the parameters of the car-following task used in the current thesis were such that the lead car did not perform any hazardous manoeuvres. For example, the lead car never suddenly stopped, and the car-following headway participants were instructed to maintain always resulted in a substantial margin for error without resulting in a crash. However, in the real world, lead cars sometimes suddenly brake, and drivers sometimes choose shorter, more dangerous following distances, both of which would increase crash risk. Furthermore, given that headway potentially affects how participants distribute attention between the car-following task and monitoring the environment with peripheral vision, it would be informative to more thoroughly examine how headway affects driver attention in more hazardous scenarios.

The current work constitutes a step towards investigating how attention is allocated along the depth axis in driving by using a car-following task similar to driving behind a car in traffic. Although stimuli do not have to be identical to the real world to generalize across contexts and provide insight into human attention and cognition, the interaction between the complexities of the driving environment and attention requires further empirical examination. Much more work needs to be done to examine how attention is allocated in a larger variety of conditions to ensure that these ideas are generalizable to real driving.

4.2.4 Implications for the design of in-car warning systems

This work may have potential implications for designing warning systems and advanced driver assistance systems (ADAS) in vehicles. Currently, autonomous cars are particularly poor at coping with suboptimal driving conditions, such as during adverse weather conditions when input from sensors is severely degraded or idiosyncratic situations that were absent in the training data. Understanding how humans cope with the demands of such adverse conditions may be useful for developing autonomous systems that perform better than humans or work in concert with the human driver to improve traffic safety.

Additionally, before fully autonomous vehicles are can be deployed at a large scale, there will likely be intermediate transition stages in which control of the vehicle is decreasingly determined by the human driver, and increasingly determined by the autonomous vehicle. This process has already started given that cars currently available to consumers are commonly equipped with semi-autonomous capabilities such as automatic lane-keeping, rear-end prevention, and blind-spot obstacle detection. However, when these ADAS communicate with human drivers, they must produce warnings that are interpretable to the driver and must communicate information quickly and effectively. Ideally, the system also adds little cognitive load to the driver who is already multi-tasking. Understanding how humans cope with the conditions of driving may reveal areas in which human performance can be improved with the appropriate autonomous intervention without overloading the human cognitive system.

The results of this thesis suggest that attention to the periphery is particularly poor (reduction in RT of at least 100 ms and accuracy of at least 30%). Tracking eye movements inside cars may help detect instances where a driver has not made sufficient eye movements to collect information more lateral locations, and an ADAS may be designed to help guide the driver's attention to relevant potential obstacles. In addition, finding that distance modulated attention suggests that it may be worthwhile to expand the design of warning systems beyond a 2D plane. Although the effects are small in the current thesis (i.e. a decrease in accuracy of about 2% and a delay of approximately 70 milliseconds for near and far targets compared to middle targets in full cue conditions), the effect of distance may be larger in real driving because many distance cues are present in real driving but were absent our experimental conditions. Given these considerations, warnings may be more efficient and informative if displayed at the distance of the hazard, perhaps using augmented reality, compared to on a 2D plane inside the car. When warnings are depicted as being located inside the car, responding to a warning requires shifting attention from a near distance inside the car to a far distance at the location of the hazard. Such a shift in attention may incur larger costs than when attention shifts once to the depth of the warning where the hazard is also located. The time constraints in driving demand quick response times, therefore removing extraneous shifts of attention will likely increase safety by reducing reaction time.

During the transition between semi-autonomous and fully autonomous vehicles, it is particularly important to consider how the information provided by semi-autonomous systems can best supplement human behaviour. The basis of the design of these systems must come from an understanding of the cognitive demands that drivers face on the road. The work presented in this thesis contributes to building a firmer foundation for the design of ADAS.

4.3 Conclusion

This thesis investigated how apparent distance simulated by pictorial cues and forward motion affects performance in a peripheral detection task. The results suggest that apparent distance has a non-monotonic effect on peripheral detection. These findings contribute to the body of literature that suggests that attention is sensitive to perceived depth and that our inquiries about spatial attention should expand beyond two dimensions. The results also have implications for the dynamics of dividing attention between vehicle control and objects or events in the environment. This thesis presents one perspective for understanding the effect of apparent depth on attention, and contributes to bridging the gap between our understanding of spatial attention in laboratory settings and how drivers use spatial attention in naturalistic situations.

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Appendix A

Chapter 2 Supplement

A1 Estimated response time delay in car-following task

Table A1.1: Estimates of response delay in the car following task in seconds and standard estimates of the mean in brackets

Condition	0.033 Hz	0.083 Hz	0.117 Hz
Expriment (Exp) 1			
Focussed Attention	0.48 (0.16)	0.62 (0.31)	0.84 (0.18)
Divided Attention	0.57 (0.07)	1.25 (0.11)	1.26 (0.07)
Exp 2a			
Focussed Attention	0.29 (0.11)	0.73 (0.20)	1.41 (0.12)
Divided Attention	0.60 (0.06)	1.16 (0.09)	0.92 (0.07)
Exp 2b			
Focussed Attention	0.57 (0.44)	0.58 (0.11)	1.29 (0.13)
Divided Attention	0.78 (0.11)	1.24 (0.10)	0.86 (0.09)
Exp 3			
Focussed Attention	0.34 (0.07)	0.56 (0.14)	0.65 (0.12)
Divided Attention	0.53 (0.09)	1.01 (0.09)	1.21 (0.08)

A2 Detection Accuracy ANOVA Tables

A2.1 Exp 1

Table A1.2: Exp 1 - ANOVA on arcsine transformed accuracy

Effect	df_1	df_2	F	p	η^2_G	$\hat{\epsilon}$	p_{adj}
Attention (Attn)	1	23	4.40	0.047	0.013		
Distance (Dist)	1	23	16.66	<0.001	0.045		
Eccentricity (Ecc)	3	69	276.48	<0.001	0.68	0.74	<0.001
Attn×Dist	1	23	1.32	0.26	0.001		
Attn×Ecc	3	69	0.15	0.93	<0.001	0.83	0.90
Dist×Ecc	3	69	4.83	0.004	0.021	0.001	<0.001
Attn×Dist×Ecc	3	69	1.79	0.16	0.004	0.88	0.16
SME of Dist							
6 dva ecc	1	23	0.95	0.34	0.008		
12 dva ecc	1	23	1.77	0.19	0.014		
18 dva ecc	1	23	34.00	<0.001	0.18		
24 dva ecc	1	23	5.45	0.03	0.08		

Table A1.3: Exp 1 - ANOVA on linear trend scores of arcsine transformed accuracy

Effect	df_1	df_2	F	p	η^2_G
Intercept	1	23	505.4	<0.001	0.92
Attn	1	23	0.016	0.90	<0.001
Dist	1	23	3.04	0.09	0.03
Attn×Dist	1	23	4.3	0.048	0.014
SME of Dist					
Focussed attention	1	23	8.07	<0.001	0.11
Divided attention	1	23	0.26	0.61	0.004

A2.2 Exp 2

Table A1.4: Exp 2a - ANOVA on arcsine transformed accuracy

Effect	df_1	df_2	F	p	η^2_G	$\hat{\epsilon}$	p_{adj}
Attn	1	23	0.85	0.37	0.006		
Dist	1	23	5.27	0.031	0.018		
Ecc	2	46	143.68	<0.001	0.56	0.80	<0.001
Attn×Dist	1	23	6.66	0.017	0.007		
Attn×Ecc	2	46	1.25	0.30	0.003	0.96	0.30
Dist×Ecc	2	46	22.26	<0.001	0.05	0.96	<0.001
Attn×Dist×Ecc	2	46	2.36	0.11	0.004	0.96	0.11
SME of Attn							
Near dist	1	23	0.004	0.94	<0.01		
Far dist	1	23	3.26	0.08	0.05		
SME of Dist							
12 dva	1	23	9.29	<0.01	0.035		
18 dva	1	23	16.34	<0.01	0.138		
24 dva	1	23	0.004	0.94	<0.01		

Table A1.5: Exp 2a - Linear trend analysis on arcsine transformed accuracy

Effect	df_1	df_2	F	p	η^2_G
Intercept	1	23	186.35	<0.001	0.84
Attn	1	23	0.87	0.36	0.004
Dist	1	23	24.79	<0.001	0.12
Attn×Dist	1	23	3.69	0.07	0.016

TABLE A1.6: Exp 2b - ANOVA on arcsine transformed accuracy

Effect	df_1	df_2	F	p	η^2_G	$\hat{\epsilon}$	p_{adj}
Attn	1	23	1.79	0.19	0.007		
Dist	1	23	19.88	<0.001	0.083		
Ecc	2	46	167.39	<0.001	0.57	0.85	<0.001
Attn×Dist	1	23	5.31	0.03	0.009		
Attn×Ecc	2	46	0.65	0.53	0.002	0.87	0.51
Dist×Ecc	2	46	46.35	<0.001	0.09	0.91	<0.001
Attn×Dist×Ecc	2	46	0.17	0.85	<0.001	0.95	0.84
SME of Dist							
12 dva	1	23	4.27	0.05	0.031		
18 dva	1	23	40.97	<0.001	0.23		
24 dva	1	23	32.68	<0.001	0.31		
SME of Attn							
Near dist	1	23	6.94	0.015	0.05		
Far dist	1	23	0.026	0.087	<0.001		

TABLE A1.7: Exp 2b - Linear trend analyses on arcsine transformed accuracy

Effect	df_1	df_2	F	p	η^2_G
Intercept	1	23	251.47	<0.001	0.86
Attn	1	23	0.42	0.52	0.004
Dist	1	23	59.33	<0.001	0.24
Attn×Dist	1	23	0.094	0.76	<0.001

TABLE A1.8: Combined Exp 2a and 2b - ANOVA on arcsine transformed accuracy

Effect	df_1	df_2	F	p	η^2_G	$\hat{\epsilon}$	p_{adj}
Exp	1	46	1.91	0.17	0.02		
Attn	1	46	0.003	0.96	<0.001		
Dist	1	46	23.98	<0.001	0.05		
Ecc	2	92	309.92	<0.001	0.56	0.84	<0.001
Exp×Attn	1	46	2.36	0.13	0.0065		
Exp×Dist	1	46	3.88	0.055	0.008		
Exp×Ecc	2	92	1.04	0.36	0.004	0.84	0.35
Attn×Dist	1	46	11.58	0.001	0.008		
Attn×Ecc	2	92	1.16	0.32	0.002	0.98	0.32
Dist×Ecc	2	92	66.52	<0.001	0.07	0.94	<0.001
Exp×Attention× Dist	1	46	0.057	0.81	<0.001		
Exp×Attn×Ecc	2	92	0.66	0.52	<0.001	0.98	0.51
Exp×Dist×Ecc	2	92	2.53	0.085	0.003	0.94	0.089
Attn×Dist×Ecc	2	92	0.71	0.49	<0.001	0.98	0.49
Exp×Attn×Dist×Ecc	2	92	1.66	0.20	0.001	0.98	0.20
SME of Dist							
Focussed Attn	1	47	4.60	0.037	0.025		
Divided Attn	1	47	48.92	<0.001	0.12		
SME of Attn							
Near dist	1	47	2.59	0.11	0.012		
Far dist	1	47	2.06	0.16	0.011		

ANOVA model: $y \sim Exp \times Attn \times Dist \times Ecc + Error(Subject/(Attn \times Dist \times Eccentricity)) + Exp$

Table A1.9: Combined Exp 2a and 2b - ANOVA on linear trend of arcsine transformed accuracy across eccentricity

Effect	df_1	df_2	F	p	η^2_G
Intercept	1	46	432.74	<0.001	0.85
Exp1	1	46	0.75	0.39	0.01
Attn	1	46	<0.001	0.98	<0.001
Dist	1	46	80.64	<0.001	0.18
Exp×Attn	1	46	1.12	0.30	0.004
Exp×Dist	1	46	3.94	0.053	0.01
Attn×Dist	1	46	1.28	0.26	0.003
Exp×Attn×Dist	1	46	2.46	0.12	0.005

A2.3 Exp 3

Table A1.10: Exp 3 - ANOVA on arcsine transformed accuracy

Effect	df_1	df_2	F	p	η^2_G	$\hat{\epsilon}$	p_{adj}
Attn	1	26	0.26	0.61	0.003		
Dist	1	26	1.61	0.22	0.015		
Ecc	2	52	104.57	<0.001	0.34	0.89	<0.001
Attn×Dist	1	26	0.20	0.66	<0.001		
Attn×Ecc	2	52	0.43	0.65	0.008	0.96	0.64
Dist×Ecc	2	52	15.34	<0.001	0.02	0.92	<0.001
Attn×Dist×Ecc	2	52	2.51	0.09	<0.004	0.91	0.10
SME of Dist							
12 dva	1	26	23.38	<0.001	0.07		
18 dva	1	26	0.97	0.33	<0.01		
24 dva	1	26	6.53	0.017	0.02		

Table A1.11: Exp 3 - Linear trend analysis of arcsine transformed accuracy

Effect	df_1	df_2	F	p	η^2
Intercept	1	26	181.97	<0.001	0.78
Attn	1	26	0.80	0.38	0.006
Dist	1	26	23.73	<0.001	0.13
Attn×Dist	1	26	2.23	0.15	0.01

TABLE A1.12: Combined Exp 2a, 2b, and 3 - ANOVA on arcsine transformed accuracy

Effect	df_1	df_2	F	p	η^2_G	$\hat{\epsilon}$	p_{adj}
Checkerboard (Check)	1	73	22.33	<0.001	0.13		
Attn	1	73	0.062	0.80	<0.001		
Dist	1	73	6.78	0.011	0.006		
Ecc	2	146	346.46	<0.001	0.44	0.89	<0.001
Check×Attn	1	73	0.10	0.75	<0.001		
Check×Dist	1	73	15.50	<0.001	0.014		
Check×Ecc	2	146	9.57	<0.001	0.021	0.89	<0.001
Attn×Dist	1	73	5.88	0.018	0.002		
Attn×Ecc	2	146	0.91	0.40	<0.001	0.98	0.40
Dist×Ecc	2	146	56.70	<0.001	0.034	0.94	<0.001
Check×Attn×Dist	1	73	2.95	0.09	0.001		
Check×Attn×Ecc	2	146	0.48	0.62	<0.001	0.98	0.61
Check×Dist×Ecc	2	146	9.82	<0.001	0.006	0.94	<0.001
Attn×Dist×Ecc	2	146	1.22	0.30	<0.001	0.97	0.30
Check×Attn×Dist×Ecc	2	146	2.94	0.056	0.002	0.97	0.06

ANOVA formula: $y \sim Check \times Attn \times Dist \times Ecc + Error(Subject/(Attn \times Dist \times Ecc)) + Check$

Table A1.13: Combined Exp 2a, 2b, and 3 - SME analysis on arcsine transformed accuracy

Effect	df_1	df_2	F	p	η_G^2
Simple effect of Dist×Ecc					
Check present	2	94	64.42	<0.001	0.09
Simple SME of Dist					
12 dva	1	47	12.60	0.001	0.032
18 dva	1	47	52.25	<0.001	0.18
24 dva ecc	1	47	36.43	<0.001	0.22
Check absent	2	52	15.34	<0.001	0.02
Simple SME of Dist					
12 dva	1	26	23.38	<0.001	0.065
18 dva	1	26	0.97	0.33	<0.01
24 dva ecc	1	26	6.53	0.017	0.02
SME of Attn					
Near dist	1	74	1.87	0.18	0.004
Far dist	1	74	2.49	0.12	0.004

Table A1.14: Combined Exp 2a, 2b, and 3 - ANOVA on linear trend of arcsine transformed accuracy

Effect	df_1	df_2	F	p	η_G^2
Intercept	1	73	518.53	<0.001	0.80
Check	1	73	14.23	<0.001	0.10
Attn	1	73	0.47	0.50	0.001
Dist	1	73	83.39	<0.001	0.14
Check×Attn	1	73	0.50	0.48	0.001
Check×Dist	1	73	1.62	0.21	0.003
Attn×Dist	1	73	0.25	0.62	<0.001
Check× Attn×Dist	1	73	3.43	0.07	0.005

A2.4 Exp 4

Table A1.15: Exp 4 - ANOVA on arcsine transformed accuracy including 3 eccentricities: 12, 18, and 24 dva

Effect	df_1	df_2	F	p	η^2_G	$\hat{\epsilon}$	p_{adj}
Ground (Gnd)	1	44	0.19	0.67	0.003		
Check Size (CheckS)	1	44	43.81	<0.001	0.027		
Wall Size (WallS)	1	44	2.38	0.13	0.001		
Ecc	2	88	100.32	<0.001	0.28	0.86	<0.001
Gnd×CheckS	1	44	0.52	0.48	<0.001		
Gnd×WallS	1	44	0.051	0.82	<0.001		
Gnd×Ecc	2	88	3.30	0.041	0.013	0.86	0.049
CheckS×WallS	1	44	2.96	0.092	0.001		
CheckS×Ecc	2	88	8.18	<0.001	0.008	0.99	<0.001
WallS×Ecc	2	88	1.036	0.36	<0.001	0.93	0.36
Gnd×CheckS×WallS	1	44	0.95	0.33	<0.001		
Gnd×CheckS×Ecc	2	88	0.10	0.91	<0.001	0.93	0.91
Gnd×WallS×Ecc	2	88	1.82	0.17	0.001	0.92	0.17
CheckS×WallS×Ecc	2	88	0.38	0.69	<0.001	0.93	0.67
Gnd×CheckS×WallS×Ecc	2	88	0.93	0.39	0.001	0.93	0.39
SME of CheckS							
12 dva	1	45	10.22	0.002	0.018		
18 dva	1	45	2.62	0.11	0.005		
24 dva	1	45	70.86	<0.001	0.12		
SME of Gnd							
12 dva	1	44	0.37	0.55	0.008		
18 dva	1	44	1.89	0.18	0.041		
24 dva	1	44	0.22	0.64	0.005		

Table A1.16: Exp 4 - Linear trend analysis on arcsine transformed accuracy including 3 eccentricities: 12, 18, and 24 dva

Effect	df_1	df_2	F	p	η^2_G
Intercept	1	44	164.51	<0.001	0.69
Gnd	1	44	1.45	0.23	0.02
CheckS	1	44	7.16	0.01	0.02
WallS	1	44	1.25	0.27	<0.01
Gnd×CheckS	1	44	0.004	0.95	<0.01
Gnd×WallS	1	44	0.14	0.71	<0.01
CheckS×WallS	1	44	0.57	0.46	<0.01
Gnd×CheckS×WallS	1	44	0.63	0.44	<0.01

Table A1.17: Exp 4 - ANOVA on arcsine transformed accuracy including 4 eccentricities: 6, 12, 18, and 24 dva

Effect	df_1	df_2	F	p	η^2_G	$\hat{\epsilon}$	p_{adj}
Gnd	1	44	0.015	0.90	<0.001		
CheckS	1	44	44.95	<0.001	0.023		
WallS	1	44	4.44	0.041	0.001		
Ecc	3	132	35.69	<0.001	0.22	0.48	<0.001
Gnd×CheckS	1	44	0.79	0.38	<0.001		
Gnd×WallS	1	44	0.38	0.54	<0.001		
Gnd×Ecc	3	132	1.46	0.23	0.011	0.48	0.24
CheckS×WallS	1	44	1.31	0.26	<0.001		
CheckS×Ecc	3	132	5.92	<0.001	0.005	0.97	<0.001
WallS×Ecc	3	132	0.79	0.50	<0.001	0.92	0.49
Gnd×CheckS×WallS	1	44	0.65	0.43	<0.001		
Gnd×CheckS×Ecc	3	132	0.12	0.95	<0.001	0.97	0.94
Gnd×WallS×Ecc	3	132	2.06	0.11	0.001	0.92	0.11
CheckS×WallS×Ecc	3	132	1.08	0.36	0.001	0.92	0.36
Gnd×CheckS×WallS×Ecc	3	132	0.78	0.51	<0.001	0.92	0.50
SME of CheckS							
6 dva	1	22	20.76	<0.001	0.041		
12 dva	1	22	12.39	0.002	0.49		
18 dva	1	22	2.80	0.11	0.013		
24 dva	1	22	87.56	<0.001	0.23		

TABLE A1.18: Exp 4 - Linear trend analysis on accuracy including 4 eccentricities: 6, 12, 18, and 24 dva

Effect	df_1	df_2	F	p	η^2
Intercept	1	44	38.56	<0.001	0.43
Gnd	1	44	1.02	0.32	0.020
CheckS	1	44	2.74	0.11	0.003
WallS	1	44	1.63	0.21	0.002
Gnd×CheckS	1	44	0.13	0.72	<0.001
Gnd×WallS	1	44	1.12	0.30	0.001
CheckS×WallS	1	44	0.42	0.52	<0.001
Gnd×CheckS×WallS	1	44	0.002	0.97	<0.001

A3 Detection RT ANOVA Tables

TABLE A1.19: Exp 1 - ANOVA on log transformed RT

Effect	df_1	df_2	F	p	η^2_G	$\hat{\epsilon}$	p_{adj}
Attn	1	23	8.00	0.01	0.027		
Dist	1	23	79.88	<0.001	0.30		
Ecc	3	69	186.87	<0.001	0.47	0.52	<0.001
Attn×Dist	1	23	4.17	0.053	0.002		
Attn×Ecc	3	69	1.83	0.15	0.002	0.62	0.17
Dist×Ecc	3	69	9.34	<0.001	0.01	0.88	<0.001
Attn×Dist×Ecc	3	69	1.56	0.21	<0.001	0.80	0.22
SME of Dist							
6 dva	1	23	48.45	<0.001	0.31		
12 dva	1	23	48.62	<0.001	0.30		
18 dva	1	23	93.90	<0.001	0.38		
24 dva	1	23	77.37	<0.001	0.32		

TABLE A1.20: Exp 1 - Linear trend analysis of log RT

Effect	df_1	df_2	F	p	η^2_G
Intercept	1	23	249.32	<0.001	0.89
Attn	1	23	2.16	0.16	0.013
Dist	1	23	16.85	<0.001	0.063
Attn×Dist	1	23	0.61	0.44	0.001

Table A1.21: Exp 2a - ANOVA on log RT

Effect	df_1	df_2	F	p	η^2_G	$\hat{\epsilon}$	p_{adj}
Attn	1	23	0.39	0.54	0.001		
Dist	1	23	0.15	0.71	<0.001		
Ecc	2	46	114	<0.001	0.23	0.70	<0.001
Attn×Dist	1	23	<0.001	0.99	<0.001		
Attn× Ecc	2	46	3.65	0.034	0.003	0.89	0.040
Dist×Ecc	2	46	2.47	0.096	0.003	0.91	0.10
Attn×Dist×Ecc	2	46	0.05	0.95	<0.001	0.94	0.94
SME of Attn							
12 dva	1	23	1.22	0.28	<0.01		
18 dva	1	23	1.70	0.20	<0.01		
24 dva	1	23	0.69	0.41	<0.01		

Table A1.22: Exp 2a - Linear trend analysis on log RT

Effect	df_1	df_2	F	p	η^2_G
Intercept	1	23	134	<0.001	0.78
Attn	1	23	4.11	0.05	0.027
Dist	1	23	3.06	0.09	0.018
Attn×Dist	1	23	0.054	0.82	<0.001

Table A1.23: Exp 2b - ANOVA on log RT

Effect	df_1	df_2	F	p	η^2_G	$\hat{\epsilon}$	p_{adj}
Attn	1	23	0.47	0.50	0.001		
Dist	1	23	13.28	0.001	0.017		
Ecc	2	46	125.32	<0.001	0.24	0.67	<0.001
Attn×Dist	1	23	0.55	0.47	<0.001		
Attn×Ecc	2	46	2.75	0.07	0.002	0.87	0.082
Dist×Ecc	2	46	8.80	<0.001	0.005	0.90	<0.001
Attn×Dist×Ecc	2	46	0.45	0.64	<0.001	0.66	0.56
SME of Dist							
12 dva	1	23	0.54	0.47	<0.01		
18 dva	1	23	33.412	<0.001	0.04		
24 dva	1	23	9.28	0.006	0.03		

TABLE A1.24: Exp 2b - Linear trend analysis on log RT

Effect	df_1	df_2	F	p	η_G^2
Intercept	1	23	158.16	<0.001	0.81
Attn	1	23	3.88	0.06	0.02
Dist	1	23	7.68	0.01	0.04
Attn×Dist	1	23	0.52	0.48	0.003
12 dva	1	23	0.54	0.47	<0.01
18 dva	1	23	33.412	<0.001	0.04
24 dva	1	23	9.28	0.006	0.03

Table A1.25: Combined Exp 2a and 2b - ANOVA on log RT

Effect	df_1	df_2	F	p	η^2_G	$\hat{\epsilon}$	p_{adj}
Exp	1	46	0.41	0.53	0.007		
Attn	1	46	0.01	0.89	<0.001		
Dist	1	46	7.68	0.008	0.006		
Ecc	2	92	237.00	<0.001	0.23	0.69	<0.001
Exp×Attn	1	46	0.86	0.36	0.001		
Exp×Dist	1	46	4.90	0.031	0.004		
Exp×Ecc	2	92	4.43	0.014	0.006	0.69	0.027
Attn×Dist	1	46	0.32	0.58	<0.001		
Attn×Ecc	2	92	5.15	0.008	0.002	0.88	0.001
Dist×Ecc	2	92	9.74	<0.001	0.004	0.97	<0.001
Exp×Attn×Dist	1	46	0.33	0.57	<0.001		
Exp×Attn×Ecc	2	92	1.27	0.29	<0.001	0.88	0.28
Exp×Dist×Ecc	2	92	0.56	0.57	<0.001	0.97	0.57
Attn×Dist×Ecc	2	92	0.13	0.88	<0.001	0.85	0.85
Exp×Attn×Dist×Ecc	2	92	0.35	0.70	<0.001	0.85	0.67
SME of Dist							
Exp 2a	1	23	0.15	0.72	<0.01		
Exp 2b	1	23	13.28	0.001	0.02		
12 dva	1	24	0.18	0.67	0.001		
18 dva	1	24	17.01	<0.001	0.05		
24 dva	1	24	6.53	0.017	0.023		
SME of Ecc							
Exp 2a	2	46	114.01	<0.001	0.27	0.70	<0.001
Exp 2b	2	46	125.32	<0.001	0.27	0.67	<0.001
SME of Attn							
12 dva	1	24	1.03	0.32	<0.01		
18 dva	1	24	0.17	0.69	<0.01		
24 dva	1	24	2.02	0.17	0.01		

Table A1.26: Combined Exp 2a and 2b - ANOVA on linear trend of log RT

Effect	df_1	df_2	F	p	η^2_G
Intercept	1	46	267.95	<0.001	0.79
Exp	1	46	0.25	0.62	0.003
Attn	1	46	8.28	0.006	0.022
Dist	1	46	10.52	0.002	0.03
Exp×Attn	1	46	1.66	0.20	0.004
Exp×Dist	1	46	1.19	0.28	0.003
Attn×Dist	1	46	0.16	0.69	<0.001
Exp×Attn×Dist	1	46	0.49	0.49	0.001

A3.1 RT Results in Experiments 3 and 4

Table A1.27: Experiment 3 - ANOVA on log RT

Effect	df_1	df_2	F	p	η^2_G	$\hat{\epsilon}_{GG}$	p_{adj}
Attn	1	26	14.73	0.001	0.031		
Dist	1	26	9.86	0.004	0.016		
Ecc	2	52	164.40	<0.001	0.27	0.91	<0.001
Attn×Dist	1	26	21.44	<0.001	0.008		
Attn×Ecc	2	52	2.09	0.13	0.001	0.98	0.13
Dist×Ecc	2	52	18.36	<0.001	0.009	0.87	<0.001
Attn×Dist×Ecc	2	52	1.94	0.15	0.002	0.92	0.16
SME of Attn							
Near dis	1	26	27.54	<0.01	0.073		
Far dist	1	26	3.36	0.078	0.009		
SME of Dist							
12 dva	1	26	1.70	0.20	0.004		
16 dva	1	26	1.97	0.17	0.004		
24 dva	1	26	27.19	<0.001	0.067		

Table A1.28: Experiment 3 - Linear trend analysis on log RT

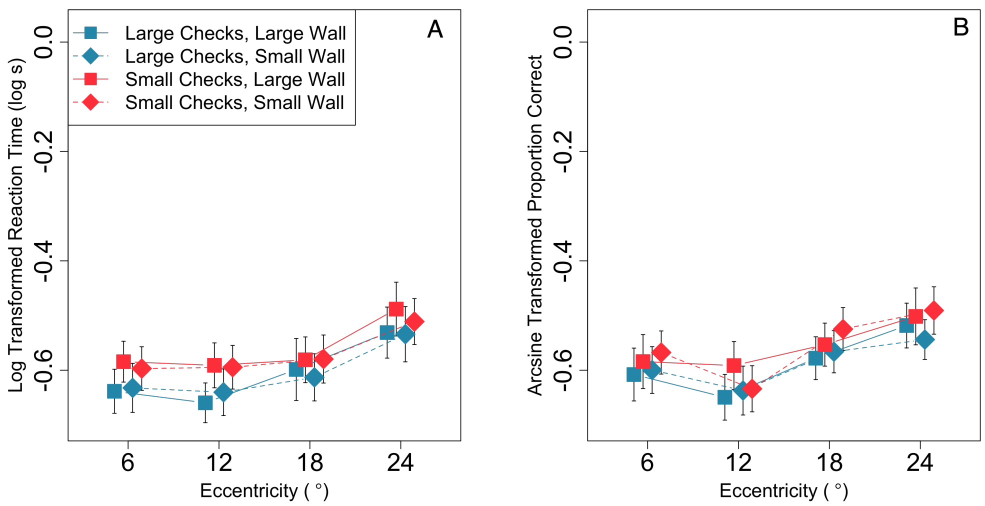
Effect	df_1	df_2	F	p	η^2_G
Intercept	1	26	252.94	<0.001	0.85
Attn	1	26	3.63	0.068	0.019
Dist	1	26	25.39	<0.001	0.10
Attn×Dist	1	26	3.27	0.082	0.020

Table A1.29: Experiment 2 and 3 comparison - ANOVA on log transformed RT

Effect	df_1	df_2	F	p	η^2_G	$\hat{\epsilon}_{GG}$	p_{adj}
Check	1	73	1.90	0.17	0.020		
Attn	1	73	5.66	0.020	0.004		
Dist	1	73	14.62	<0.001	0.008		
Ecc	2	146	321.50	<0.001	0.22	0.77	<0.001
Check×Attn	1	73	6.52	1.27	5.37		
Check×Dist	1	73	0.14	0.71	<0.001		
Check×Ecc	2	146	4.63	0.011	3.95	0.77	0.002
Attn×Dist	1	73	10.46	1.83	0.002		
Attn×Ecc	2	146	5.84	3.63	0.001	0.93	0.005
Dist×Ecc	2	146	13.70	<0.001	0.003	0.99	<0.001
Check×Attn×Dist	1	73	6.15	0.015	<0.001		
Check×Attn×Ecc	2	146	0.32	0.73	<0.001	0.923	0.71
Check×Dist×Ecc	2	146	6.84	0.001	0.002	0.99	0.001
Attn×Dist×Ecc	2	146	0.87	0.42	<0.001	0.91	0.41
Check×Attn×Dist×Ecc	2	146	1.54	0.22	<0.001	0.91	0.22

Table A1.30: Experiment 2 and 3 comparison - Linear trend analysis of log transformed RT across eccentricity

Effect	df_1	df_2	F	p	η^2_G
Intercept	1	73	412.22	<0.001	0.78
Check	73	3.92	0.051	0.032	
Attn	1	73	9.42	0.003	0.016
Dist	1	73	26.16	<0.001	0.043
Check×Attn	1	73	0.53	0.47	0.001
Check×Dist	1	73	0.57	0.45	0.001
Attn×Dist	1	73	0.91	0.34	0.002
Check× Attn×Dist	1	73	2.18	0.14	0.004



(a) Ground Present (b) Ground Absent

Figure A1.1: Peripheral target detection RT in Exp 4 plotted as a function of eccentricity, check size, and WallS in the (a) Ground plane present condition and (b) Ground plane absent condition. The large checks condition yielded shorter RTs than the small check condition. RTs were approximately equal at eccentricities of 6 and 12 dva, but increase approximately linearly at larger eccentricities. Wall SIze and the presence of the Ground plane did not affect RTs.

Table A1.31: Experiment 4 - ANOVA on log RT including 3 eccentricities: 12, 18, and 24 dva

Effect	df_1	df_2	F	p	η^2_G	$\hat{\epsilon}_{GG}$	p_{adj}
Gnd	1	44	0.040	0.84	<0.001		
CheckS	1	44	26.24	<0.001	0.008		
WallS	1	44	0.10	0.75	<0.001		
Ecc	2	88	33.38	<0.001	0.046	0.80	<0.001
Gnd×CheckS	1	44	0.17	0.69	<0.001		
Gnd×WallS	1	44	0.045	0.83	<0.001		
Gnd×Ecc	2	88	1.50	0.23	0.002	0.80	0.23
CheckS×WallS	1	44	0.97	0.76	<0.001		
CheckS×Ecc	2	88	0.52	0.60	<0.001	0.97	0.59
WallS×Ecc	2	88	0.47	0.63	<0.001	0.99	0.62
Gnd×CheckS×WallS	1	44	0.074	0.78	<0.001		
Gnd×CheckS×Ecc	2	88	0.78	0.46	<0.001	0.97	0.46
Gnd×WallS×Ecc	2	88	0.99	0.38	<0.001	0.99	0.37
CheckS×WallS×Ecc	2	88	1.74	0.18	0.001	0.96	0.18
Gnd×CheckS×WallS×Ecc	2	88	0.99	0.38	0.001	0.96	0.37

Table A1.32: Experiment 4 - Linear trend analysis on log RT including 3 eccentricities: 12, 18, and 24 dva

Effect	df_1	df_2	F	p	η^2_G
Intercept	1	44	49.81	<0.001	0.39
Gnd	1	44	0.085	0.77	<0.01
CheckS	1	44	0.44	0.51	<0.01
WallS	1	44	0.12	0.73	<0.01
Gnd×CheckS	1	44	0.91	0.35	<0.01
Gnd×WallS	1	44	0.59	0.45	<0.01
CheckS×WallS	1	44	2.78	0.10	0.01
Gnd×CheckS×WallS	1	44	2.46	0.12	0.01

Table A1.33: Experiment 4 - ANOVA on log transformed RT including 4 eccentricities: 6, 12, 18, and 24 dva

Effect	df_1	df_2	F	p	η^2_G	$\hat{\epsilon}_{GG}$	p_{adj}
Gnd	1	44	0.065	0.80	0.001		
CheckS	1	44	38.33	<0.001	0.007		
WallS	1	44	0.009	0.93	<0.001		
Ecc	3	132	21.88	<0.001	0.039	0.56	<0.001
Gnd×CheckS	1	44	0.54	0.47	<0.001		
Gnd×WallS	1	44	0.25	0.62	<0.001		
Gnd×Ecc	3	132	0.97	0.41	0.002	0.56	0.37
CheckS×WallS	1	44	0.17	0.68	<0.001		
CheckS×Ecc	3	132	0.38	0.77	<0.001	0.95	0.76
WallS×Ecc	3	132	0.45	0.72	<0.001	0.94	0.71
Gnd×CheckS×WallS	1	44	0.31	0.58	<0.001		
Gnd×CheckS×Ecc	3	132	0.64	0.59	<0.001	0.95	0.58
Gnd×WallS×Ecc	3	132	0.83	0.48	<0.001	0.94	0.47
CheckS×WallS×Ecc	3	132	1.18	0.32	<0.001	0.94	0.31
Gnd×CheckS×WallS×Ecc	3	132	0.71	0.55	<0.001	0.94	0.54

Table A1.34: Experiment 4 - Linear trend analysis on RT including 4 eccentricities: 6, 12, 18, and 24 dva

Effect	df_1	df_2	F	p	η^2
Intercept	1	44	23.17	<0.001	0.27
Gnd	1	44	0.020	0.89	<0.001
CheckS	1	44	0.22	0.64	<0.001
WallS	1	44	0.51	0.48	0.001
Gnd×CheckS	1	44	0.98	0.33	0.002
Gnd×WallS	1	44	0.042	0.84	<0.001
CheckS×WallS	1	44	0.84	0.36	0.002
Gnd×CheckS×WallS	1	44	0.34	0.56	<0.001

A3.2 Analyses on car-following data

ANOVA Tables

Table A1.35: Experiment 1 - ANOVA on car-following amplitude gain

Effect	df_1	df_2	F	p	η^2	$\hat{\epsilon}_{GG}$	p_{adj}
Attn	1	23	0.033	0.86	<0.001		
Frequency (Freq)	2	46	13.18	<0.001	0.09	0.59	<0.001
Attn×Freq	2	46	0.73	0.049	0.009	0.57	0.42

Table A1.36: Experiment 1 - ANOVA on car-following phase shift

Effect	df_1	df_2	F	p	η^2	$\hat{\epsilon}_{GG}$	p_{adj}
Attn	1	23	15.46	<0.001	0.059		
Freq	2	46	25.72	<0.001	0.28	0.94	<0.001
Attn×Freq	2	46	2.08	0.14	0.026	0.84	0.15

Table A1.37: Experiment 2a - ANOVA on Amplitude Gain

Effect	df_1	df_2	F	p	η^2_G	$\hat{\epsilon}_{GG}$	p_{adj}
Attn	1	23	6.58	0.017	0.077		
Freq	2	46	21.88	<0.001	0.18	0.91	<0.001
Attn×Freq	2	46	1.71	0.19	0.020	0.86	0.20

Table A1.38: Experiment 2a - ANOVA on Phase Shift

Effect	df_1	df_2	F	p	η^2_G	$\hat{\epsilon}_{GG}$	p_{adj}
Attn	1	23	13.25	0.001	0.11		
Freq	2	46	95.12	<0.001	0.52	0.77	<0.001
Attn×Freq	2	46	4.83	0.001	0.039	0.90	0.016
SME of Attn							
0.033 Hz	1	23	7.21	0.013	0.12		
0.083 Hz	1	23	5.20	0.032	0.077		
0.117 Hz	1	23	13.81	0.001	0.22		

Table A1.39: Experiment 2b - ANOVA on Amplitude Gain

Effect	df_1	df_2	F	p	η^2	$\hat{\epsilon}_{GG}$	p_{adj}
Attn	1	23	5.27	0.03	0.02		
Freq	2	46	7.86	0.001	0.11	0.92	0.002
Attn×Freq	2	46	0.10	0.90	0.001	0.72	0.84

Table A1.40: Experiment 2b - ANOVA on Phase Shift

Effect	df_1	df_2	F	p	η^2	$\hat{\epsilon}_{GG}$	p_{adj}
Attn	1	23	18.09	<0.001	0.11		
Freq	2	46	47.33	<0.001	0.40	0.6	<0.001
Attn×Freq	2	46	3.27	0.047	0.041	0.60	0.074

Table A1.41: Experiment 3 - ANOVA on amplitude gain

Effect	df_1	df_2	F	p	η^2	$\hat{\epsilon}_{GG}$	p_{adj}
Attn	1	26	1.60	0.022	0.013		
Freq	2	52	45.14	<0.001	0.32	0.73	<0.001
Attn×Freq	2	52	1.09	0.34	0.014	0.83	0.34

Table A1.42: Experiment 3 - ANOVA on phase shift

Effect	df_1	df_2	F	p	η^2	$\hat{\epsilon}_{GG}$	p_{adj}
Attn	1	26	30.7	<0.001	0.12		
Freq	2	52	69.80	<0.001	0.38	0.91	<0.001
Attn×Freq	2	52	6.68	0.003	0.064	0.71	0.007
SME of Attn							
0.033 Hz	1	26	3.85	0.061	0.30		
0.83 Hz	1	26	6.82	0.014	0.10		
0.117 Hz	1	26	19.34	<0.001	0.21		

Amplitude Spectra

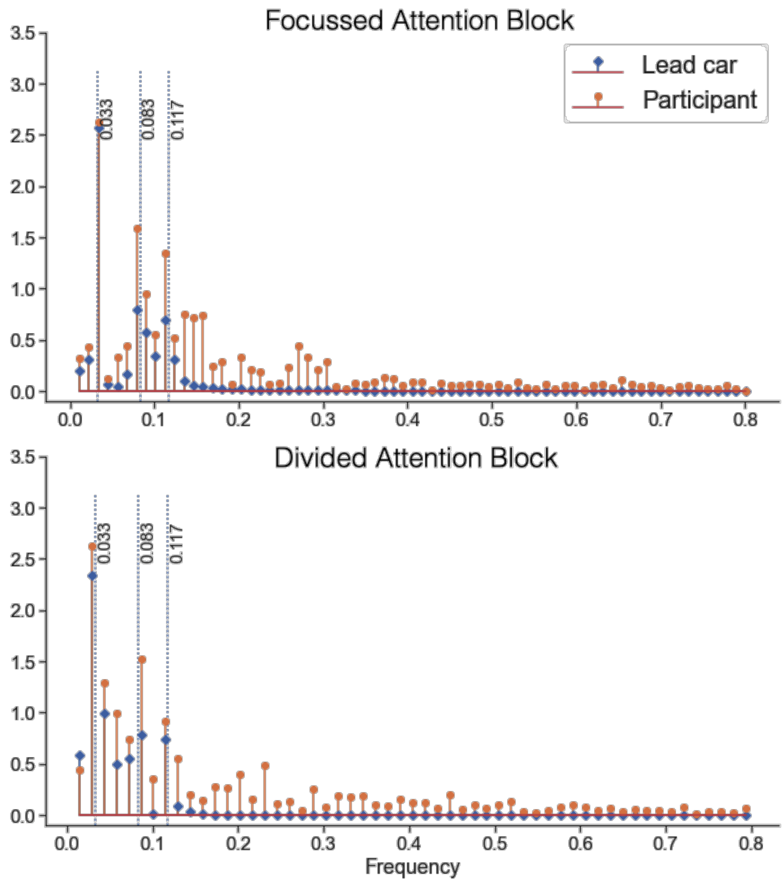


FIGURE A1.2: Representative amplitude spectrum of a single participant and single block in the focussed attention (top) and divided attention (bottom) conditions without cropping. Lead car speed is represented by blue diamonds, and participants responses are represented by orange circles. The dotted lines indicate the three signal frequencies determining the lead car's speed.

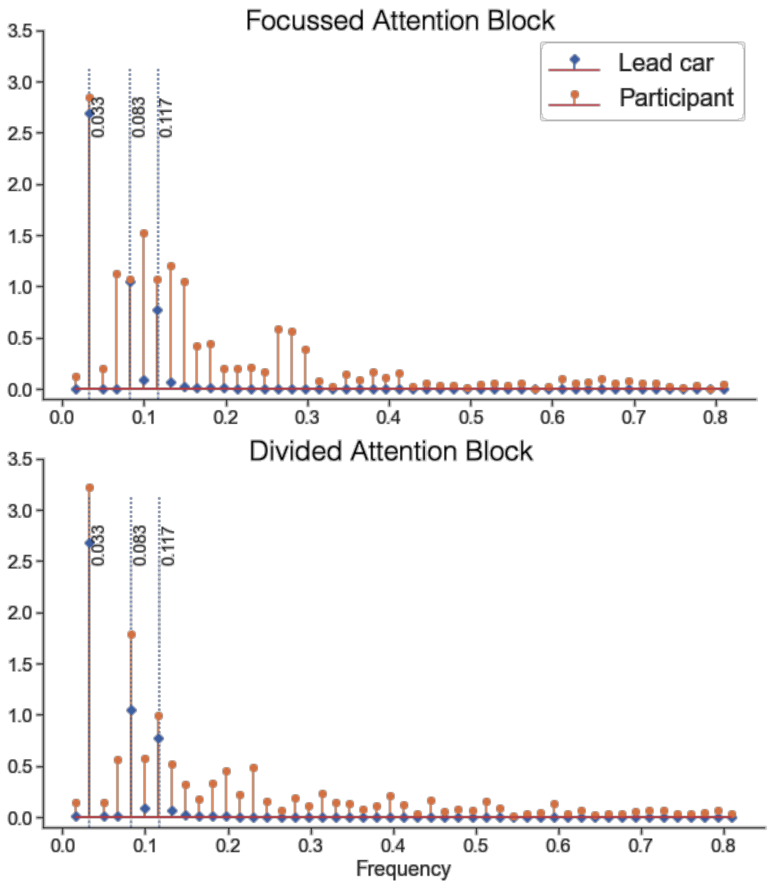


FIGURE A1.3: The same representative dataset shown after data-cropping in the focussed attention (top) and divided attention (bottom) conditions. Same symbol conventions as Figure A1.3.

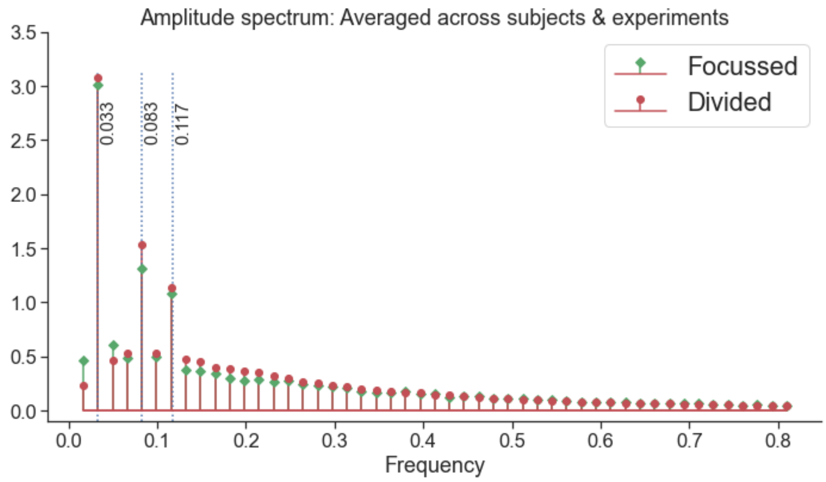


Figure A1.4: Amplitude of participant car-following speed as a function of frequency after averaging across subjects and experiments. Amplitudes in the focussed attention condition are represented by green diamonds and divided attention condition represented by red circles.

One set of representative amplitude spectra for a single subject and block are show in Figure A1.3 and the averaged amplitude spectra are shown in Figure A1.4.

Inspection of A1.2 suggests that there is some evidence of leakage between the signal frequencies, as well as small peaks in the participants data at many higher frequencies, suggesting that participants did not perfectly match the speed changes in the lead car. The data reported in the manuscript were based on data that were not cropped to equal lengths as there were variations in the length of a trial depending on how fast the participants were travelling, which may result in some bandwidth leakage. Cropping each block to the same length meant that all blocks of data could only be as long as the shortest block, which resulted in the removal of almost 1.5 blocks of data per participant on average. However, cropped data yielded virtually the same results as the non-cropped data.

Averaged spectra of individual experiments are virtually the same as the overall average. Across both individual and group-level data, a few patterns can be seen. First, amplitudes tend to be larger for the divided attention condition at the three signal frequencies, particularly at 0.83 and 0.117 Hz. This results are consistent with the idea that there were divided attention costs in the car-following task. Secondly, participants did not perfectly lock onto the frequency of speed changes in the lead car, as adjacent frequencies also show peaks in participant data. Furthermore, there were no obvious peaks at intermodulation frequencies or higher harmonics.

Analysis of time delay as a function of frequency

Although phase shift was a circular variable, our dataset had approximately 1% of all data in each experiment land within 1 radian of the wrap-around. We also examined whether our phase shift results supported the idea that participants followed the lead car with a constant delay. We examined the slopes and interceptions of phase shifts in each condition and whether they significantly differed from zero. In phase against frequency plots, linear phase systems with a constant delay intercept the y-axis at zero, and the the slope of the line correspond to the value of constant group delay. To test whether our participants behaved like a system with a linear phase delay, we fit mixed-effect linear regression models to the phase data in each experiment using the lmer4 package in R. We specified random intercepts for each subject, and tested whether the y-intercepts differed from zero. The p-values were acquired using the lmerTest pacakge. The model used in R to fit the data was: $phase \sim \ frequency \times attention + (1|subject)$ The results of these analyses are in Table A1.43. We attempted the analysis using the model $phase \sim \ frequency \times attention + (1 + frequency|subject)$, where the slope across frequency were allowed to vary across participants. The results from this more complex model were virtually identical, but failed to converge for Experiments 2a and 3, suggesting that we did not have enough data to accurately estimate the random effect of the frequency×subject interaction.

TABLE A1.43: Analysis of y-intercepts of linear regression on phase lag

Condition	**Intercept**	***t***	***p***	**Slope**	***t***	***p***
Exp 1						
Focussed Attn	−0.96	−4.22	<0.001	−0.35	−5.90	<0.001
Divided Attn	−0.57	−9.64	<0.001	−1.54	−6.81	<0.001
Exp 2a						
Focussed Attn	−0.37	−8.69	<0.001	−1.16	−8.69	<0.001
Divided Attn	−0.59	−13.74	<0.001	−1.72	−11.41	<0.001
Exp 2b						
Focussed Attn	−0.35	−8.36	<0.001	−1.16	−8.47	0.001
Divided Attn	−0.58	−13.92	<0.001	−1.50	−8.47	<0.001
Exp 3						
Focussed Attn	−0.28	−6.67	<0.001	−0.76	−5.75	<0.001
Divided Attn	−0.51	−12.15	<0.001	−1.50	−11.13	<0.001

All intercepts differed from zero, suggesting that our participants did not behave like linear phase filters. One aspect of this non-linearity may come from the fact that participant also showed positive amplitude gains. Delay varied with frequency, suggesting that participants did not lock onto each frequency component of speed changes equally well.

Visual inspection of the time delays of car-following task (Appendix Table 1) suggest that delay increases slightly with frequency and participants are slightly worse at locking on the phase changes at higher frequencies. Given a single reaction time, it may seem strange that participants did not have the same delay depending on frequency. However, participants sometimes chose to ignore smaller changes in speed in the lead car. Because higher frequency components also had smaller amplitudes, higher frequency components were more likely to be ignored. This may result in the observed larger delay at higher frequencies. Amplitude gain results indicate that participants also accelerated and decelerated to wider ranges of speeds than the lead car. Furthermore, the regression analysis showed that all intercepts differed from zero, suggesting that our participants did not behave like linear phase filters. One aspect of this non-linearity may come from the fact that participant also showed positive amplitude gains. Delay varied with frequency, suggesting that participants did not lock onto each frequency component of speed changes equally well.This result also goes against the idea that participants behaved like simple linear delay systems.

In all experiments, slopes were steeper under divided attention than focussed attention, indicating longer group delays when attention was divided. This result is consistent with a divided attention cost in car-following. Although the slopes may not be perfect estimates of time delay, interestingly, the average reaction times of the peripheral task range 0.5-0.7s. The difference in slopes between focussed and divided attention corresponds well with this range. This observation is consistent with the idea that the divided attention cost was due to responding to the peripheral detection task.

Table A1.44: Difference between slopes in divided vs focussed attention conditions

Experiment	**Difference**	t	p
Exp 1	0.59	1.835	0.07
Exp 2a	0.56	2.63	0.02
Exp 2b	0.55	2.190	0.03
Exp 3	0.71	3.802	<0.001

Appendix B

Chapter 3 Supplement

A1 ANOVA Tables

Table A2.1: Experiment 1 - Peripheral detection accuracy

Effect	df_1	df_2	F	p	η^2_G	$\hat{\epsilon}$	p_{adj}
Distance (Dist)	2	42	21.11	<0.001	0.09	0.087	<0.001
Dist: Linear	1	42	0.86	0.36	0.002		
Dist: Quadratic	1	42	41.37	<0.001	0.08		
Eccentricity (Ecc)	1	21	463.20	<0.001	0.59		
Attention (Attn)	1	21	1.37	0.25	0.004		
Dist×Ecc	2	42	5.11	0.01	0.03	0.85	0.01
Dist×Attn	2	42	0.043	0.65	0.001	0.98	0.65
Ecc×Attn	1	21	0.45	0.51	0.001		
Dist×Ecc×Attn	2	42	0.62	0.54	0.002	0.96	0.54

Table A2.2: Experiment 1 - Peripheral detection reaction time

Effect	df_1	df_2	F	p	η^2_G	$\hat{\epsilon}$	p_{adj}
Dist	2	42	20.25	<0.001	0.09	0.79	<0.001
Dist: Linear	1	42	6.93	0.01	0.02		
Dist: Quadratic	1	42	33.58	<0.001	0.08		
Ecc	1	21	159.06	<0.001	0.17		
Attn	1	21	0.39	0.54	0.002		
Dist×Ecc	2	42	10.63	<0.001	0.02	0.77	<0.001
Dist×Attn	2	42	3.30	0.05	0.01	0.87	0.05
Ecc×Attn	1	21	3.30	<0.08	0.003		
Dist×Ecc×Attn	2	42	1.55	0.22	0.004	0.76	0.23

Table A2.3: Experiment 1 - Car-following amplitude gain

Effect	df_1	df_2	F	p	η^2_G	$\hat{\epsilon}$	p_{adj}
Attn	1	21	11.86	0.002	0.14		
Frequency (Freq)	2	42	38.31	<0.001	0.21	0.87	<0.001
Attn×Freq	2	42	2.05	0.14	0.01	0.83	0.15

Table A2.4: Experiment 1 - Car-following phase shift

Effect	df_1	df_2	F	p	η^2_G	p_{adj}	
Attn	1	21	13.1	0.002	0.18		
Freq	2	42	118.11	<0.001	0.59	0.75	<0.001
Attn×Freq	2	42	21.63	<0.001	0.13	0.98	<0.001

Table A2.5: Experiment 2 - Peripheral detection accuracy

Effect	df_1	df_2	F	p	η^2_G	$\hat{\epsilon}$	p_{adj}
Headway (Hdw)	2	62	0.42	0.66	0.01		
Dist	2	124	15.14	<0.001	0.03	0.83	<0.01
Ecc	1	62	853.01	<0.001	0.58		
Attn	1	62	6.78	0.01	0.01		
Hdw×Dist	2	62	0.31	0.74	0.001	0.83	0.86
Hdw×Ecc	2	62	0.31	0.74	0.001		
Hdw×Attn	2	62	1.69	0.19	0.004		
Dist×Ecc	2	124	30.87	<0.001	0.03	0.96	<0.001
Dist×Attn	2	124	0.13	0.87	<0.001	0.93	0.86
Ecc×Attn	1	62	3.11	0.08	0.002		
Hdw×Dist×Ecc	4	124	0.92	0.45	0.002	0.96	0.89
Hdw×Dist×Attn	4	124	0.92	0.45	0.002	0.93	0.45
Hdw×Ecc×Attn	2	62	1.54	0.22	0.002		
Dist×Ecc×Attn	2	124	0.91	0.41	0.001	0.93	0.40
Hdw×Dist×Ecc×Attn	4	124	0.63	0.64	0.001	0.93	0.63

Table A2.6: Experiment 2 - Peripheral detection reaction time

Effect	df_1	df_2	F	p	η^2_G	$\hat{\epsilon}$	p_{adj}
Hdw	2	62	2.42	0.10	0.04		
Dist	2	124	64.73	<0.001	0.090	0.84	<0.001
Ecc	1	62	331.75	<0.001	0.29		
Attn	1	62	15.11	<0.001	0.02		
Hdw×Dist	4	124	0.09	0.99	<0.001	0.84	0.97
Hdw×Ecc	2	62	0.80	0.45	0.002		
Hdw×Attn	2	62	0.38	0.68	0.001		
Dist×Ecc	2	124	45.11	<0.001	0.03	0.85	<0.001
Dist×Attn	2	124	1.43	0.24	0.001	0.94	0.24
Ecc×Attn	1	62	2.69	0.11	0.001		
Hdw×Dist×Ecc	4	124	0.52	0.72	<0.001	0.85	0.69
Hdw×Dist×Attn	4	124	1.51	0.20	0.002	0.94	0.21
Hdw×Ecc×Attn	2	62	0.16	0.85	<0.001		
Dist×Ecc×Attn	2	124	0.03	0.97	<0.001	0.96	0.97
Hdw×Dist×Ecc×Attn	4	124	0.41	0.80	<0.001	0.96	0.80

Table A2.7: Experiment 2 - Car-following phase shift

Effect	df_1	df_2	F	p	η^2_G	p_{adj}	
Hdw	2	62	4.41	0.016	0.05		
Attn	1	62	30.77	<0.001	0.11		
Freq	2	124	385.64	<0.001	0.54	0.92	<0.001
Hdw×Attn	2	62	3.90	0.03	0.03		
Hdw×Freq	4	124	2.08	0.09	0.01	0.92	0.09
Attn×Freq	2	124	9.67	<0.001	0.03	0.82	<0.001
Hdw×Attn×Freq	4	124	12.27	<0.001	0.07	0.82	<0.001

Table A2.8: Experiment 2 - Car-following amplitude gain

Effect	df_1	df_2	F	p	η^2_G	$\hat{\epsilon}$	p_{adj}
Hdw	2	62	2.26	0.11	0.03		
Attn	1	62	6.35	0.01	0.02		
Freq	2	124	59.23	<0.01	0.21	0.76	<0.001
Hdw×Attn	2	62	5.45	0.006	0.03	0.88	<0.001
Hdw×Freq	4	124	1.66	0.16	0.015	0.76	0.18
Attn×Freq	2	124	8.41	<0.001	0.02		
Hdw×Attn×Freq	4	124	1.82	0.13	0.01	0.88	0.14

A2 Further analyses of car-following data

Table A2.9: Experiment 1 & 2 - Estimated time delay in seconds

Headway	**0.033 Hz**		**0.083 Hz**		**0.117 Hz**	
	Focussed	**Divided**	**Focussed**	**Divided**	**Focussed**	**Divided**
18.5 m (Exp1)	-0.961 (0.186)	-0.961 (0.097)	-0.969 (0.085)	-1.391 (0.096)	-0.867 (0.096)	-1.436 (0.077)
9.25 m (Exp2)	-1.201 (0.222)	-1.685 (0.170)	-1.250 (0.183)	-1.866 (0.115)	-1.322 (0.177)	-1.758 (0.085)
18.5 m (Exp2)	-0.901 (0.145)	-1.558 (0.127)	-1.126 (0.116)	-2.115 (0.114)	-1.304 (0.112)	-1.990 (0.085)
37 m (Exp2)	-1.280 (0.166)	-2.5888 (0.231)	-1.732 (0.138)	-2.492 (0.165)	-2.042 (0.165)	-1.473 (0.187)

Numbers in brackets represent standard error of the mean.

TABLE A2.10: Experiment 1 & 2 - Estimated slope and intercept of phase shift as a function of frequency

Headway	**Attention**	**Measure**	**Estimate**	**SE**	***t***	***p***
18.5 m (Exp 1)	Focussed	Slope	-0.84	0.13	-6.53	< 0.001
		Intercept	-0.45	0.03	-14.32	< 0.001
	Divided	Slope	-1.63	0.13	-12.64	< 0.001
		Intercept	-0.66	0.03	21.14	< 0.001
9.25 m (Exp 2)	Focussed	Slope	-1.36	0.17	-8.05	< 0.001
		Intercept	-0.62	0.05	-12.61	<0.001
	Divided	Slope	-1.80	0.17	-10.65	< 0.001
		Intercept	-0.87	0.05	-17.61	< 0.001
18.5 m (Exp 2)	Focussed	Slope	-1.45	0.17	-8.38	< 0.001
		Intercept	-0.58	0.05	-11.42	< 0.001
	Divided	Slope	-2.18	0.17	-12.63	< 0.001
		Intercept	-0.96	0.05	-19.05	< 0.001
37 m (Exp 2)	Focussed	Slope	-2.32	0.20	-11.87	< 0.001
		Intercept	-0.89	0.06	-15.58	< 0.001
	Divided	Slope	-1.14	0.20	-5.83	< 0.001
		Intercept	-0.97	0.06	-17.03	< 0.001