The effect of apparent distance on peripheral target detection

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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 traveling 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 reaction time (RT). Experiment 3 removed the checkerboard background implemented in Experiments 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.

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 focused 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 & Kramer, 1993; Finlayson & Grove, 2015; Roudaia et al., 2017, 2018). Furthermore, in the absence of distractors, it is also easier to switch attention to a near plane compared to a far plane in both virtual (Arnott & Shedden, 2000) and real distance contexts (Gawryszewski et al., 1987; Miura et al., 2002).

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 focused

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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 & 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 and reaction time (RT) are similar across all eccentricities (typically between 5 and 30 degrees visual angle [dva]; Sekuler & Ball, 1986; Sekuler et al., 2000; Owsley, Ball, et al., 1998). Some studies also attempted to extend this two-dimensional (2D) paradigm to more naturalistic contexts. For example, when watching prerecorded 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.

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 & Andersen, 2014, Experiment 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 color 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.

Second, driving accident risk is correlated with the magnitude of the divided attention cost in the UFOV task, particularly in older adults (Owsley, McGwin, et al., 1998; 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 focused attention conditions.

Third, 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 toward 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.

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 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

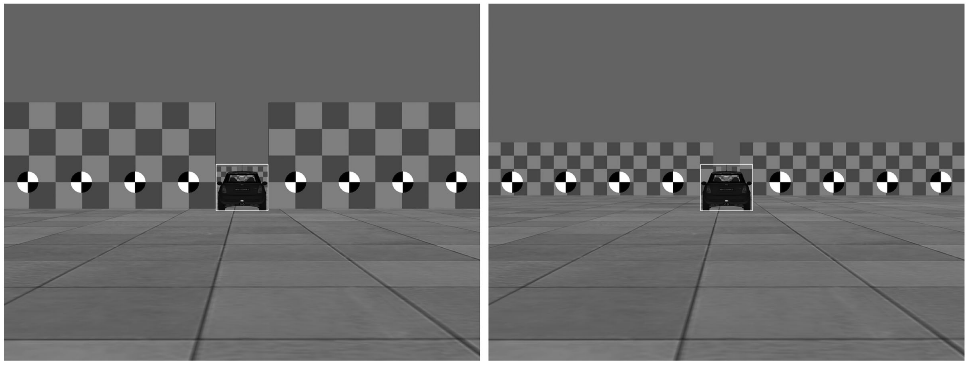

Figure 1. A schematic of all possible target locations in the near condition (left) and the far condition (right). Note that the retinal size of checks on the near and far walls differed, but the retinal position and size of the targets were identical at the two virtual distances. Target contrast was 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 center of the screen moved along a straight path at a speed that varied unpredictably over time.

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 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 m_v) or far (37 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. Focused attention was assessed using a peripheral detection alone block, in which car-following was passive, and an active 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 was assessed by comparing detection performance in the focused 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 was also assessed by comparing the car-following alone condition with the divided attention condition.

The goals of Experiment 1 are to (a) examine whether target detection is affected by the effect of apparent distance simulated by pictorial cues and optic flow, (b) provide a measure of peripheral attention comparable to the UFOV paradigm using a short target duration, and (c) assess how performance on both peripheral detection and car-following tasks varies under focused and divided attention. In Experiment 1, the target always appeared in either near or far distance per a pair of walls. Experiment 2 examines the effect of onset uncertainty on detection. Experiments 3 and 4 examine the relative contributions of stimulus features to the distance effect. Throughout these experiments, we focused 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.

Experiment 1: Effect of target distance

Method

Subjects

Twenty-eight undergraduate students at McMaster University who were naive 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 and design

Stimuli were back-projected onto a white screen. A JVC DLA-sx21 projector was placed 2.85 m from the center 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 1,366 × 1,024 pixels resolution with a refresh rate of 60 Hz.

An egocentric view of the virtual environment, illustrated in Figure 1, was shown from an eye-height of 1 virtual meter (m_v). Participants traveled 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 centered 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 eight possible positions at retinal eccentricities of 6, 12, 18, or 24 dva on the left and the right wall (Figure 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 1,658 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 Figure 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 m_v per frame or the down arrow key to decelerate by 0.1 m_v per frame.

Procedure

The experiment used a 2 (Attention: focused vs. divided) × 4 (Eccentricity: 6, 12, 18, or 24 dva) × 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 m_v, lasting approximately 25 min. In part two, participants completed one block of the central car-following task under focused attention, in which no peripheral targets appeared. The second part lasted approximately 2 min. In part three, participants completed the peripheral detection and the car-following tasks concurrently for 20 blocks of 16 trials, lasting approximately 25 min. 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 focused attention parts. Participants had opportunities to take breaks between blocks. All participants completed the three parts in the order

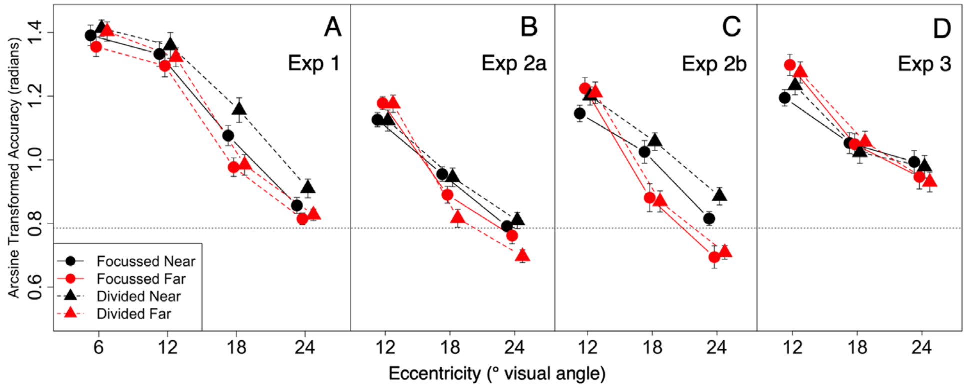

Figure 2. Arcsine transformed accuracy of peripheral target detection in Experiments 1, 2a, 2b, and 3 plotted as a function of eccentricity. The horizontal dotted line indicates chance performance (50%). Higher values indicate better performance, with values of 0.8, 1.0, 1.2, and 1.4 representing 51%, 71%, 87%, and 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 *SEM*.

described above. Using such a block order would mean that the cost due to divided attention and the improvement due to practice 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_G^2; Olejnik & 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 3 s 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; van der 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 1 indicate that the range of speeds in the lead and following cars was well matched, whereas gains greater or less than 1 imply that the range of speeds in the following car was 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.

Results

Peripheral detection task

Figure 2A shows arcsine transformed accuracy in the focused and divided attention conditions plotted as a function of target eccentricity. The data were analyzed with a 2 (Attention) × 4 (Eccentricity) × 2 (Distance) analysis of variance (ANOVA) (see Table B.2). There was a significant main effect of Eccentricity ($F(3, 69) = 276.5$, $p < 0.001$, $\eta_G^2 = 0.68$), response accuracy decreased with increasing target eccentricity. In addition, accuracy was overall higher for near targets than far targets ($F(1, 23) = 16.66$, $p < 0.001$, $\eta_G^2 = 0.045$). There also was a Distance × Eccentricity interaction ($F(3, 69) = 4.83$, $p < 0.001$, $\eta_G^2 = 0.021$, $\hat{\epsilon} = 0.001$), as the effect of eccentricity at the far distance was larger than the 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 focused attention condition ($F(1, 23) = 4.40$, $p = 0.047$, $\eta_G^2 = 0.013$).

To increase statistical power, we conducted a more focused analysis of the effects of Attention and Distance

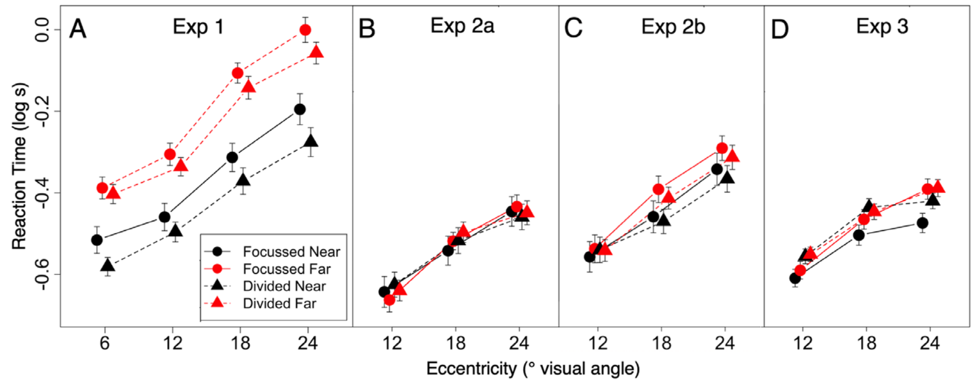

Figure 3. Log-transformed RT of peripheral target detection in Experiments 1, 2a, 2b, and 3 plotted as a function of eccentricity. Black and red symbols indicate performance in the near and far distance conditions, respectively. Circle and triangle symbols indicate performance in the focused and divided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

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 B.3). There was a significant overall linear trend ($F(1, 23) = 505.4$, $p < 0.001$, $\eta_G^2 = 0.92$), which is consistent with the significant main effect of eccentricity above. The Distance × Attention interaction ($F(1, 23) = 4.33$, $p = 0.049$, $\eta_G^2 = 0.014$) was also significant. The linear trends for near and far targets differed significantly in the divided attention condition ($F(1, 23) = 8.07$, $p = 0.001$, $\eta_G^2 = 0.11$) but not in the focused attention condition ($F(1, 23) = 0.26$, $p = 0.61$, $\eta_G^2 = 0.004$). No other effects were significant.

Log-transformed RT in the peripheral detection task is plotted in Figure 3A. We conducted a 2 (Attention) × 4 (Eccentricity) × 2 (Distance) ANOVA on these data (see Table C.20 for full ANOVA table). Visual inspection of Figure 3A shows that RTs were shorter for targets at small eccentricities than large eccentricities ($F(3, 69) = 186.86$, $p < 0.001$, $\eta_G^2 = 0.47$). RTs also were shorter in the divided attention condition than in the focused attention condition ($F(1, 23) = 8.00$, $p = 0.009$, $\eta_G^2 = 0.027$) and for near targets than far targets ($F(1, 23) = 79.87$, $p < 0.001$, $\eta_G^2 = 0.03$). We also found a significant Distance × Eccentricity interaction ($F(3, 69) = 9.34$, $p < 0.001$, $\eta_G^2 = 0.021$): 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 C.20).

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 ($F(1, 23) = 249.32$, $p < 0.01$, $\eta_G^2 = 0.89$). There also was a significant main effect of Distance ($F(1, 23) = 16.85$, $p < 0.001$, $\eta_G^2 = 0.063$), indicating that the linear effect of eccentricity was larger for far targets. No other effects were significant (see Table C.21).

Car-following task

Amplitude gains are shown in Figure 4A and phase shifts are shown in Figure 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 ($F(2, 46) = 13.18$, $p < 0.01$, $\eta_G^2 = 0.09$), with no other significant effects. In contrast, the ANOVA on phase shift measures found significant main effects of Attention ($F(1, 23) = 15.45$, $p < 0.01$, $\eta_G^2 = 0.06$) and Frequency ($F(2, 46) = 25.71$, $p < 0.01$, $\eta_G^2 = 0.28$), 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 ($F(2, 46) = 2.08$, $p = 0.15$, $\eta_G^2 = 0.026$). Overall, our analyses suggest that dividing attention caused participants to respond more slowly to changes in the lead car's speed.

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

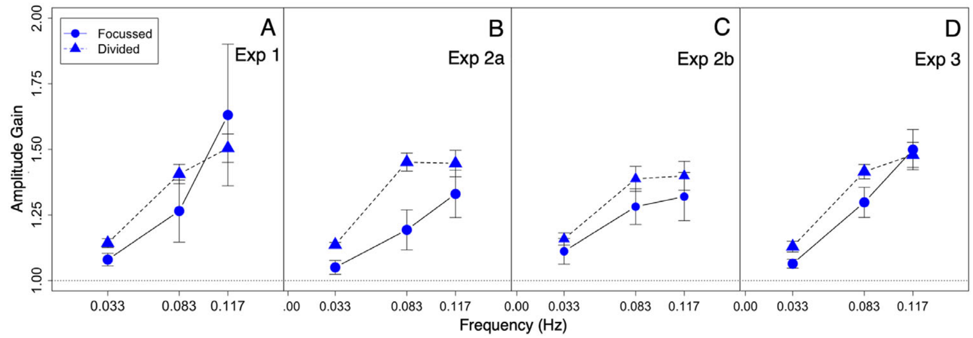

Figure 4. Amplitude gain of participants' following speed relative to that of the lead car as a function of frequency. Circle and triangle symbols indicate performance in the focused and divided attention conditions, respectively. The horizontal dotted lines indicate perfect performance, and deviations 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 $\pm$ 1 *SEM*.

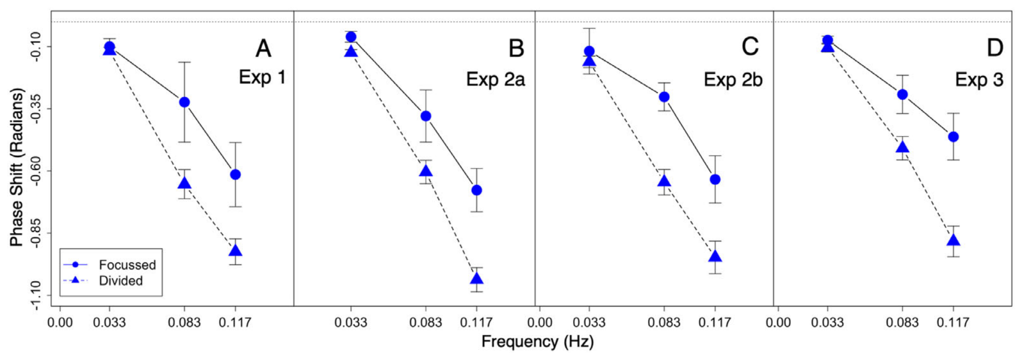

Figure 5. Phase shift of participants' following speed relative to that of the lead car as a function of frequency. Symbol conventions are same as Figure 4. Deviations below the dotted horizontal line indicate response delay. In Experiment 1 (far left), the focused attention condition, average phase 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 A.1.

behavior 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.

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 & 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 Experiments 1, 2, and 3. Therefore, we will postpone our discussion of these results in the general discussion (see Supplementary Materials for full ANOVA tables).

Experiment 2: Effect of anticipation of target onset

The distance effect found in Experiment 1 may have been caused by reduced uncertainty about stimulus onset for near targets. In Experiment 1, a target appeared on each pair of walls *either* at the far distance or the near distance. Therefore, while approaching 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 Experiment 1 and in Pierce and Andersen

(2014). Comparing our Experiments 1 and 2 allows us to quantify the contribution of target predictability.

Experiment 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 (a) no target was presented at either distance, and (b) 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 Experiments 1 and 2 were not due to chance, we ran Experiment 2b as a direct replication of Experiment 2a using a separate sample of naive participants recruited at a different time of year.

Method

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 Experiment 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 naive 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 and design

The stimuli and procedure in both Experiments 2a and 2b were the same as Experiment 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 1 hr. The procedure was the same as Experiment 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 Experiment 1, except using only three eccentricities rather than four.

Results

Peripheral detection task

Target detection accuracy in Experiments 2a and 2b are shown in Figure 2B and 2C, respectively. Because the two experiments were run separately, we report the analyses for each experiment separately in the appendix (Tables B.4, B.7 and Tables C.22, C.25). 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 Experiment 1. The 2 (Experiment) × 2 (Attention) × 2 (Distance) × 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 focused 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 B.8). The results of the linear trend analysis were consistent with these observations (see Table B.9).

Response time data are plotted in Figure 3B (Experiment 2a) and Figure 3C (Experiment 2b). Visual inspection of the figures indicates that the effect of target distance was much smaller in Experiments 2a and 2b than Experiment 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 Experiments 2a and 2b. First, although the effect was in the same direction in both experiments, the effect of Eccentricity was larger in Experiment 2b than Experiment 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 Experiment 2b than in Experiment 2a ($F(1, 46) = 4.90$, $p = 0.031$, $\eta^2_G = 0.004$): The main effect of Distance was significant in Experiment 2b ($F(1, 23) = 13.28$, $p = 0.001$, $\eta^2_G = 0.017$) but not Experiment 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) × 2 (Attention) × 2 (Distance) ANOVA on the linear trend of RT across eccentricity, which also found a main effect of Distance ($F(1, 46) = 10.52$, $p = 0.002$, $\eta^2_G = 0.03$). These effects did not differ between Experiments 2a and 2b.

Finally, the effect of eccentricity was larger in the focused attention condition than the divided attention condition, as indicated by the significant Attention ×

Eccentricity interaction ($F(2, 92) = 5.15$, $\hat{\epsilon} = 0.88$, $p = 0.001$, $\eta^2_G = 0.002$), and also by a larger linear trend in the focused attention condition than the divided attention condition ($F(1, 46) = 8.28$, $p = 0.006$, $\eta^2_G = 0.022$). No other effects were significant (see Tables C.26 and C.27).

Discussion

Experiment 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 Experiments 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 Experiment 2b.

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

Experiment 3: Effect of distance in the absence of checkerboard background

Experiment 2 suggests that 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 covaried with distance contributed to the effect. One potential contributing visual feature is the texture 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 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 Experiment 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 the checkerboard patterns on the walls on target detection by removing the checkerboard pattern but retaining optical flow and linear perspective cues. Comparisons of Experiments 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 Experiment 3.

Method

Participants

Twenty-eight undergraduate students from McMaster University were recruited in the same manner as in Experiment 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 and design

We used the same stimuli, methods, and analyses as in Experiments 2a and 2b except the checkerboard patterns on the walls were replaced by a uniform gray that had the same average luminance (8.40 cd/m^2) as the walls used in Experiments 1 and 2 (Figure 6).

Data analysis

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

Results

Figure 2D plots detection accuracy as a function of attention, distance, and eccentricity. The main effect

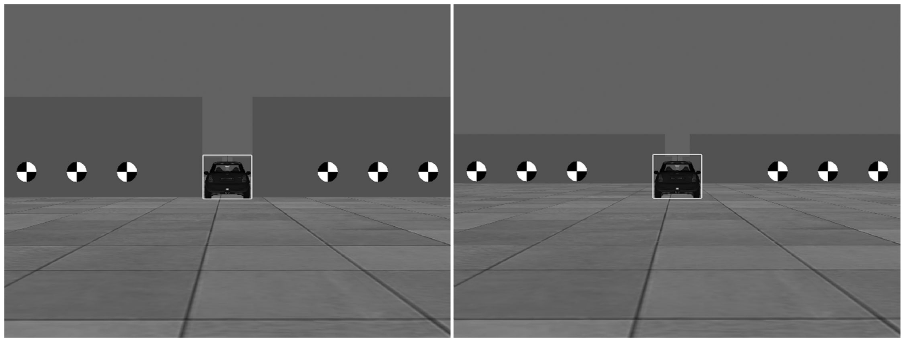

Figure 6. An illustration of all possible targets at the near (left) and far (right) distances in Experiment 3. Target contrast was increased for illustration in this image. The stimuli and possible target locations were identical to Experiment 2 except the walls were covered by a uniform gray.

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 B.10 for full ANOVA). The results of the linear trend analysis corroborated this interaction (Table B.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 Experiments 2 and 3. The analysis suggests 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 (Experiment 3, $M = 1.08$) than when checkerboards were present (Experiment 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 Experiment 2 and Experiment 3. Compared to Experiment 2 (see Table B.8), Experiment 3 had a larger far advantage at 12 dva and a smaller near advantage at 24 dva (see Table B.10). Moreover, at 18 dva, there was a significant near advantage in Experiment 2, but no significant effect of distance was observed in Experiment 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 effect of distance on linear trend scores ($F(1, 73) = 1.62$, $p = 0.21$, $\eta^2_G = 0.003$; see Tables B.12 and B.14 for full ANOVA tables). These results suggest that removing the checkerboard pattern reduced but did not eliminate the interaction.

Discussion

Experiment 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 Experiments 2 and 3 ($F(1, 73) = 15.50$, $p < 0.001$, $\eta^2_G = 0.014$). The effect of distance was nonsignificant in Experiment 3 ($\eta^2_G = 0.015$) and much smaller in magnitude compared to Experiment 2 ($\eta^2_G = 0.05$). These results suggest that the overall near advantage when averaged across eccentricities observed in Experiment 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 Experiment 3 ($\eta_G^2 = 0.02$) than in Experiment 2 ($\eta_G^2 = 0.09$), the interaction was significant and in the same direction in both experiments. Furthermore, the effect of checkerboard on the Distance × Eccentricity interaction ($\eta_G^2 = 0.006$) was much smaller in magnitude than that of the overall Distance × Eccentricity interaction found across Experiments 2 and 3 ($\eta_G^2 = 0.014$). 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 Experiment 4.

Experiment 4: Effect of static pictorial cues

Experiment 3 examined the target distance effect when the checkerboard backgrounds were not present but assumed that the effect of the checkerboard pattern is additive. However, the checkerboard pattern may have nonadditive effects in the presence of other distance cues. For example, perceived depth may have been reduced by the exclusion of the checkerboard in Experiment 3, which may also have changed the interpretation of the other depth cues present in the stimulus. Experiment 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 and examines 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 Experiment 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 focused attention condition because we were interested primarily in how these stimulus variables affected detection rather than how they interacted with divided attention.

Method

Participants

Fifty-five naive participants were recruited in the same manner as in Experiment 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

The stimuli were the same as in Experiment 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 Figure 7A). The combination of large checks and large wall area corresponded to the walls in the near condition in Experiment 1, whereas the combination of small checks and small wall area corresponded to the walls in the far condition in Experiment 1. Walls and target were presented with a textured ground plane (Figure 7A), as in Experiment 1, or in a uniform gray field with a luminance of 7.95 cd/m^2 (Figure 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 center 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 center of the screen and remained visible throughout the trial. The background appeared 1,000 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 gray field for 17 ms, after which the text "Where was the target?" was presented in the center 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 1 hr.

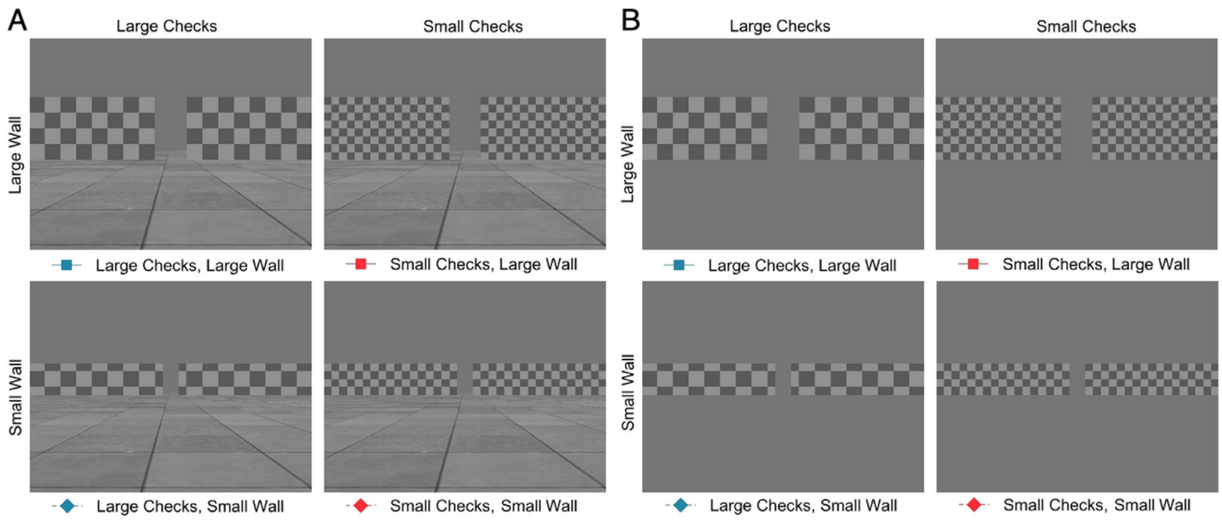

Figure 7. An illustration of all backgrounds used in Experiment 4 in the ground present condition (A) and in the ground absent condition (B). Note that the targets are not displayed in the figure but are the same as Experiment 1. In all conditions, the retinal eccentricity and size of the targets were identical to Experiment 1. On each trial, only one background and one target appeared.

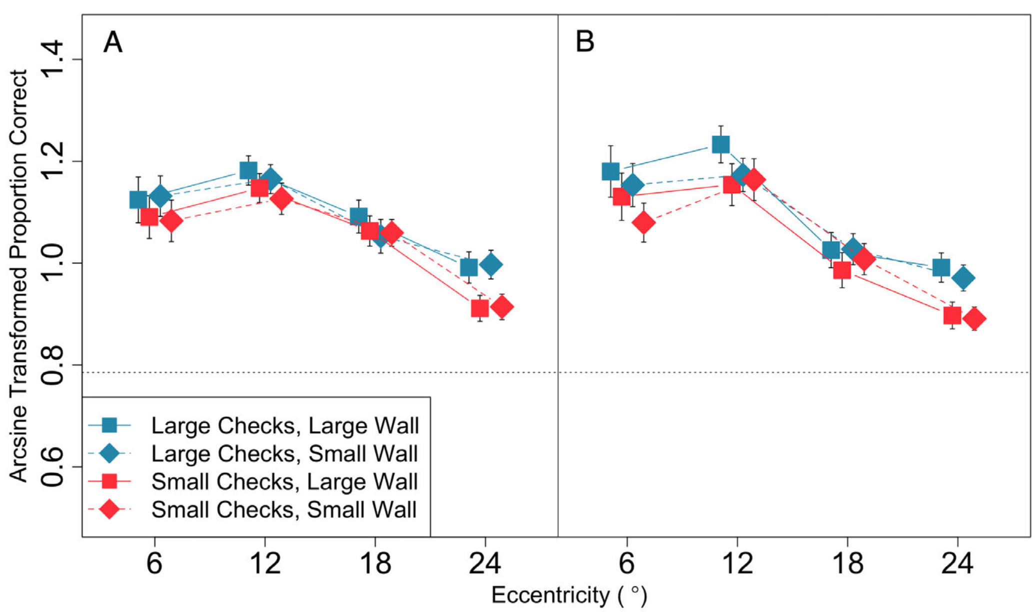

Figure 8. Peripheral target detection accuracy in Experiment 4 plotted as a function of target eccentricity, check size, and wall size in the (A) ground plane present and (B) ground plane absent condition. Blue and red symbols indicate performance in the small and large check size conditions, respectively. Square and diamond symbols indicate performance in the small and large wall sizes, respectively. Error bars represent $\pm$ 1 *SEM*.

Results

Target detection accuracy is plotted as a function of eccentricity in Figure 8. Experiment 4 included four levels of eccentricity (6, 12, 18, 24 dva) and Experiment 2 included only three (12, 18, 24 dva). The results of Experiment 4 including only three eccentricities were qualitatively similar to those obtained using all four eccentricity levels (see Tables B.17 and B.18 for details of the analysis using four eccentricities). Analyses discussed below include only the eccentricities that were in both Experiments 2 and 4.

The effects involving ground and wall size were generally small and nonsignificant ($F < 1.62$, $p > 0.21$, $\eta_G^2 < 0.022$ in each case), except for a small significant Ground $\times$ Eccentricity interaction ($F(2, 88) = 3.30$, $\hat{\epsilon} = 0.86$, $p = 0.049$, $\eta_G^2 = 0.013$; see Table B.15). This interaction is due to the fact that the effect of the ground plane 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 B.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 B.16).

Discussion

Experiment 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 Experiment 4 ($\eta^2_G = 0.027$). This result is consistent with the idea that check size contributed to the main effect of Distance in Experiment 2 ($\eta^2_G = 0.05$). The effect of wall size ($\eta^2_G = 0.001$) and ground plane ($\eta^2_G = 0.003$) was nonsignificant and negligible in Experiment 4.

The fact that we found a significant Check Size × Eccentricity interaction in Experiment 4 is consistent with the idea that check size contributed to the Distance × Eccentricity interaction found in Experiment 2. However, the magnitude of the Check Size × Eccentricity interaction in Experiment 4 ($\eta^2_G = 0.008$) was approximately nine times smaller than the Distance × Eccentricity interaction in Experiment 2 ($\eta^2_G = 0.07$). Furthermore, the Check Size × Eccentricity interaction was qualitatively different from the Distance × Eccentricity interaction. Whereas Experiment 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, Experiment 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 Experiment 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 Experiment 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 to 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 & He, 2000; Ni et al., 2005; Bian et al., 2006; Bian & Andersen, 2006; Ozkan & 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 & 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 Experiments 2 and 3 but not Experiment 4. In Experiments 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, and 11.01 dva per second, and near targets moved 6.45, 12.87, 19.34, and 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 Experiments 2 and 3. In addition, target displacement may explain why Experiments 2 and 3 found a slight far advantage at 12 dva, whereas Experiment 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 Experiments 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 general performance across eccentricity to be better for far targets than for near targets. In addition, although the proportional difference in displacement between eccentricities was equal across distances, the absolute difference in displacement between eccentricities was 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 Experiments 1–3. Therefore, our findings are consistent with 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 Experiment 4 may be due to a reduced impression of depth.

General discussion

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

Experiment 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 Experiment 1 due to differences in target onset uncertainty. Experiment 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 Experiment 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. Experiment 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 Experiments 1 and 2.

In Experiment 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 Experiment 4 was significant although much smaller than the Eccentricity × Distance interaction found in Experiment 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.

Experiment 3 examined the target distance effect after removing the checkerboard backgrounds from the dynamic stimuli used in Experiment 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 B.19). 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.

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 is 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 behavioral 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. Second, 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 from an observer's heading than near objects. Also, during driving, distant objects and events are less relevant to behavior 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 overlearned with practice, such that this pattern of behavior is shown even when hazards are absent. However, it is worthwhile to note that in ideal driving conditions, objects of interest usually have 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 nighttime 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.

Experiments 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 focused attention. However, there were no divided attention costs in peripheral detection. In fact, detection performance was more accurate under divided attention only in Experiment 1. This is likely due to a practice 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 & Ball, 1986; Sekuler et al., 2000; Owsley et al., 1998a). It is possible that a practice 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 that 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 to 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 reflects 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 has 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. Second, the focused 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 led participants to 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 in 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 and 600 ms in the divided attention condition compared to the focused attention condition (except for at the highest frequencies, which sometimes showed smaller delays in the divided attention condition; see Table A.1). At an average speed of 60 km/h, these delays correspond to traveling an extra 1.6 and 10 m 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 18.5 m. 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 18.5 m corresponded to a time-headway of 1.1 s, which is well within the range of common time headways drivers choose in real driving (Treiterer & Nemeth, 1970; von Buseck et al., 1980; Ayres et al., 2001). This is likely a reasonable choice as it allows for enough RT delay to respond to a sudden change in the vehicle ahead. Traveling at high speeds may also affect the prioritization of tasks, as at a higher speed of 100 km/h, the same delays of 100 and 600 ms corresponds to 2.7 and 16.7 m, and drivers may be poorer at estimating car-following headways at faster speeds (Risto & 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.

Keywords: peripheral target detection, driving, spatial attention, depth, divided attention

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Footnote

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

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Appendix A. Estimated response time delay in car-following task

Condition	0.033 Hz	0.083 Hz	0.117 Hz
Experiment 1			
Focused 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)
Experiment 2a			
Focused 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)
Experiment 2b			
Focused 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)
Experiment 3			
Focused 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)

Table A.1. Estimates of response delay in the car-following task in seconds and standard estimates of the mean in parentheses.

Appendix B. Detection accuracy: Full ANOVA tables

B.1. Experiment 1

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

Table B.2. Experiment 1: ANOVA on arcsine transformed accuracy.

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

Table B.3. Experiment 1: ANOVA on linear trend scores of arcsine transformed accuracy.

B.2. Experiment 2

Effect	df_1	df_2	F	p	η_G^2	$\hat{\epsilon}$	p_{adj}
Attention	1	23	0.85	0.37	0.006		
Distance	1	23	5.27	0.031	0.018		
Eccentricity	2	46	143.68	<0.001	0.56	0.80	<0.001
Attention × Distance	1	23	6.66	0.017	0.007		
Attention × Eccentricity	2	46	1.25	0.30	0.003	0.96	0.30
Distance × Eccentricity	2	46	22.26	<0.001	0.05	0.96	<0.001
Attention × Distance × Eccentricity	2	46	2.36	0.11	0.004	0.96	0.11
SME of Attention							
Near distance	1	23	0.004	0.94	<0.01		
Far distance	1	23	3.26	0.08	0.05		
SME of Distance							
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 B.4. Experiment 2a: ANOVA on arcsine transformed accuracy.

Effect	df_1	df_2	F	p	η_G^2
Intercept	1	23	186.35	<0.001	0.84
Attention	1	23	0.87	0.36	0.004
Distance	1	23	24.79	<0.001	0.12
Attention × Distance	1	23	3.69	0.07	0.016

Table B.5. Experiment 2a: Linear trend analysis on arcsine transformed accuracy.

Effect	df_1	df_2	F	p	η_G^2	$\hat{\epsilon}$	p_{adj}
Attention	1	23	1.79	0.19	0.007		
Distance	1	23	19.88	<0.001	0.083		
Eccentricity	2	46	167.39	<0.001	0.57	0.85	<0.001
Attention × Distance	1	23	5.31	0.03	0.009		
Attention × Eccentricity	2	46	0.65	0.53	0.002	0.87	0.51
Distance × Eccentricity	2	46	46.35	<0.001	0.09	0.91	<0.001
Attention × Distance × Eccentricity	2	46	0.17	0.85	<0.001	0.95	0.84
SME of Distance							
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 Attention							
Near distance	1	23	6.94	0.015	0.05		
Far distance	1	23	0.026	0.087	<0.001		

Table B.6. Experiment 2b: ANOVA on arcsine transformed accuracy.

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

Table B.7. Experiment 2b: Linear trend analyses on arcsine transformed accuracy.

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

Table B.8. Combined Experiments 2a and 2b: ANOVA on arcsine transformed accuracy. ANOVA model:
$y \sim Experiment \times Attention \times Distance \times Eccentricity + Error(Subject/(Attention \times Distance \times Eccentricity)) + Exp$

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

Table B.9. Combined Experiments 2a and 2b: ANOVA on linear trend of arcsine transformed accuracy across eccentricity.

B.3. Experiment 3

Effect	df_1	df_2	F	p	η^2_G	$\hat{\epsilon}$	p_{adj}
Attention	1	26	0.26	0.61	0.003		
Distance	1	26	1.61	0.22	0.015		
Eccentricity	2	52	104.57	<0.001	0.34	0.89	<0.001
Attention × Distance	1	26	0.20	0.66	<0.001		
Attention × Eccentricity	2	52	0.43	0.65	0.008	0.96	0.64
Distance × Eccentricity	2	52	15.34	<0.001	0.02	0.92	<0.001
Attention × Distance × Eccentricity	2	52	2.51	0.09	<0.004	0.91	0.10
SME of Distance							
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 B.10. Experiment 3: ANOVA on arcsine transformed accuracy.

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

Table B.11. Experiment 3: Linear trend analysis of arcsine transformed accuracy.

Effect	df_1	df_2	F	p	η^2_G	$\hat{\epsilon}$	p_{adj}
Checkerboard	1	73	22.33	<0.001	0.13		
Attention	1	73	0.062	0.80	<0.001		
Distance	1	73	6.78	0.011	0.006		
Eccentricity	2	146	346.46	<0.001	0.44	0.89	<0.001
Checkerboard × Attention	1	73	0.10	0.75	<0.001		
Checkerboard × Distance	1	73	15.50	<0.001	0.014		
Checkerboard × Eccentricity	2	146	9.57	<0.001	0.021	0.89	<0.001
Attention × Distance	1	73	5.88	0.018	0.002		
Attention × Eccentricity	2	146	0.91	0.40	<0.001	0.98	0.40
Distance × Eccentricity	2	146	56.70	<0.001	0.034	0.94	<0.001
Checkerboard × Attention × Distance	1	73	2.95	0.09	0.001		
Checkerboard × Attention × Eccentricity	2	146	0.48	0.62	<.001	0.98	0.61
Checkerboard × Distance × Eccentricity	2	146	9.82	<0.001	0.006	0.94	<0.001
Attention × Distance × Eccentricity	2	146	1.22	0.30	<0.001	0.97	0.30
Checkerboard × Attention × Distance × Eccentricity	2	146	2.94	0.056	0.002	0.97	0.06

Table B.12. Combined Experiments 2a, 2b, and 3: ANOVA on arcsine transformed accuracy. ANOVA model:
$y \sim Checkerboard \times Attention \times Distance \times Eccentricity + Error(Subject/(Attention \times Distance \times Eccentricity)) + Checkerboard$

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

Table B.13. Combined Experiments 2a, 2b, and 3: SME analysis on arcsine transformed accuracy.

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

Table B.14. Combined Experiments 2a, 2b, and 3: ANOVA on linear trend of arcsine transformed accuracy.

B.4. Experiment 4

Effect	df_1	df_2	F	p	η^2_G	$\hat{\epsilon}$	p_{adj}
Ground	1	44	0.19	0.67	0.003		
Check Size	1	44	43.81	<0.001	0.027		
Wall Size	1	44	2.38	0.13	0.001		
Eccentricity	2	88	100.32	<0.001	0.28	0.86	<0.001
Ground × Check Size	1	44	0.52	0.48	<0.001		
Ground × Wall Size	1	44	0.051	0.82	<0.001		
Ground × Eccentricity	2	88	3.30	0.041	0.013	0.86	0.049
Check Size × Wall Size	1	44	2.96	0.092	0.001		
Check Size × Eccentricity	2	88	8.18	<0.001	0.008	0.99	<0.001
Wall Size × Eccentricity	2	88	1.036	0.36	<0.001	0.93	0.36
Ground × Check Size × Wall Size	1	44	0.95	0.33	<0.001		
Ground × Check Size × Eccentricity	2	88	0.10	0.91	<0.001	0.93	0.91
Ground × Wall Size × Eccentricity	2	88	1.82	0.17	0.001	0.92	0.17
Check Size × Wall Size × Eccentricity	2	88	0.38	0.69	<0.001	0.93	0.67
Ground × Check Size × Wall Size × Eccentricity	2	88	0.93	0.39	0.001	0.93	0.39
SME of Check Size							
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 Ground							
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 B.15. Experiment 4: ANOVA on arcsine transformed accuracy including three 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
Ground	1	44	1.45	0.23	0.02
Check Size	1	44	7.16	0.01	0.02
Wall Size	1	44	1.25	0.27	<0.01
Ground × Check Size	1	44	0.004	0.95	<0.01
Ground × Wall Size	1	44	0.14	0.71	<0.01
Check Size × Wall Size	1	44	0.57	0.46	<0.01
Ground × Check Size × Wall Size	1	44	0.63	0.44	<0.01

Table B.16. Experiment 4: Linear trend analysis on arcsine transformed accuracy including three eccentricities: 12, 18, and 24 dva.

Effect	df_1	df_2	F	p	η_G^2	$\hat{\epsilon}$	p_{adj}
Ground	1	44	0.015	0.90	<0.001		
Check Size	1	44	44.95	<0.001	0.023		
Wall Size	1	44	4.44	0.041	0.001		
Eccentricity	3	132	35.69	<0.001	0.22	0.48	<0.001
Ground × Check Size	1	44	0.79	0.38	<0.001		
Ground × Wall Size	1	44	0.38	0.54	<0.001		
Ground × Eccentricity	3	132	1.46	0.23	0.011	0.48	0.24
Check Size × Wall Size	1	44	1.31	0.26	<0.001		
Check Size × Eccentricity	3	132	5.92	<0.001	0.005	0.97	<0.001
Wall Size × Eccentricity	3	132	0.79	0.50	<0.001	0.92	0.49
Ground × Check Size × Wall Size	1	44	0.65	0.43	<0.001		
Ground × Check Size × Eccentricity	3	132	0.12	0.95	<0.001	0.97	0.94
Ground × Wall Size × Eccentricity	3	132	2.06	0.11	0.001	0.92	0.11
Check Size × Wall Size × Eccentricity	3	132	1.08	0.36	0.001	0.92	0.36
Ground × Check Size × Wall Size × Eccentricity	3	132	0.78	0.51	<0.001	0.92	0.50
SME of Check Size							
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 B.17. Experiment 4: ANOVA on arcsine transformed accuracy including four 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
Ground	1	44	1.02	0.32	0.020
Check Size	1	44	2.74	0.11	0.003
Wall Size	1	44	1.63	0.21	0.002
Ground × Check Size	1	44	0.13	0.72	<0.001
Ground × Wall Size	1	44	1.12	0.30	0.001
Check Size × Wall Size	1	44	0.42	0.52	<0.001
Ground × Check Size × Wall Size	1	44	0.002	0.97	<0.001

Table B.18. Experiment 4: Linear trend analysis on accuracy including four eccentricities: 6, 12, 18, and 24 dva.

Effect of interest	Experiment	Main effect	Interaction with eccentricity	12 dva[a]	18 dva[a]	24 dva[a]	effect on linear trend
Distance	1	0.045	0.021	0.014	0.18	0.08	0.03
Distance	2a	0.018	0.050	0.035[b]	0.138	0.01[c]	0.12
Distance	2b	0.083	0.090	0.031[b]	0.230	0.31	0.24
Distance (all cues)	2a&b	0.050	0.070	0.032[b]	0.180	0.22	0.18
Distance (no checker)	3	0.015[c]	0.020	0.070[b]	0.010[c]	0.02	0.13
Checkerboard Presence	2 vs. 3	0.014[d]	0.006[e]				0.003[c,d]
Check Size	4	0.027	0.008	0.180	0.005[c]	0.12	0.02

Table B.19. Sizes of effects of interest on accuracy from all experiments.
[a]Simple main effect of distance.
[b]Far advantage, opposite of the main effect of distance.
[c]Effect was nonsignificant.
[d]Checker × Distance interaction.
[e]Checker × Distance × Eccentricity interaction.

Appendix C. Detection RT results

Effect	df_1	df_2	F	p	η^2_G	$\hat{\epsilon}$	p_{adj}
Attention	1	23	8.00	0.01	0.027		
Distance	1	23	79.88	<0.001	0.30		
Eccentricity	3	69	186.87	<0.001	0.47	0.52	<0.001
Attention × Distance	1	23	4.17	0.053	0.002		
Attention × Eccentricity	3	69	1.83	0.15	0.002	0.62	0.17
Distance × Eccentricity	3	69	9.34	<0.001	0.01	0.88	<0.001
Attention × Distance × Eccentricity	3	69	1.56	0.21	<0.001	0.80	0.22
SME of Distance							
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 C.20. Experiment 1: ANOVA on log transformed RT.

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

Table C.21. Experiment 1: Linear trend analysis of log RT.

Effect	df_1	df_2	F	p	η^2_G	$\hat{\epsilon}$	p_{adj}
Attention	1	23	0.39	0.54	0.001		
Distance	1	23	0.15	0.71	<0.001		
Eccentricity	2	46	114	<0.001	0.23	0.70	<0.001
Attention × Distance	1	23	<0.001	0.99	<0.001		
Attention × Eccentricity	2	46	3.65	0.034	0.003	0.89	0.040
Distance × Eccentricity	2	46	2.47	0.096	0.003	0.91	0.10
Attention × Distance × Eccentricity	2	46	0.05	0.95	<0.001	0.94	0.94
SME of Attention							
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 C.22. Experiment 2a: ANOVA on log RT.

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

Table C.23. Experiment 2a: Linear trend analysis on log RT.

Effect	df_1	df_2	F	p	η^2_G	$\hat{\epsilon}$	p_{adj}
Attention	1	23	0.47	0.50	0.001		
Distance	1	23	13.28	0.001	0.017		
Eccentricity	2	46	125.32	<0.001	0.24	0.67	<0.001
Attention × Distance	1	23	0.55	0.47	<0.001		
Attention × Eccentricity	2	46	2.75	0.07	0.002	0.87	0.082
Distance × Eccentricity	2	46	8.80	<0.001	0.005	0.90	<0.001
Attention × Distance × Eccentricity	2	46	0.45	0.64	<0.001	0.66	0.56
SME of Distance							
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 C.24. Experiment 2b: ANOVA on log RT.

Effect	df_1	df_2	F	p	η^2_G
Intercept	1	23	158.16	<0.001	0.81
Attention	1	23	3.88	0.06	0.02
Distance	1	23	7.68	0.01	0.04
Attention × Distance	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 C.25. Experiment 2b: Linear trend analysis on log RT.

Effect	df_1	df_2	F	p	η^2_G	$\hat{\epsilon}$	p_{adj}
Experiment	1	46	0.41	0.53	0.007		
Attention	1	46	0.01	0.89	<0.001		
Distance	1	46	7.68	0.008	0.006		
Eccentricity	2	92	237.00	<0.001	0.23	0.69	<0.001
Experiment × Attention	1	46	0.86	0.36	0.001		
Experiment × Distance	1	46	4.90	0.031	0.004		
Experiment × Eccentricity	2	92	4.43	0.014	0.006	0.69	0.027
Attention × Distance	1	46	0.32	0.58	<0.001		
Attention × Eccentricity	2	92	5.15	0.008	0.002	0.88	0.001
Distance × Eccentricity	2	92	9.74	<0.001	0.004	0.97	<0.001
Experiment × Attention × Distance	1	46	0.33	0.57	<0.001		
Experiment × Attention × Eccentricity	2	92	1.27	0.29	<0.001	0.88	0.28
Experiment × Distance × Eccentricity	2	92	0.56	0.57	<0.001	0.97	0.57
Attention × Distance × Eccentricity	2	92	0.13	0.88	<0.001	0.85	0.85
Experiment × Attention × Distance × Eccentricity	2	92	0.35	0.70	<0.001	0.85	0.67
SME of Distance							
Experiment 2a	1	23	0.15	0.72	<0.01		
Experiment 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 Eccentricity							
Experiment 2a	2	46	114.01	<0.001	0.27	0.70	<0.001
Experiment 2b	2	46	125.32	<0.001	0.27	0.67	<0.001
SME of Attention							
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 C.26. Combined Experiments 2a and 2b: ANOVA on log RT.

Effect	df_1	df_2	F	p	η_G^2
Intercept	1	46	267.95	<0.001	0.79
Experiment	1	46	0.25	0.62	0.003
Attention	1	46	8.28	0.006	0.022
Distance	1	46	10.52	0.002	0.03
Experiment × Attention	1	46	1.66	0.20	0.004
Experiment × Distance	1	46	1.19	0.28	0.003
Attention × Distance	1	46	0.16	0.69	<0.001
Experiment × Attention × Distance	1	46	0.49	0.49	0.001

Table C.27. Combined Experiments 2a and 2b: ANOVA on linear trend of log RT.