Global Visual Motion Affects the Distribution of Spatial Attention

by

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A thesis submitted in conformity with the requirements for the degree of Master of Arts
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Abstract

Decades of research has established that spatial attention concentrates near the centre of the visual field, attenuating sharply toward the periphery. In a static scene, humans are better at deploying attention to objects among clutter that appear near central vision. However, while walking or driving people often encounter global motion of the visual environment. Little is known about this motion’s impact on spatial attention, or whether the arrangement of distractor objects impacts target detection. The current study investigated whether (1) a random distractor arrangement and (2) target and distractor motion impact the distribution of spatial attention. Experiment 1 shows that distractor arrangement does not affect spatial attention. Experiment 2 shows that humans are better at detecting targets across the visual field when there is global motion. Spatial attention in a static context differs from spatial attention in a dynamic context; thus, previous knowledge may not generalize to some contexts.
Acknowledgments

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1 Introduction

In this thesis, I will be investigating the distribution of spatial attention in a new context that strives to be more generalizable to real world conditions. The existing body of literature shows that people are better at noticing objects among clutter when those objects are closer to the centre of the visual field. However, this was typically done in a static context (where no stimuli were moving) and with a rigid (non-random, repeating) arrangement of clutter. Through the two studies contained in this thesis, I aim to determine whether either the arrangement of stimuli within clutter or the global motion of the stimuli affects the detection of objects in the central visual field and beyond.

A typical human has about 190 degrees of peripheral vision in the horizontal direction (Wolfe, Kluender, Levi, Bartoshuk, & Herz, 2006) and while this extended range is crucial for survival, the central 60 degrees of the visual field, which consists of central vision and the near periphery, is arguably the most important region for daily functioning. This area is known as the attentional visual field (AVF) (Hassan et al., 2008) (sometimes also referred to as the Useful Field of View [UFOV] (Ball, Beard, Roenker, Miller, & Griggs, 1988), or the functional field of view [FFOV] (Sanders, 1970)), and represents the area from which we can extract information from the visual environment at a glance without an eye or head movement (Ball, Wadley, & Edwards, 2002). The ability to distribute attention simultaneously over the entire AVF is important for many daily activities such as walking and driving. It is important to be able to quickly deploy attention across the AVF to notice objects that suddenly appear among the visual clutter. These objects are often things that are on a collision course with the observer (e.g. other pedestrians while navigating a sidewalk, or a baseball suddenly veering toward one’s head). People are very good at detecting objects that suddenly appear among clutter within central vision, but are markedly
worse when these objects suddenly appear in the near periphery (Ball et al., 1988). The ability to spread attention across the AVF in the presence of clutter is distinct from the ability to detect single objects in the periphery.

In a static context, (i.e. where there is no motion in the visual environment), attention concentrates most readily near the centre of vision; the more peripherally located an item is, the less likely attention will be distributed to it, especially if the observer is also focused on a central task (Sekuler, Bennett, & Mamelak, 2000; Ball et al., 1988). Detecting single targets in an otherwise empty visual field relies on intact peripheral vision. Detecting targets among clutter, however, relies on different mechanisms. Humans are quite accurate at detecting a target within clutter when it is 10 degrees eccentric, but relatively poor at detecting a target in clutter that is 30 degrees eccentric (i.e. on the outer edge of the near periphery). Spatial attention in a static context has been compared to a spotlight (Posner, Snyder, & Davidson, 1980) that is bright in the centre and dims quickly near the edges. The size of this “spotlight” can be influenced, for example, by factors such as age (Ball et al., 1988; Sekuler et al., 2000), gender (Feng, Spence, & Pratt, 2007), and video game training (Green & Bavelier, 2003; Feng, Spence, & Pratt, 2007).

Ball et al. (1988) utilize what might be considered a traditional AVF paradigm. In this paradigm, each trial consists of a display of several distractors, arranged evenly in three (invisible) concentric rings around a fixation point. These rings are centred on the screen and are located 10, 20, and 30 degrees eccentric from centre. On each trial, a target replaces one of the distractors somewhere in the display. This display containing the target and distractors is presented to the viewer briefly, usually for less than 100 ms (in Ball et al. [1988] it was presented for 90 ms). Participants are required to detect a target placed among a fixed number of distractors – Ball et al. (1988) used separate conditions with 23, 47, or no distractors.
Participants are then asked to indicate its location on the screen relative to the centre. Targets are always located on one of the cardinal or intercardinal radials. Participants are often also expected to simultaneously perform a central task; in Ball et al. (1988), this task varied in demand – participants had to identify whether an image of a face was present in the centre of the screen, or which emotion the face expressed. Ball et al. (1988) found that eccentricity of the target affected performance – target localization accuracy was lower at higher eccentricities. Many subsequent studies have utilized a similar procedure (usually with 23 distractors), corroborating these findings (e.g. Sekuler et al., 2000; Green & Bavelier, 2003; Feng et al., 2007). Some studies have shown that certain factors, such as advanced age, are associated with poorer performance on AVF tasks. Sekuler et al. (2000) argue that a reduction in the AVF does not represent a decrease in the range within which individuals can extend spatial awareness, but rather a decrease in the speed with which they can do this. In the words of Ball, Owsley, and Beard (1990), some individuals with an AVF deficit (such as older adults) simply “take smaller samples and are slower to process them.” (p.123)

Other studies have taken a slightly different approach to measuring AVF. Ball (1990) introduced a staircase method; that is, the stimulus presentation was time scaled according to the observer’s ability to correctly localize targets. This allowed researchers to measure, for each individual, the time needed to process targets at specific eccentricities with a pre-specified accuracy. This provided a measurement of an individual’s processing speed (e.g., 60 ms needed to process most targets at 30 degrees). Stimulus displays were presented in the range of 10 ms to 200 ms. This was to determine the eccentricity threshold, in degrees, at which the observer would correctly localize a target 50% of the time. Subsequent studies have used this method – for instance, Edwards, Wadley & Vance (2005) used a 17 ms to 500 ms presentation time to determine the eccentricity threshold at which the observer was 75% correct. Ball’s (1990) method became a
popular method of assessing AVF, allowing researchers to determine how far from central vision target detection ability starts to effectively “drop off.”

AVF impairment should also not be confused with general loss of peripheral vision. Vision problems, such as loss of acuity in central vision and diseases of the eye such as cataracts or glaucoma could certainly impact the ability to quickly locate and identify targets in the near periphery. However, visual perimetry testing confirms that AVF impairment is a distinct condition that can exist independently from these problems. During visual perimetry testing (a common test performed by ophthalmologists), a patient sits still while individual lights of various intensities flash all over the visual field. The lights can appear as static or moving targets, and help to establish the boundaries of peripheral vision. One key difference between visual perimetry and AVF is that only one target at a time is presented during visual perimetry testing, whereas during AVF testing, the task is not to detect a lone target on a blank background, but to locate a target among a clutter of similar objects. It is relatively common for older adults, for instance, to perform worse on AVF tests than younger adults; however, they typically perform just as well when there are no distractors present (Ball et al., 1990). It is possible then to possess intact peripheral vision and at the same time show signs of a diminished AVF. Due to the scarcity of younger adults with AVF problems, it is unknown whether this extends to the general population; however, these results indicate that (at least in the case of older adults) the loss of range of AVF is a problem of attention, not a deficiency of peripheral visual capabilities.

1.1 Applications

A reduction in AVF can pose a serious threat to individuals in certain contexts, such as driving. While driving, it is useful to be able to focus not only on the road ahead but also on objects that
unexpectedly emerge from the sides, such as pedestrians suddenly crossing the street, cars merging in front of you, or another driver making a surprise turn across an intersection. A reduced AVF may interfere with the ability to avoid these obstacles. Older adults (65+) with a reduced AVF are more likely to have a history of vehicle crashes (Ball, Owsley, Sloane, Roenker, & Bruni, 1993; Owsley et al., 1998). A reduced AVF has also been shown to relate specifically to unsafe driving behaviours in an on-road assessment (Roenker, Cissell, Ball, Wadley, & Edwards, 2003; an “unsafe driving behaviour” was defined as any instance in which the examiner had to grab the wheel from a participant in order to avoid a collision). A wider AVF might also be useful not only for avoiding collisions, but also for lane keeping. Drivers may use central vision for maintaining heading, but they employ ambient vision (the area of the visual field directly adjacent to central vision) to keep track of lane boundaries and maintain lane positioning (Summala, Niemenen, & Punto, 1996; Wickens, 2002). Both types of input are vital, and are processed in parallel (Wickens, 2002). This is one of the many instances in which AVF is directly applicable to daily life. Having a thorough understanding of how AVF is affected by outside factors is of utmost relevance. Driving and other forms of self-motion involve unavoidable global motion of the visual environment (in the form of optic flow). This creates the appearance of movement not only in irrelevant background objects, but also in targets of interest (i.e. objects that may pose an immediate threat to the observer). The impact of this motion, particularly the motion of objects of relevance within the optic flow, on the ability to distribute attention across the AVF is relatively unknown.

1.2 Motion

Although much is known about how spatial attention is distributed in a static environment, much of what we encounter in the real world is not static. Often we encounter objects moving
on a static background (e.g. watching cars go by at an intersection, or watching a lone cat cross a yard). Sometimes, however, there is constant cohesive motion of the entire visual environment, most often due to self-motion (e.g. when walking or driving), during which we must also detect targets within clutter (for instance, looking out for turning cars while crossing an intersection on foot). Global motion of a scene relative to the observer is referred to as optic flow.

Optic flow is produced when an observer moves through a stationary environment or when a static observer is present in an environment that is moving globally. There are several kinds of optic flow, each produced by different types of motion. The most frequent variety of optic flow humans encounter on a daily basis is radial expansion, in which the motion in the visual environment appears to expand outward from a central point. Radial expansion results from moving forward through the environment, e.g. walking down a hallway or driving a car on a highway. The opposite, radial contraction, can occur from an observer moving backward.

Radially expansive optic flow is of particular interest – not only because it is something humans are typically subjected to for a large portion of their day – but because it is an intrinsic condition for navigating the environment. Humans encounter radially expansive optic flow every time they move forward. The speed of the optic flow varies with the observer’s speed; assuming a static environment, the faster one walks or drives, the faster the flow. The centre of the flow field may allow the observer to plan and adjust their trajectory through the environment, and the edges of the flow field may be important for avoiding obstacles and other threats (Wickens, 2002). For instance, while driving on a highway, the central areas of the flow field may be occupied by a curve in the road ahead, scenery, and the car directly in front; the more peripheral areas may include cars in adjacent lanes, nearby lane markers, buildings that one is about to pass, and nearby road signs. While central areas of the AVF are certainly important to attend to,
it is also critical to monitor the peripheral edges of the AVF to avoid, for example, running into poles or other people, getting scraped by tree branches, or merging into another car. The near periphery may be full of objects that require immediate attention.

I will focus on radial expansion not only because of its ubiquity, but also because of its vital importance in a multitude of applications involving self-motion. Radially expansive optic flow is often present in contexts where efficiently distributing spatial attention is crucial; however, it is unknown how radial expansion affects spatial attention. Both AVF and radially expansive optic flow have been studied in isolation from each other. We know, for instance, that radially expansive optic flow can be informative about heading (Crowell & Banks, 1993) and speed (Larish & Flach, 1990), because these judgments utilize information from the near periphery. When this information is unavailable, it not only impacts these abilities but also has the possibility to severely impair general driving ability -- AVF is important as a predictor of vehicle crashes (Ball et al., 1993; Roenker et al., 2003). What is unclear is whether radially expansive motion alters the distribution of attention across the AVF, if at all.

Another issue that has been largely ignored in the literature is whether the arrangement of irrelevant background objects across the AVF has any impact on the detectability of objects of interest within the clutter. AVF has been extensively studied by embedding a target in a neatly arranged array of distractors that repeats on every trial. It is possible that a repeated, predictable arrangement affects target detection in a different way than a more random distribution (which is what is more likely to be found in the real world).

1.3 Motion processing in the brain

Eye gaze preferentially orients itself toward the focus (i.e., vanishing point) of expansive radial flow during passive viewing (Niemann, Lappe, Buscher, & Hoffman, 1999); this suggests that
attention is drawn toward the centre of the flow. The current study’s dynamic AVF task consists of distractors continuously flowing out from the centre of the screen, occasionally being replaced by the appearance of a target. Overall this somewhat resembles moving forward through a starfield. In such a task, we might then expect to see higher target localization accuracy near the centre, much like in the static AVF task; however, the presence of global visual motion may affect detection in other parts of the visual field.

Scenes containing motion are processed differently in the brain compared to static scenes. Motion preferentially activates the magnocellular visual pathway (dorsal stream; “vision for action”) as opposed to the parvocellular pathway (ventral stream; “vision for perception”) (Goodale & Milner, 1992). The magnocellular layers are important for the perception of quickly moving objects, whereas the parvocellular layers are important for visual acuity and processing colour (Purves, Augustine, Fitzpatrick, et al. 2001). The magno- system transmits information about movement and depth, and is important for interpreting spatial organization (Livingstone & Hubel, 1988). This information is necessary for moving smoothly through the environment. Determining one’s position in the 3D environment relative to other objects, especially in optic flow conditions (walking or driving), is critical. The split in visual pathways begins at the ganglion cells (Livingstone & Hubel, 1988). Two types of ganglion cells, M-cells and P-cells project to the magno- and parvocellular layers of the lateral geniculate nucleus (LGN), respectively. From there both pathways continue into V1 and V2; the magnocellular pathway continues from there into V3, V5/middle temporal visual area (MT), and parietal cortex, and the parvocellular pathway continues into V4 and inferior temporal cortex (IT). However, some motion signals (e.g. coherent dot motion) are capable of initially bypassing V1, instead proceeding directly to MT (Beckers & Zeki, 1995). V1 activation decreases as speed of motion increases (Chawla, Phillips, Buechel, Edwards, & Friston, 1998), suggesting that higher speeds
allow more information to bypass the slower V1 and go directly to the faster V5/MT. This allows the signal to be processed very quickly – faster than through the parvocellular stream. Evidence from transcranial magnetic stimulation (TMS) studies suggests that latency for a motion signal to reach V1 is about 60 ms, while latency to reach MT is only about 20 ms (Beckers & Zeki, 1995). Perhaps for this reason, the magnocellular system excels at detecting transient stimuli and rapid changes (Gozli, West, & Pratt, 2012). This may also help predict what might happen in an AVF task with coherently moving targets and distractors. Motion information propagates through the magnocellular pathway; fMRI evidence has revealed areas of MT that are specialized for optic flow (Morrone et al., 2000). Magnocellular processing could result in an estimated speed of processing boost of about 20-30 ms compared to parvocellular processing (Laycock, Crewther, & Crewther, 2007).

1.4 AVF & Motion

Few studies to date have examined how the AVF is affected by the presence of global visual motion. Two instances of studies that have investigated this did so in the context of driving. First, Schieber and Benedetto (1998) combined a static AVF superimposed on an optic flow stimulus provided in the background via a driving video. The video provided a first-person perspective of driving on a road. Older and younger adults viewed the AVF stimuli (LEDs) on Plexiglas positioned between themselves and the video. They performed a central task (using a steering wheel to “steer” a wandering light back to centre). Peripheral stimuli were presented for 75-125 ms at 10, 20, and 30 degrees eccentric from centre. Schieber and Gilland (2005) took this further by combining real-world highway driving with an AVF task. While the participant followed and fixated on a pace vehicle, they also attended to LED targets on the windshield at 8, 16, and 24 degrees of eccentricity. Older and younger participants performed a relatively simple
central task (identifying a symbol that appeared on the back of the pace vehicle) while simultaneously detecting peripheral targets, which were presented for 250 ms. In both studies, participants localized targets less accurately when they were located at higher eccentricities, and older participants performed less accurately younger participants. These results are consistent with previous static AVF studies (Sekuler et al., 2000, Ball et al., 1988). This would seem to imply that the presence of global motion in the background does not alter the distribution of spatial attention. However, neither study utilized a control group in which AVF was performed without the background motion. Although performance patterns look similar to standard static AVF, it is difficult to make precise comparisons about how performance in the presence of global motion compares to standard static AVF. It is possible, for instance, that both conditions would show downward accuracy slopes as eccentricity increases – Schieber and Benedetto (1998) and Schieber and Gilland (2005) support that. But how would the slopes compare to one another? Another important distinction to note is that in both cases, the optic flow was present in the background scene (in Schieber and Benedetto, in the driving video projection; in Schieber and Gilland, in the environment outside the car), while the actual stimuli used in the AVF task were static relative to the observer. It is unclear if this has any effect on the detectability of the targets. It is not known whether a target that appears to be moving congruently with the flow of the background motion would be more detectable than a static target within the same flow. The current study investigated how motion affects the distribution of spatial attention when targets and distractors are fully integrated into the background motion, and not simply superimposed on it. I have done this by presenting a collection of targets and distractors that are constantly in motion (dynamic stimuli) across the visual field.
1.5 General hypotheses

Few previous studies have sought to investigate how motion and the arrangement of irrelevant background objects affect the detection and processing of targets in a cluttered scene. We cannot assume that the visual and attentional mechanisms utilized in these contexts are the same as the mechanisms involved in processing stimuli in a static, systematically arranged scene. The presence of motion activates the magnocellular pathway, causing the stimuli to be processed in MT instead of V1. Since MT has lower processing latency than V1, processing of target and distractor stimuli may be faster across the AVF. This may result in overall improvement in target detection and localization accuracy compared to static AVF. An increase in processing speed may mean that attention “spreads” faster to the peripheral boundaries of the AVF. It is also unclear how distractor distribution would affect target processing, as this has not been previously explored. Therefore, in this thesis I will be investigating this by directly comparing localization accuracy with systematic and pseudo-random distractor arrangements, and then directly comparing localization and detection accuracy in both static and dynamic contexts.

First I will establish whether a more random distribution of distractors affects target localization across the AVF. Next, I will investigate whether radially expansive motion affects the distribution of spatial attention. Specifically, I will measure target localization and detection accuracy across the AVF when: (1) target and distractors do not move (static condition), and (2) target and distractors move outward from the centre of the display in a radially expansive manner (dynamic condition). I will not be simulating true optic flow in this study. Radially expansive optic flow consists of stimuli not only flowing outward from the centre, but also accelerating toward the periphery and expanding in size as they do so. For simplicity, I will use radially expansive motion with a constant stimulus size and speed.
I predict that target localization and detection accuracy will be higher overall in the dynamic condition compared to the static condition, especially as eccentricity of the target increases. The motion of the target and distractors may lead to a processing advantage over static stimuli.

2 Experiment 1: Systematic vs. Random Distractor Arrangement

This first experiment established whether the arrangement of the distractors influences detectability of the target. Many previous studies have used a systematic arrangement of stimuli located along three concentric circles (typically 10, 20, and 30 degrees eccentric from centre) and eight radials that corresponded to the cardinal and intercardinal directions (Sekuler et al., 2000; Roenker et al., 2003; Feng, Spence, & Pratt, 2007). A systematic arrangement such as this provides a natural mapping between each radial and a standard keyboard’s number pad, and thus makes it easy for participants to choose the appropriate response. In the real world, however, stimuli are not so neatly arranged. Objects do not snap conveniently to a grid or move along equally spaced radials. Therefore, for added generalizability, it was important to first investigate whether distractor arrangement affects target localization.

In addition to the reasons already mentioned, there may be additional unwanted effects from repeated stimulus arrangements such as priming. Repeated arrangements with preserved spatial relational information could facilitate target detection. It is unclear whether this would apply to AVF, but it has been shown in visual search that repeated distractor configurations (i.e., contextual cuing) reduce reaction times when finding targets (Chun & Jiang, 1998). However, the repeated arrangement of the AVF stimuli is not particularly informative about where the target lies. The only additional information an observer has is that a target is constrained to appearing in one of 24 predefined locations. It is possible that simply knowing these constraints
can assist the observer in where to direct attention. However, it could be argued that the goal in AVF is not about preferentially directing attention to a certain location, but instead trying to encompass as much of the visual field as possible. In terms of Posner et al.’s (1980) spotlight, this would be akin to aiming the spotlight at the centre of the visual field and quickly increasing the brightness to illuminate as much of it as possible. In this case it would not matter how distractors are positioned relative to each other, the target, and the centre of the screen, since they would simply be “visible” as soon as the light hits them. Nevertheless, no one has yet investigated whether distractor arrangement affects the AVF, so any possible effects are currently unknown.

Experiment 1 compared two different types of static AVF arrangements—systematic and random distractor arrangement. For both types of arrangements the target always appeared at one of the predefined radials and eccentricities. To maintain an approximately even coverage of clutter across the screen in the random condition, the distractors were randomly shifted up to half a radial and half an eccentricity from their standard positions. Although this was not a truly random arrangement, none of the relational spatial information among stimuli was preserved. In standard systematic AVF, relational information is preserved (and thus predictable) throughout the task. It is possible that this aids detection by priming attention for these locations. It is possible that stimuli will take longer to process if locations are different (both absolutely and relatively) from trial to trial. It is possible that there will be a difference in accuracy between systematic and random conditions.
2.1 Method

2.1.1 Participants

23 undergraduates (11 women, 12 men; ages 18-30, \( M = 19.45 \) years) from an introductory psychology course at the University of Toronto completed this experiment. They were compensated with course credit. Criteria for participating in this study included having normal or corrected-to-normal vision. Participants with glasses were screened to make sure that they could see the entire display through their lenses.

2.1.2 Materials

Stimuli were presented using MATLAB with Psychtoolbox-3 (Brainard, 1997; Pelli, 1997; Kleiner et al, 2007) on a 20-inch ViewSonic CRT monitor with a resolution of 1280x1024 pixels and an 85 Hz refresh rate. Participants sat 23 cm from the screen and used a chin rest to ensure accurate visual angles. Responses were given via the keyboard. The experiment was conducted in a well-lit room; lighting level was consistent across all sessions.

2.1.3 Stimuli

Each trial consists of a pre-trial and post-trial fixation display, a stimulus display, and a mask. See Table 1 for details. The pre-trial fixation display contained a black fixation cross (width 1.2 degrees) in the centre of the screen. This turned into an unfilled circle (width 2.4 degrees) to signal an impending trial. The stimulus screen consisted of 23 distractors (unfilled black circles, width 2.4 degrees) and 1 target (an unfilled black circle, width 2.4 degrees, which contained a dark grey square, width 1.6 degrees, in the centre). The unfilled centre circle remained present during the stimulus display. The post-trial fixation display consisted of only the pre-trial fixation cross. There were two conditions in the experiment, systematic and random, each taking place in a separate block. In the systematic condition, the distractors and target were arranged
symmetrically along 8 invisible radials and 3 invisible concentric circles at 10, 20, and 30 degrees eccentricity from the centre of the display. In the random condition, the distractors were no longer arranged evenly, but each individual distractor was randomly offset up to 5 degrees of eccentricity (half of a concentric circle) from the centre and up to 22.5 degrees radially (half of a radial). This arrangement was recalculated for every trial, giving each trial its own unique arrangement. The target still appeared along one of the radials at 10, 20, or 30 degrees from the centre (i.e., no offset to coordinates). The target and distractors were always the same size, independent of eccentricity. See Figure 1 for an example of a systematic and a random layout.

<table>
<thead>
<tr>
<th>Item</th>
<th>Size</th>
<th>Colour; (RGB Value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background</td>
<td>82.9 x 67.1 degrees</td>
<td>Grey; [207 207 207]</td>
</tr>
<tr>
<td>Distractor</td>
<td>width 2.4 degrees</td>
<td>Black; [0 0 0]</td>
</tr>
<tr>
<td>Target – outer circle</td>
<td>width 2.4 degrees</td>
<td>Black; [0 0 0]</td>
</tr>
<tr>
<td>– inner square</td>
<td>width 1.6 degrees</td>
<td>Dark grey; [121 121 121]</td>
</tr>
<tr>
<td>Mask lines</td>
<td>length 5 – 60 degrees</td>
<td>Black; [0 0 0]</td>
</tr>
<tr>
<td>Fixation cross</td>
<td>width 1.2 degrees</td>
<td>Black; [0 0 0]</td>
</tr>
<tr>
<td>Centre circle</td>
<td>width 2.4 degrees</td>
<td>Black; [0 0 0]</td>
</tr>
</tbody>
</table>

Table 1. Experiment 1 parameters.
Figure 1. Sample stimulus displays for systematic (A) and random (B) distractor arrangements. One target (black unfilled circle with dark grey inscribed square) and 23 distractors are present in each display. Concentric circles and eccentricity labels are for reference only and do not appear during the task.

2.1.4 Procedure

Participants were first given instructions and 10 practice trials of each condition. They then commenced the experiment, where they performed 240 trials of each block. The target appeared in each of 24 locations 10 times in each block (representing 80 times at each eccentricity level, and 30 times at each radial). There were two blocks, one for each condition. Blocks were counterbalanced across participants (half of the participants performed the systematic block first, and the other half performed the random block first).

Each block began when the participant pressed the space bar. Each trial began with a fixation cross for 1 second followed by an unfilled centre circle for 500 ms. The stimulus display containing the target and distractors was presented for 30 ms, after which the mask was
presented for 200 ms. The post-trial fixation cross appeared until a response was made, or until 6 seconds had elapsed from the beginning of the mask, whichever occurred first. Participants were asked to indicate, using the number pad on the keyboard, the direction of the target relative to the centre. Participants were instructed to be as quick and accurate as possible when making a response. If no response was made after 6 seconds, the next trial began. This was coded as “no response” and excluded from calculations. See Figure 2 for a visualization of this procedure.

There were two breaks built into each block (every 80 trials), allowing the participant to pause for an unlimited amount of time. There was also an opportunity for a break between blocks (after 240 trials). The participant could press the space bar to resume the experiment.

Figure 2. Sequence of displays in Experiment 1. The stimulus screen with target is displayed for 30 ms and followed by a 200 ms mask. Each trial begins and ends with a fixation cross.
2.2 Results

Only one key press was recorded per trial, except in rare instances where participants pressed two keys simultaneously. These trials were excluded from calculations. Trials with a reaction time under 100 ms were also excluded, as it is extremely unlikely that someone would be able to process the stimulus and make a decision in that amount of time.

2.2.1 Accuracy

![Graph of Proportion correct vs Eccentricity](image)

Figure 3. Experiment 1: Accuracy for systematic versus random arrangement of distractors. Error bars represent the standard error of the mean.

Accuracy was calculated by dividing the number of trials where the participant pressed the correct number by the total number of trials (excluding those trials with invalid responses or reaction times, as explained above). A 2 (stimulus condition; static vs. random) x 3 (eccentricity; 10, 20, 30 degrees) repeated-measures ANOVA found a main effect of eccentricity, $F(2,44) = 14.03$, $p<.001$. Neither stimulus arrangement nor the interaction between...
stimulus and eccentricity were significant. Eccentricity showed a trend with significant linear, $F(1,22)=14.75, p=.001$, and quadratic components, $F(1,22)=11.15, p=.003$, indicating that accuracy decreased as eccentricity increased. The nonlinear downward trend is evident in Figure 3.

2.2.2 Reaction Time

![Graph showing reaction time (in ms) for systematic versus random arrangement of distractors. Error bars represent the standard error of the mean.](image)

Figure 4. Experiment 1: Reaction time (in ms) for systematic versus random arrangement of distractors. Error bars represent the standard error of the mean.

A repeated measures ANOVA found a main effect of eccentricity, $F(2,44)=7.47, p=.002$. Neither stimulus arrangement nor the interaction between stimulus and eccentricity were significant. Eccentricity showed a trend with significant linear, $F(1,22)=6.19, p=.021$, and quadratic components, $F(1,22)=9.65, p=.005$, indicating that reaction time increased as eccentricity increased. This upward trend begins at eccentricities greater than 20 degrees, as can be seen in Figure 4.
2.3 Discussion

The main effect of eccentricity with regards to both accuracy and reaction time is consistent with the existing AVF literature. As eccentricity increases, accuracy declines and reaction time generally increases. Reaction time at 10 degrees of eccentricity is not lower than reaction times at 20 or 30 degrees; this may be partly due to the increased difficulty of choosing the correct radial near the centre, since the radials are closer together. In general, however, these results indicate that it takes participants longer to process targets in the peripheral areas of the display and that their detection performance is poorer. The lack of interaction indicates that eccentricity of the target affected accuracy with both distractor arrangements in similar ways. Whether the distractors were arranged systematically in predictable locations or randomly shifted from trial to trial makes no difference in terms of accuracy or reaction time. A repeated, orderly arrangement of distractors does not affect target detection. Experiment 2 used randomly shifted distractors.

3 Experiment 2: Static vs Dynamic Stimuli

Experiment 2 sought to uncover differences that may exist between static and dynamic stimuli. One of the main challenges was creating a dynamic AVF task that mimicked the static task as much as possible. The dynamic task needed to be continuous – that is, targets and distractors would need to be in constant motion, displayed without any trial breaks in between as is traditional in the static stimuli protocols. Introducing “trials” in the dynamic task would also introduce unwanted breaks in the radially expansive motion. For this reason, rather than modifying the dynamic task to meet the conditions of the static task, in Experiment 2 the static AVF task was altered to present stimulus displays continuously, without trial breaks to make it more comparable to the dynamic condition.
This experiment investigated the use of both dynamic and static stimuli in an AVF task while using a random distractor arrangement. A random arrangement was necessary to eliminate target onset predictability. If a systematic arrangement were used, the distractors would repeatedly align to 10, 20, and 30 degrees of eccentricity. The participant might easily deduce that a target could only appear during this alignment. With the random arrangement, the position of the distractors was not informative of when the target might appear. With each stimulus type, the participant was required to either detect (using the space bar) or localize (using the number pad) the target. All tasks presented stimuli continuously -- i.e., without trial divisions or pausing to wait for user input.

In the previous, trial-based setup used in Experiment 1, it was not possible to precisely control the interstimulus intervals, given that the speed of moving from trial to trial was controlled by the participant (capped at 6 seconds). This means that stimulus displays could be anywhere from about 1.5 seconds to more than 6 seconds apart. This discrepancy was eliminated in Experiment 2, and the static and dynamic conditions were matched with respect to target frequency, with targets appearing every 3 or 6 seconds. The distribution of intertarget intervals was randomized to reduce the likelihood of implicit learning.

Two tasks, detection and localization (requiring a single button press and a choice response, respectively), were utilised in Experiment 2. In a trial-based AVF, localization is the typical task choice, as it provides insight into where participants are actually seeing targets. In a detection task, there is only the indication that a participant saw a target somewhere on the display. In an experiment where stimuli are presented continuously, however, localizing targets is a two-step process -- the observer must first detect whether there is a target in that moment, and then evaluate its location. In the static trial-based tasks of Experiment 1, target appearances were
consistent and predictable since they all shared the same onset asynchrony after target initiation, which was controlled by the user. In the static and dynamic conditions of Experiment 2, there is no such assistance from trial divisions. It may be more difficult for an observer to detect a target when they do not know exactly when to anticipate it. Therefore, for the sake of comparison participants were required to perform separate blocks of localization and detection for each stimulus condition (static and dynamic) in Experiment 2.

Below (Table 2) is a chart containing details of each task.

<table>
<thead>
<tr>
<th>Item</th>
<th>Size (height x width)</th>
<th>Colour; [RGB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background - outer</td>
<td>82.9 x 67.1 degrees</td>
<td>light grey; [229 229 229]</td>
</tr>
<tr>
<td>Background - inner</td>
<td>69.4 x 69.4 degrees</td>
<td>medium grey; [207 207 207]</td>
</tr>
<tr>
<td>Distractors</td>
<td>2.4 x 2.4 degrees</td>
<td>light grey; [229 229 229]</td>
</tr>
<tr>
<td>Target</td>
<td>2.4 x 2.4 degrees</td>
<td>dark grey; [121 121 121]</td>
</tr>
<tr>
<td>Fixation cross</td>
<td>1.6 x 1.6 degrees</td>
<td>black; [0 0 0]</td>
</tr>
<tr>
<td>Mask (static only)</td>
<td>2.4 x 2.4 degrees</td>
<td>dark grey; [121 121 121]</td>
</tr>
</tbody>
</table>

Table 2. Parameters for all four blocks of Experiment 2.

Both blocks featured a central circular area (“central background” in Table 2 below) of a different shade than the background that extended 35 degrees from the centre of the screen. All stimuli were presented in this circular area. This area was constructed to help eliminate any after images in the dynamic condition that would have resulted from a light distractor disappearing on
a darker background. Since the background colour beyond the circular area was the same colour as the distractors, this allowed the distractors to disappear gracefully into it.

Figure 5. A: A sample display (with target) from the static condition, or a single frame from the dynamic condition. B: A sample mask from the static condition.

3.1.1 Method

3.1.1.1 Participants

27 younger adults (18 women, 9 men; ages 18-29, $M = 22.4$ years) participated for course credit or chocolate bars. Three participants (2 women, 1 man) out of the 27 were excluded from analyses because they completed only 1 out of 2 sessions of the experiment (i.e., they did not return to the lab for the second session). Criteria for participating in this study included having normal or corrected-to-normal vision. Participants with glasses were screened to make sure that they could see the entire display through their lenses.
3.1.1.2 Materials

The experiment was presented using Psychtoolbox-3 (Brainard, 1997; Pelli, 1997; Kleiner et al, 2007) implemented in MATLAB. Stimuli were displayed on a 20 inch ViewSonic CRT monitor with a resolution of 1280x1024 pixels and an 85 Hz refresh rate. A chin rest, adjusted for each individual, was used to ensure accurate visual angles. Participants sat 23 cm from the monitor. Testing was conducted in a well-lit room; lighting level was consistent across all sessions.

3.1.1.3 Stimuli

All combinations of stimulus type (static vs. dynamic) and task type (detection vs. localization) were included in this study, resulting in four separate blocks: 1) static-detection, 2) static-localization, 3) dynamic-detection, and 4) dynamic-localization. 240 targets were presented in each block.

Stimuli were presented continuously in the dynamic blocks. At the beginning of each block, a random arrangement of light grey distractor circles filled the screen and began to move outward toward the periphery. When a distractor reached the edge of the background circle, it disappeared and a new distractor was recalculated and generated near the centre of the screen. Distractors flowed outward along straight paths toward the periphery at a constant speed of 0.74 degrees per second. The directions of the distractor paths were chosen semi-randomly, offset from the radials as in Experiment 1. When a new target was generated, a distractor appeared near the centre and instead flowed outward on a path aligned to one of the eight cardinal and inter-cardinal directions. At 10, 20, or 30 degrees, the distractor became a target, turning dark grey for 30 ms. Subsequently, the target became a distractor again, flowing outward until disappearing at the border of the background circle. A new path was selected and a new
distractor was generated at a distance of 2.5 degrees from the centre to replace the distractor that had just left the display. A fixation cross remained visible throughout the task.

The static blocks presented static displays of distractors and/or targets continuously at a fixed interval (1 display per second). Most displays contained 24 light grey distractor circles. The target displays (occurring either 3 or 6 seconds apart) contained 23 distractors and 1 dark grey target. The target appeared in one of 24 possible locations, at the intersections of the imaginary radials and eccentricity circles. A mask appeared after each distractor and/or target display. The mask consisted of 24 dark grey pound symbols (#) of the same size as the stimulus circles centred at the exact locations of each stimulus circle. A fixation cross remained visible throughout the task.

### 3.1.1.4 Procedure

Each participant performed four blocks in total, one for each of the condition-task combinations. Blocks were counterbalanced across participants: participants were divided into 8 different orders with 3 participants per order. The orders were designed such that each participant performed both conditions and both tasks in each session (for instance, static/detection and dynamic/localization for the first session, then dynamic/detection and static/localization for the second session). If a participant dropped out of the experiment, they were replaced by a new participant who performed tasks in the same order. The experiment took place over two 1-hour sessions conducted on different days ($M = 14.4$ days apart) to minimize fatigue. See Table 3 below for details about the counterbalancing orders.

<table>
<thead>
<tr>
<th>Session 1</th>
<th>Session 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static/detect</td>
<td>Dynamic/localize</td>
</tr>
<tr>
<td></td>
<td>Static/localize</td>
</tr>
<tr>
<td></td>
<td>Dynamic/detect</td>
</tr>
</tbody>
</table>
Table 3. Counterbalancing orders. The first two blocks were completed in the first session, and the rest were completed in the second session. There was a gap between sessions.

Participants performed 10 practice trials before starting each block. There was one break in each dynamic block and there were two breaks in each static block. The additional break was given in the static blocks because pilot participants had indicated that the static blocks felt much more tiring on the eyes than the dynamic blocks (which some participants actually reported as “soothing”).

The static blocks began with a space bar press. The fixation cross appeared in the centre of the screen for 500 ms. A stimulus display (24 distractors or 23 distractors/1 target) appeared for 30 ms. The mask then replaced the stimulus display, lasting 200 ms. The fixation cross then appeared alone in the centre of the screen until the next stimulus display. Stimulus displays were presented at a rate of one display per second.
Figure 6. Sequence of displays in Experiment 2, static condition. The stimulus screen, which may or may not contain a target, is displayed for 30 ms and followed by a 200 ms mask. Each set of displays begins and ends with a fixation cross.

The dynamic blocks also began with a space bar press. The fixation cross appeared in the centre, and distractors began flowing outward from the centre. Every 3 or 6 seconds a distractor became dark grey for 30 ms (becoming a target).

The detection task required participants to press the space bar as soon as they detected a target. Reaction time was calculated for every response that immediately followed a target. If the reaction time was less than 100 ms or greater than 2.5 SD from the participant’s mean reaction time at that specific target’s eccentricity, the response was counted as a false alarm. An abnormally slow reaction time may indicate that the participant was not responding to the preceding target, but something else entirely; this particular cutoff (2.5 SD above the mean) was
chosen because it is a common threshold used for determining outliers. If a response immediately followed another response, that was also counted as a false alarm. Targets were counted as missed if they were followed by another target, or if the reaction time was invalid (as explained above). The localization task required participants to indicate the direction of the target relative to the centre using the number pad as soon as they saw a target. Both static and dynamic blocks were continuous, and did not pause to wait for user input. Responses could be made at any time.

3.1.2 Results

Two participants were removed from analyses due to extremely low accuracy (2.5 SD below the mean) in at least 2 blocks, extremely high reaction times (2.5 SD above the mean) in at least 3 blocks, and a very large proportion of false alarms (2.5 SD above the mean) in all 4 blocks. One of these participants had up to 85% false alarms in one block, 7.5% correct localization in another, and an average reaction time of up to 2.19 seconds. The other participant had up to 65% false alarms, 2.1% correct localization in one block, and an average reaction time of up to 1.73 seconds. Taken together, extremely high values such as this cast serious doubts that these participants were able to successfully detect any targets. Removal of these participants did not greatly affect statistical conclusions.
3.1.2.1 Accuracy

![Figure 7](image)

**Figure 7.** Detection (left) and localization (right) accuracy for static and dynamic conditions. Error bars represent the standard error of the mean.

Accuracy was measured by the proportion of targets that were correctly localized or detected in a given block. A correct localization was a response where the direction indicated matched the direction of the target, with the restriction that reaction time was >100 ms. A correct detection was a response that occurred after a target appearance, with the restriction that reaction time was >100 ms and <2.5 SD above the mean for that participant at the target’s eccentricity. Reaction times outside of the specified bounds suggested that the response was likely to be a false alarm (i.e. unrelated to the previous target), thus the preceding target was considered “missed.”

A 2 (stimulus condition; static vs. dynamic) x 2 (task type; detection vs. localization) x 3 (eccentricity; 10, 20, 30) repeated-measures ANOVA for proportion of targets that were correctly detected or localized was conducted in SPSS. There were significant main effects of stimulus condition, $F(1,21)=18.01, p<.001$, and eccentricity, $F(2,42)=43.52, p<.001$. There were significant two-way interactions between task and eccentricity, $F(2,42)=18.10, p<.001$, and between stimulus and eccentricity $F(2,42)=21.74, p<.001$. The three-way interaction was
significant, $F(2,42)=6.29, p=.004$. The main effect of task and the two-way interaction between task and stimulus type were not significant.

An analysis of simple effects showed that eccentricity was significant for static detection, $F(2,42)=55.00, p<.001$, and static localization, $F(2,42)=27.14, p<.001$; for the dynamic condition eccentricity was significant only in the detection task, $F(2,42)=5.07, p=.01$. Thus, accuracy did not differ among eccentricity levels in the dynamic/localization block. The trend for static detection had significant linear, $F(1,21)=68.59, p<.001$, and quadratic components, $F(1,21)=14.84, p=.001$. The trend for static localization had significant linear, $F(1,21)=19.67, p<.001$, and quadratic components, $F(1,21)=51.50, p<.001$. Dynamic detection had significant linear, $F(1,21)=4.48, p=.046$, and quadratic components, $F(1,21)=6.98, p=.015$, but it is clear that accuracy in this block declined much more slowly than in either static block.

Six pairwise comparisons were made to determine at which eccentricities static and dynamic accuracy differed. The alpha level for each comparison was set to .008 to maintain a familywise alpha of .05. For detection, static and dynamic accuracy differed at 20 degrees, $p=.006$, and at 30 degrees, $p<.001$. For localization, static and dynamic accuracy differed only at 30 degrees, $p=.002$.

An analysis of sequence effects indicated no difference in accuracy between blocks, $p>.1$.

3.1.2.1.1 False Alarms

The total number of false alarms varied with each task and condition. See Figure 7 below. A false alarm was defined as a key press that did not correspond to a target, i.e. a key press that immediately followed another key press, or a key press with a reaction time less than 100ms or greater than the specified cutoff (2.5 SD above the mean for that individual at the eccentricity of
the preceding target). The proportion of false alarms for each individual/block was calculated by dividing the number of false alarms by the number of total responses.

Due to the differing nature of the detection task versus the localization task, false alarm criteria were slightly different as well. In the detection task, false alarms were responses that were made when no target was present, or response times that were too short (<100 ms) or too long (>2.5 SD above the mean for that participant at that eccentricity). In the localization task, false alarms were responses that were made when no target was present, or response times that were too short (<100 ms). Response times that were too long (>2.5 SD above the mean) were not taken into consideration because the localization task provided a measure of target detection that the detection task did not: a numeric response corresponding to the direction where the target appeared. This additional piece of information helps to match targets with intended responses. Perhaps more importantly is that localization took longer than detection, and reaction times were more variable (depending on the time needed to move a finger to a particular key), so implementing a cutoff may not have been as informative. Overall, the proportion of responses in the detection task that were counted as false alarms due to the >2.5 SD criterion was about 6.4% of the total number of responses.
Figure 8. Proportion of all responses that were false alarms in each task/condition of Experiment 2. Error bars represent the standard error of the mean.

Overall, the proportion of total responses that were false alarms was higher in the detection task. It is possible that participants were more likely to respond in the detection task, even in cases of uncertainty. A 2 (task; detection vs. localization) x 2 (stimulus; dynamic vs. static) ANOVA revealed a significant main effect of task, F(1,21) = 47.94, p<.001, and a significant interaction, F(1,21)=6.01, p=.023.
3.1.2.2 Reaction Time

![Graph showing reaction times for detection and localization tasks.](image)

Figure 9. Left: mean reaction times for localization task. Right: mean reaction times for detection task. Error bars represent the standard error of the mean.

Reaction times under 100 ms (detection and localization) and greater than 2.5 SD above the mean for that participant at the preceding target’s eccentricity (detection only) were excluded from reaction time analyses, due to those responses being flagged as likely false alarms. These reaction times were considered invalid.

A 2x2x3 repeated-measures ANOVA on valid reaction times was conducted in SPSS. There were significant main effects of stimulus condition (dynamic vs. static), F(1,21)=7.65, p=.012, and task type (detection vs. localization), F(1,21)=212.38, p<.001. The interaction of task and eccentricity was significant, F(2,42)=8.66, p=.001. The three-way interaction was significant, F(2,42) = 4.29, p =.020. The main effect of eccentricity and interactions between task and stimulus and stimulus and eccentricity were not significant.

Six pairwise comparisons were made to determine at which eccentricities static and dynamic accuracy differed. The alpha level for each comparison was set to .008 to maintain a familywise alpha of .05. For detection, static and dynamic accuracy differed at 20 degrees, p=.004, and at
30 degrees, \( p=.001 \). For localization, static and dynamic accuracy did not differ at any eccentricity. See Figure 8. These results suggest that reaction time was mainly affected by task type (localization vs. detection) and stimulus condition (static vs. dynamic), although the amount that stimulus condition affected reaction time depended on task. Eccentricity affected reaction time only in the detection task, and only at 20 degrees and above.

An analysis of sequence effects indicated no difference in reaction time between blocks, \( p>.1 \).

3.1.3 Discussion

In terms of accuracy, neither static nor dynamic conditions differed as a function of task type. This suggests that the nature of the task (localization or detection) did not affect participants’ ability to correctly perceive targets across the visual field. For both tasks, accuracy was lower overall in the static condition, especially at higher eccentricities. Accuracy in the dynamic condition remained high at all eccentricities, but dropped substantially in the static condition as eccentricity increased. This suggests that the radially expansive motion of the stimuli in the dynamic condition led to improved accuracy in general, especially near the peripheral areas of the display. This indicates that the target was more salient in the dynamic condition compared to the static condition; this may be due to the target’s motion. As the target moves along its path, it partially occludes itself. This may cause the target to appear somewhat elongated -- the target (2.4 x 2.4 degrees) travels .02 degrees from onset to offset, which may give the impression that the size in one dimension has increased slightly. This may have attracted attention more strongly than a static target (that does not self-occlude).

Overall accuracy in the static condition was higher in the localization task than in the detection task. It is not immediately clear why this is, as one would expect higher accuracy in the simpler
(i.e. detection) task. This is not due to the detectability of the target, as that should be equivalent regardless of the task being performed.

The proportion of responses that were false alarms was higher overall in the detection task versus the localization task. This suggests that participants had a more liberal response bias when they only had to detect targets and not identify their location – that is, they were more likely to respond in general. The number of false alarms dropped when participants were also required to localize the target. There is no obvious reason that participants should choose to be more conservative with their response (i.e., there are no negative consequences); however, when participants were less sure of whether they saw a target, they may have been less inclined to respond when they were also required to choose a direction. In the detection task, every time a participant thought they saw a target (regardless of whether there was one), they hit the space bar; in the localization task, they may have been more hesitant to respond if they weren’t sure where it was located.

The proportion of false alarms was highest in the dynamic/detection combination. Taken alone, this could be seen as a contributing factor to higher accuracy, and might suggest that accuracy (number of hits) was higher in the dynamic condition not because of greater target salience, but merely due to an increased number of responses. However, accuracy is still higher in localization for the dynamic condition versus the static condition, when the number of false alarms for the dynamic condition has dropped substantially (and is, in fact, even lower than in the static condition). This helps to rule out the possibility that the higher accuracy in the dynamic condition is due to an increased number of responses.

In terms of reaction time, significant differences were observed as a function of task type, stimulus condition, and eccentricity. For localization, reaction time did not differ by stimulus
condition or eccentricity. In the detection task, stimulus condition was an important factor for determining reaction time. Reaction times were similar across all eccentricities in the dynamic condition, but were higher overall in the static condition. It is likely that we could not see this trend in the localization task due to the overhead associated with choosing a number key versus pressing the space bar. In some cases, choosing a number key led to an average increase in reaction time of over 300ms. This is not unusual given the increased complexity of making a choice among several possible keys. However, there is no such convenient explanation for why static and dynamic conditions should differ when this overhead is removed. Pressing the space bar each time a target is seen is a quick, intuitive response. Since this took longer in the static condition, it suggests that targets were more easily detectable in the dynamic condition. Taken together with the differences in accuracy, this suggests that the distractor and target motion in the dynamic condition facilitated visual processing of targets.

The major difference between static and dynamic conditions, apart from the motion of the distractors, is that in the dynamic condition the target was also moving. This is also different from previous studies that have combined AVF and motion (Schieber & Gilland, 2005; Schieber & Benedetto, 1997), where the target was static. In the current study’s Experiment 2, the target travelled .02 degrees in the 30 ms that it appeared on screen. Motion alone is not a powerful attractor of attention when it is not task relevant (Hillstrom & Yantis, 1994) – and in the case of the dynamic condition of Experiment 2, since all stimuli are in motion, motion of the target is not task relevant. Target motion could be more salient if it were somehow incongruent with the surrounding global motion. Humans can detect objects moving in an optic flow field that deviate in speed (Royden & Moore, 2012) or angle (Royden & Connors, 2010) compared to the rest of the flow field. The detection advantage for angle deviation increases with eccentricity (although Royden & Connors [2010] suggest that it may be the higher speed of the flow that is responsible
for increased detectability of the target). However, this does not provide information about the detectability of targets that move congruently with the surrounding motion in terms of both speed and direction. Reduced reaction times in the dynamic/detection versus the static/detection block suggest that the moving target in the dynamic condition is more salient than the non-moving target in the static condition.

3.1.4 Limitations

It should be noted that what was implemented in Experiment 2 is not optic flow as it would typically occur in the natural world. The speed of the stimuli was constant; in the real world, when there is forward self-motion stimuli accelerate toward the edges of the field of view. Velocity of the flow field is slower at the centre and much more rapid in the periphery. Experiment 2 used a constant speed to establish whether the presence of radially expansive motion affects spatial attention, since no study to date has investigated this. Schieber and Benedetto (1998) and Schieber and Gilland (2005) took the first steps by investigating whether the presence of optic flow in the background affects AVF performance. However, their stimuli were static and superimposed on the flow field, instead of integrated into it. The results of my study stand in contrast to their findings, indicating that radially expansive motion does indeed have an impact on AVF. Radially expansive motion appears to lead to a more gradual decline of target detection and localization accuracy as eccentricity increases compared to static AVF. This suggests that radially expansive optic flow would have a similar effect.

Though there were clear differences between static and dynamic conditions, both in accuracy and reaction time, it is possible that these were caused by something other than radially expansive motion. The major difficulty in this set of experiments was creating tasks that were equivalent on all dimensions. Static and dynamic conditions were designed to parallel each other
as closely as possible, sharing the same appearance, target frequency, response method, and structure; however, there will always be differences that are difficult to eliminate. One major difference is the mask that was present only in the static condition. The mask (# over each stimulus) was used to halt visual processing of stimuli after their appearance. Using the same mask as in the static condition would have meant using a static mask; this would have interrupted the motion. An alternative might have been to use a mask that continues to move along the same path as the target. However, little (if anything) is known about the impact that this sort of mask would have on visual processing. The dynamic task does not use a mask in the traditional sense; instead, each stimulus occludes itself as it moves across the display. In this way, a target, at offset, becomes masked by a new distractor.

The type of mask used can have a profound influence on detectability of targets; some masks can disrupt processing to the point of rendering the preceding stimulus “invisible” (see Kim & Blake, 2005). It is possible that the mask in the static condition is more disruptive of processing than the implicit masking in the dynamic condition, rendering the task more difficult – it is possible that this is the reason for lower overall accuracy in the static condition. However, this does not account for difference in accuracy slopes.

Additionally, there are two changes in target luminance that occurred in the dynamic condition that did not occur in the static condition. When attention is broadly distributed, such as in an AVF task, abrupt changes in luminance can capture attention (Theeuwes, 1991). In both the static and dynamic conditions of Experiment 2, the target has different luminance than the distractors. However, only the dynamic condition contains changes in luminance – once at target onset, and once at offset. The differences in accuracy between the static and dynamic conditions
could be due to the motion of the target and distractors, but it is possible that it is the changes in luminance that lead to increased detectability of the target.

In order to confirm that radially expansive motion, not changes in target luminance, caused the differences between static and dynamic stimuli, a follow-up experiment could be conducted in which a 30 ms “snapshot” of the dynamic condition is presented to the observer. This segment would begin by displaying the 23 distractors and 1 target; the distractors and target would travel at a constant speed toward the periphery for 30 ms, after which entire display would be masked. This would be contrasted with a fairly standard static AVF procedure, as outlined in the experiments above. This would eliminate changes in target luminance, which could rule this out as a possible explanation for the results of Experiment 2.

4 Conclusion

This study aimed to extend knowledge about the AVF under conditions that are relevant to the real world and have not yet been fully investigated. In the standard AVF paradigm, target and distractor stimuli are arranged in a systematic, predictable fashion, where spatial relational information among distractors is preserved. Experiment 1 established that a random distractor arrangement does not affect the AVF differently than a systematic arrangement. The random distractor arrangement was then applied in Experiment 2 to investigate the effects of target and distractor motion. Accuracy of target localization and detection was higher and did not decline with eccentricity as much in the dynamic condition compared to the static condition. The static condition showed a sharper decline at higher eccentricities than the dynamic condition. This suggests that radially expansive motion facilitates detection of peripheral targets, perhaps by helping to deploy spatial attention more quickly to the peripheral regions. This idea is reinforced by the faster reaction times in the dynamic condition of the detection task. This conclusion
supports the initial hypothesis that target and distractor motion may lead to improved detectability of targets among clutter across the visual field. This effect is more pronounced at higher eccentricities.

The absence of a sharp decline in accuracy as eccentricity increases in the dynamic condition may support the idea that the magnocellular stream is involved. Static stimuli are first processed in the parvocellular layers of the LGN and sent to the relatively slow V1 to be processed further. Moving stimuli are processed via the faster magnocellular stream, sometimes skipping V1 and instead going to MT. This may be a reason why the reaction times are lower in the dynamic/detection block compared to the static/detection block. This higher response speed, coupled with increased accuracy relative to the static condition, seems to indicate that visual stimuli are being processed more quickly across the visual field. Routing through the magnocellular stream may result in only a small speed boost, but this can still make a difference when many stimuli across the visual field are vying for their turn to be processed. Faster throughput could result in less congestion and ultimately more processing efficiency. This could very plausibly impact one’s ability to process stimuli at higher eccentricities and result in improvements in target detection (at least to some extent) in those regions.

It was mentioned that the radial expansion used in this study is not true optic flow, as stimuli maintain a constant speed from the centre to the edges of the display. Optic flow would instead accelerate toward the periphery, with the highest speeds found immediately adjacent to the edges of the display. Speed would increase nonlinearly with eccentricity. This increase in speed near the periphery could result in even higher detection accuracy in those regions compared to constant motion and static AVF. Royden & Connors (2010) indicate that observers are more sensitive to discrepancies in target angle occurring in the periphery in this context; it is possible
that this would generalize to changes in other target properties, such as luminance, though this remains to be investigated. The next step would be to apply positive acceleration, and then size scaling to the existing set of dynamic stimuli. Stimuli would need to accelerate and expand in size as they move toward the periphery if they were to mimic the conditions of true optic flow. Increasing stimulus size could lead to an additional boost to detection in the more peripheral regions. Future studies should continue to investigate along these lines.

Incorporating a pseudo-random stimulus arrangement and target and distractor motion into an AVF task was an important step in investigating spatial attention in a more realistic context. Previous knowledge of the AVF focused on a static, systematically arranged context; although I have established that distractor arrangement does not have an impact on the distribution of attention, generalization of static AVF findings is still limited to other static contexts such as standing, sitting, and looking at non-moving objects. One could argue that this provides limited insight into how spatial attention is normally deployed, in part because humans are often in motion. Understanding how humans distribute spatial attention in a dynamic context is critical for understanding how visual processing is affected by self-motion (e.g. walking or driving) or any other activity that causes global motion of the visual environment. Distractor and target motion are important factors in increasing the detectability of targets among clutter.
References


