

The role of presentation method and depth singletons in visual search for objects moving in depth

Nonie J. Finlayson

School of Psychology, The University of Queensland,
St. Lucia, Queensland, Australia



Roger W. Remington

School of Psychology, The University of Queensland,
St. Lucia, Queensland, Australia



Philip M. Grove

School of Psychology, The University of Queensland,
St. Lucia, Queensland, Australia



Are objects moving in depth searched for efficiently? Previous studies have reported conflicting results, with some finding efficient search for only approaching motion (Franconeri & Simons, 2003), and others reporting that both approaching and receding motion are found more efficiently than static targets (Skarratt, Cole, & Gellatly, 2009). This may be due to presentation protocol differences and a confounding variable. We systematically tested the effect of the motion-in-depth presentation method and the effect of a confounding unique depth singleton on search performance. Simulating motion in depth using size scaling, changing binocular disparity, or a calibrated combination of these two depth cues, we found that search performance was affected by presentation method and that a combination of size scaling and changing disparity gives rise to the most compelling motion-in-depth perception. Exploiting this finding in [Experiment 2](#), we found that removing the depth singleton does not affect motion-in-depth search performance. Overall, we found that search is more efficient for targets moving in depth than static targets. Approaching and receding motion had an equal advantage over static targets in target selection, shown through shallower search slopes. However, approaching motion had lower intercepts, consistent with an advantage over receding motion in later stages of processing associated with target identification and response.

Keywords: visual search, visual attention, motion in depth, depth perception, looming

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Introduction

Attention is the ability to concentrate our limited perceptual and cognitive resources on pertinent aspects of the available perceptual data. Because the world is not predictable we must coordinate our voluntary control of attention in pursuit of task goals with involuntary control by events in the world that could signal danger or otherwise be of interest. From an evolutionary perspective, it makes sense that physical cues in the world associated with potential threats should be preferentially detected and attended. This line of reasoning underlies the *behavioral urgency hypothesis* (Franconeri & Simons, 2003), which claims that stimuli moving toward us in depth would be expected to capture attention, whereas stimuli moving away from us would not. This follows since approaching stimuli pose a potential threat that may require rapid action in contrast to receding stimuli, which do not.

If a stimulus property, such as approaching motion, is preferentially attended, then objects with that attribute should be found more quickly than other items in a cluttered display. Specifically, response times to approaching stimuli should be particularly rapid and search for them efficient, such that search times should be relatively unaffected by increasing numbers of distractors (set size). For example, Yantis and Jonides (1984) showed that a salient abruptly-onset stimulus embedded in an array of distractors was identified faster than a non-onset stimulus and that the response time did not vary as a function of set size, whereas the reaction time to find the non-onset target increased as the set size increased. Other claims of efficient search have been made for motion (Franconeri & Simons, 2003) and highly salient colors (Folk, Remington, & Johnston, 1992; Theeuwes, 1991, 1992). These and other findings are primarily based on experiments conducted on two-dimensional displays. However, humans function in a three-dimensional (3D) environment and despite the obvious importance of 3D

perception in this context, few studies have examined the influence of 3D properties on attention, particularly with motion in depth.

One such study was conducted by Franconeri and Simons (2003), who tested their behavioral urgency hypothesis using an *irrelevant feature search task* where participants were presented with an array of placeholders, one of which appeared to move in depth, signaled by changing size, approaching or receding from the observer. At the end of the motion in depth, the placeholders turned into static letters for a visual search task. Despite being nonpredictive of the target location, they found shorter latencies to detect approaching compared to receding targets, as well as shallower search slopes (response time increases over set size increases) compared to static targets for approaching but not receding targets. They inferred from this that approaching motion captured attention but receding motion did not (see also Muhlenen & Lleras, 2007).

However, Abrams and Christ (2005) suggested that the monocular depth cue of size scaling that Franconeri and Simons (2003) used to simulate motion in depth was insufficient for the perception of motion in depth. They speculated that participants in Franconeri and Simons' (2003) experiment attributed the size scaling to changes in size rather than changes in depth. Abrams and Christ (2005) used changing binocular disparity in combination with size scaling to simulate motion-in-depth search items in the same irrelevant feature search task. They only tested receding motion to determine if they could find efficient search for receding motion in order to match that previously shown for approaching motion. They found facilitated search for receding targets as evidenced by shallower search slopes compared to static targets and concluded that receding motion can capture attention. Skarratt, Cole, and Gellatly (2009) came to a similar conclusion investigating approaching and receding motion, finding similar response times for each motion.

The studies reviewed above demonstrate a lack of consensus about the search efficiency for motion in depth. One major inconsistency among these studies is how they simulated motion in depth. Studies that find efficient search only for approaching motion have used monocular depth cues such as size scaling (Franconeri & Simons, 2003) or optic flow (Muhlenen & Lleras, 2007). On the other hand, studies that find efficient search for both approaching and receding motion employed a combination of monocular and binocular depth cues, size scaling, and changing disparity (Abrams & Christ, 2005; Skarratt et al., 2009). It is important to our understanding of motion in depth that we resolve the methodological differences between studies in constructing motion in depth that could be responsible for the conflicting empirical results. In

order to determine if stimulus presentation methods are responsible for the lack of consensus in the studies reviewed above, we first explored how different presentation protocols affect search efficiency by systematically manipulating size scaling, changing disparity, and the combination of these cues to simulate motion in depth (**Experiment 1**). We next exploited these findings to investigate visual search performance as a function of target motion in depth while controlling for a potential confound contained in **Experiment 1** as well as in previous studies (**Experiment 2**).

Experiment 1

Our goal in **Experiment 1** was to determine if the manner of simulating motion in depth was responsible for the empirical discrepancies in search efficiency. Using the irrelevant feature search task (Abrams & Christ, 2005; Franconeri & Simons, 2003), **Experiment 1** explored the effect on search efficiency results of motion in depth as simulated by size scaling, changing binocular disparity with no size scaling, and the combination of size scaling and changing disparity. We predicted that the method of motion-in-depth simulation would show different search results for each depth cue condition. In addition, we asked participants to rate their impression of motion in depth for each of the presentation methods.

Method

Participants

Eight male and 10 female undergraduates were recruited from the first-year participant pool at the University of Queensland, Australia. Stereoscopic acuity was measured using the Titmus stereo test (Stereo Optical Co., Chicago, IL), and all had acuities of 30 arc s or less. All received course credit in return for participation and were naïve to the purpose of the experiment.

Stimuli and apparatus

Stimuli were drawn and scripted using Psychophysics Toolbox (Pelli, 1997) for Matlab (The MathWorks, Natick, MA) and presented on two 24" Macintosh Cinema displays (1680 × 1050 pixels) in a mirror stereoscope. The two monitors faced each other with mirrors set between and reflecting an image from each monitor to each eye. The viewing distance was 60 cm, and one pixel subtended 1.5' (arc min).

The stimuli were presented on a black background with a white fixation point (6' radius) at the centre of

the display. Three or six white figure-eight placeholders were arranged on an imaginary circle with a radius of 5° centered at fixation. For set size three, elements were positioned around the circle at 0° (directly above fixation), 120°, and 240°. For set size six, elements were positioned at 0°, 60°, 120°, 180°, 240°, and 300°.

The stimuli could be presented in one of three apparent depth planes: zero disparity, the plane of the monitors and fixation; a nearer depth plane simulated 5 cm nearer than the display; and a farther depth plane simulated 5 cm beyond the display. Depth was simulated in one of three ways: size scaling, changing disparity, or a combination of the two. Items on the middle plane were always 3° × 1.5° wide, and at zero disparity (0′).

In the size scaling condition, items were scaled in size to simulate depth. Items in the back plane were 2.7° × 1.4°, and in the front plane 3.3° × 1.6°. Motion in depth was simulated by increasing or decreasing the size for approaching and receding motion respectively, scaling size 0.05° × 0.0167° on each frame over six frames (each frame lasting 33.3 ms). Our linear method of size scaling deviates from veridical values, though these deviations are negligible (max deviation 0.47 arc min, or 0.28%). For changing disparity, the binocular disparity of the stimuli was changed with size held constant. Stimuli were horizontally shifted in opposite directions in each eye; for items in the back plane, the image was horizontally displaced right in the right eye and left in the left eye by 15′ each (30′ total). This was reversed for items in the front plane. Motion in depth was simulated by moving the item in horizontally opposite directions in each eye back to zero disparity, reducing disparity in each eye by 5′ on each frame over six frames (each frame lasting 33.3 ms). The combination depth cue condition directly mapped the size scaling and binocular disparity conditions onto each other. Items were simulated in depth using the size and disparity values previously described, as was the motion in depth.

The size changes and changing binocular disparity were carefully calibrated to be consistent with real depth changes of ±5 cm, using the size distance relation (S. E. Palmer, 1999), which describes how change in distance (real or perceived) of an object leads to changes in the calculated size. The details of these calibrations between size and disparity were not reported in the previous studies (Abrams & Christ, 2005; Skarratt et al., 2009).

Procedure and design

Figure 1 shows the trial sequence. On a given trial, the placeholders were displayed at zero disparity, with one placeholder displaced in depth in front or behind the others for 1000 ms. Next, the placeholder in depth

moved in depth to zero disparity over 200 ms. Once the placeholder reached zero disparity, segments of all the placeholders were removed to reveal letters. One letter was the target (either S or E) while others were distractors (randomly selected from H, U, L, F, or P). The search task was displayed until a response was made, at which point the fixation dot turned green if correct or red if incorrect. Additionally, a tone sounded if the response was incorrect. The target motion type was described in terms of the motion of the placeholder that coincided with the position of the search target letter—approaching, receding, or static.

Participants completed 648 trials in total, blocked across depth cue, with rests halfway through and between each block. Presentation order of the depth cue conditions was randomized, and set size and target motion type were randomized within each block. One third of the trials in each block were set size three and the remaining two thirds of trials were set size six. Each set size contained half approaching/receding placeholder trials, with the target equally likely “S” or “E,” transformed from the moving placeholder on $p = 1/n$. In this way the moving element was equally likely to be the target as any other element within the display, not predictive of the target position.

Participants were queried after every 108 trials on the quality of the simulated depth. During rest periods participants verbally rated the quality of the depth, being asked: “On a scale of 1 to 5, how much depth can you perceive in this display, 1 being all items look like they’re at the same depth, and 5 being there is definitely a depth difference between the depth planes?” Ratings for each depth cue condition were averaged to create a total score out of 5.

Results

Error trials and trials with response times greater than two standard deviations above the overall mean for each subject were removed, resulting in a removal of 4.7% of all responses from the analysis. Data from one participant were removed due to a mean response time greater than two standard deviations above the group mean. Accuracy was above 90% for each of the 17 remaining participants, with a mean of 97.6%. Mean response time to static targets did not differ as a function of the approaching and receding motion of nontarget items ($t[1, 14] = -0.02, p = 0.981$). Therefore, subsequent analyses collapse the two static conditions across approaching and receding motion.

Mean response times are shown in Figure 2. As seen in the graph, the response times vary across motion type and depth cue condition. A repeated-measures ANOVA with factors of set size (3, 6), target motion type (approaching, receding, and static), and depth cue

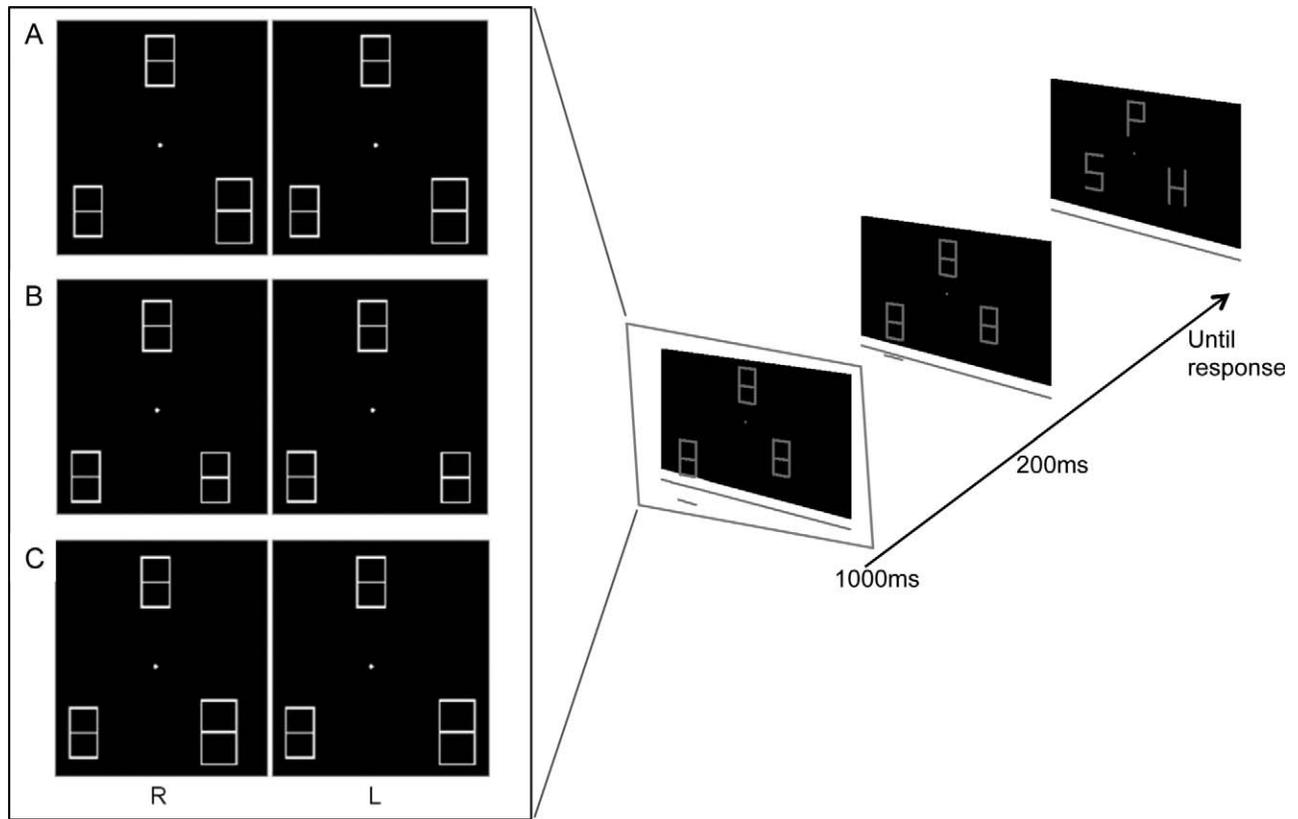


Figure 1. Experimental stimuli and sequence of a trial during Experiment 1. The inset shows a stereogram of the stimuli (for crossed fusion), where one randomly selected placeholder was seen as in front (or behind) of the others by means of (A) size scaling, (B) changing binocular disparity, and (C) a combination of both these depth cues. In the sequence, the unique placeholder then appeared to recede (or approach) until it was at the same depth as the other elements, at which time the placeholders turned into letters for the search task. See main text for additional details.

(size scaling, changing disparity, and a combination) found significant main effects of set size ($F[1, 16] = 65.53, p < 0.001, \eta^2 = 0.80$) and target motion type ($F[2, 32] = 16.07, p < 0.001, \eta^2 = 0.50$), as well as a significant two-way interaction between depth cue and target

motion type ($F[2, 32] = 2.97, p = 0.036, \eta^2 = 0.16$). This two-way interaction was followed up with three ANOVAs, one for each level of depth cue (size scaling, changing disparity, and the combination) and a Bonferroni correction for three comparisons each ($\alpha =$

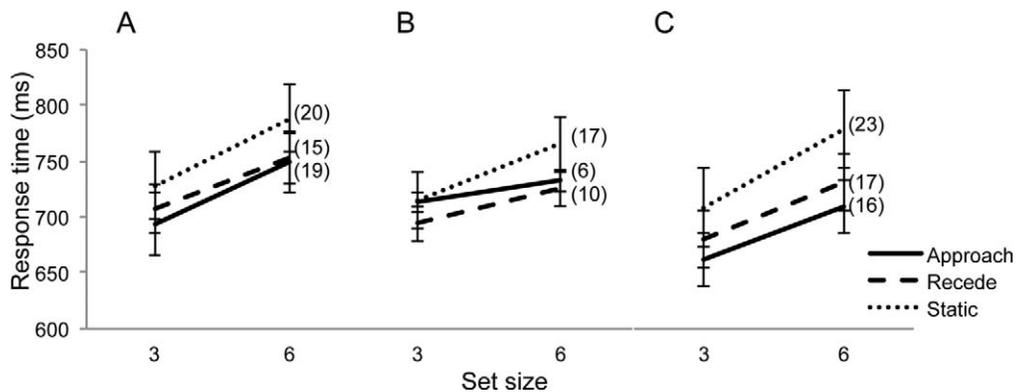


Figure 2. Mean response times to approaching, receding, and static targets as a function of set size from Experiment 1. Slopes are labeled according to target type, and search slope values are given in brackets (ms/item). Results are graphed according to depth cue condition, with (A) size scaling, (B) changing disparity, and (C) a combination of size scaling and changing disparity. Error bars show standard error.

.017). The ANOVA for size scaling showed significant main effects of motion type ($F[2, 32] = 7.93, p = 0.002, \eta^2 = 0.33$), with approaching targets responded to faster than static targets ($t[16] = -4.26, p = 0.001, \eta^2 = 0.53$), and receding targets trending towards faster responses than static targets ($t[16] = -2.62, p = 0.019, \eta^2 = 0.30$). The ANOVA for changing disparity showed significant main effects of motion type ($F[2, 32] = 4.09, p = 0.026, \eta^2 = 0.20$), the only significant difference being that receding targets were responded to faster than static targets ($t[16] = -4.17, p = 0.001, \eta^2 = 0.52$). The ANOVA for the combination showed significant main effects of motion type ($F[2, 32] = 15.43, p < 0.001, \eta^2 = 0.49$), with both approaching and receding motion targets responded to significantly faster than static targets, ($t[16] = -5.04, p < 0.001, \eta^2 = 0.61$) and ($t[16] = -3.70, p = 0.002, \eta^2 = 0.46$), and no significant difference between approaching and receding targets ($t[16] = -2.04, p = 0.058, \eta^2 = 0.21$).

The depth cue ratings are shown in [Figure 3](#). These data were submitted to paired sample t tests with a Bonferroni correction for three comparisons ($\alpha = 0.017$), with the mean ratings for size scaling, binocular disparity, and the combination condition compared against each other. This revealed that the size scaling condition ($M = 2.2$) rated significantly less compelling depth perception than both the changing disparity condition ($M = 3.3$), ($t[17] = -2.99, p = 0.008$) and the combination condition ($M = 4.2$), ($t[17] = -6.17, p < 0.001$), with a significantly higher depth perception rating for the combination condition than the binocular disparity condition ($t[17] = -3.57, p = 0.002$).

Discussion

We failed to find a statistically consistent pattern of search performance across the different depth cue conditions. When only size scaling was used to simulate motion in depth, there appeared to be a slight advantage for approaching motion; approaching targets were responded to faster than static targets, whereas receding targets only showed a nonsignificant trend toward faster responses than static targets. When motion was rendered only by changing disparity, receding, but not approaching, targets were responded to significantly faster than static targets. For the combination condition, both approaching and receding targets were responded to faster than static targets, with no significant difference between the two. Furthermore, the search slopes for approaching and receding motion differed for each depth cue condition, corresponding with the inconsistencies among previous reports using different depth cues (Abrams & Christ, 2005; Franconeri & Simons, 2003; Skarratt et al., 2009). Our results clearly show that the different methods

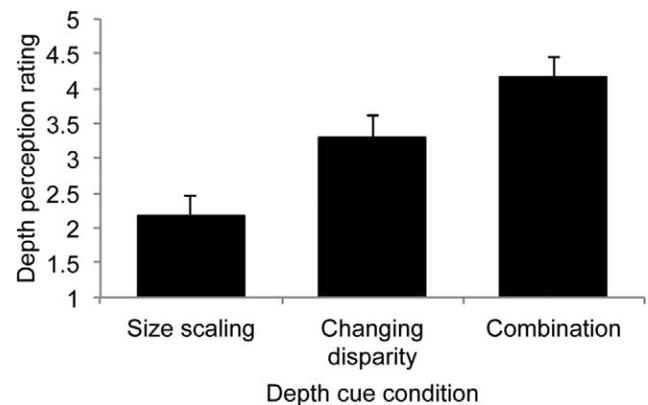


Figure 3. Mean ratings for how compelling the perception of depth was for participants for each depth cue condition.

employed to simulate motion in depth are a significant factor contributing to the inconsistency of results in the literature.

Additionally, data from our depth rating scale indicated that using a combination of size scaling and binocular disparity resulted in significantly more compelling perceptions of depth than either size scaling or changing disparity alone. Our results support the prediction that the presentation protocol and the resulting perceptual impression of motion in depth do affect the efficiency of searching for targets moving in depth. This provides the first empirical support for the conjecture by Abrams and Christ (2005) that the attentional impact of motion in depth depends upon the manner in which it is rendered. The subjective ratings indicate the most compelling method to present motion in depth is to use a calibrated combination of changing binocular disparity and size scaling.

Experiment 2

[Experiment 1](#) demonstrated that visual search performance and observers' impressions of motion in depth are critically dependent on how motion in depth is simulated. We exploited these findings to investigate whether or not visual search is affected by targets moving in depth using the combined changing disparity and size scaling, which created the most compelling sensation of motion in depth. When testing the effect of motion in depth on search performance using these optimal stimuli, we were careful to control for a potential confound previously unaccounted for in [Experiment 1](#) and other studies (Abrams & Christ, 2005; Franconeri & Simons, 2003; Skarratt et al., 2009), that of a unique depth singleton. In all previous search tasks involving motion in depth, the irrelevant item was made conspicuous by approaching or receding motion; however, in addition to motion in depth, this irrelevant

feature differed from the other elements in its initial depth at the beginning of each trial. Depth singletons have been reported to be searched for efficiently in their own right (Nakayama & Silverman, 1986), and as a result, the previous research (Abrams & Christ, 2005; Franconeri & Simons, 2003) indicating efficient search for motion in depth may actually be efficient search for a depth singleton.

Experiment 2 investigated the effects of motion in depth on search performance while controlling for the depth singleton confound by directly comparing search efficiency for motion in depth with and without a depth singleton. We distributed distractor items across both depth planes so that the motion cue was never a depth singleton, and we compared this to the condition with the depth singleton still present. In other respects, the experiment was the same as **Experiment 1**.

Method

Participants

Thirteen male and 14 female undergraduates were recruited. Data from four participants were removed due to insufficient stereoacuity, in the same manner as **Experiment 1**.

Stimuli and procedure

Except as noted, the apparatus and displays were identical to those used in **Experiment 1**. The calibrated combination depth cue condition was used to present motion in depth.

We had two types of display, one with a depth singleton and one without. The singleton condition was presented in the same manner as the combination condition block in **Experiment 1**. The placeholders were $3^\circ \times 1.5^\circ$ and at zero disparity, with any item in the far or near depth plane smaller ($2.6^\circ \times 1.3^\circ$) or larger ($3.4^\circ \times 1.7^\circ$), respectively. A larger binocular disparity was used to match these size changes ($32'$ to the left or right), slightly larger than **Experiment 1** to ensure a clearly detectable motion in depth.

In the “no singleton condition” the trial sequence remained the same; however, placeholders were randomly presented on the near and far depth planes, not at zero disparity. The items on the far and near plane were $2.8^\circ \times 1.4^\circ$ and $3.2^\circ \times 1.6^\circ$, respectively, and the disparity separating the near and far plane was $32'$ ($\pm 16'$ respectively). The unique motion in depth placeholder moved from one depth plane to the other, with the change in disparity the same in both singleton conditions.

Participants completed 720 trials in total, separated into two blocks—depth singleton and no depth singleton—with block order randomized across participants. Set size and target motion were randomized

within each block as in **Experiment 1**, as was the target letter and the target position. The no singleton condition placeholders were randomly allocated to one of two depth planes, such that the motion-in-depth element was not a unique depth singleton.

Results

Response time outliers were excluded as in **Experiment 1**, resulting in a removal of 4.6% of trials. Accuracy for the 23 participants was above 91%, with a mean of 94.6%. Mean response time to static targets did not differ as a function of the approaching and receding motion of nontarget items ($t[1, 17] = 1.66, p = 0.112$). Therefore, subsequent analyses collapse the two static conditions across approaching and receding motion.

Mean response times are shown in **Figure 4**. These data were submitted to a $2 \times 2 \times 3$ repeated-measures ANOVA with depth singleton (singleton, no singleton), set size (3, 6), and target motion type (approaching, receding, and static) as the three factors. We found no significant effect between the singleton ($M = 759.18$ ms) and no singleton conditions ($M = 759.66$ ms), ($F[1, 22] = 89.98, p < 0.001, \eta^2 < 0.001$). A set size main effect was obtained ($F[1, 22] = 89.98, p < 0.001, \eta^2 = 0.80$), and the target motion types also significantly differed ($F[2, 44] = 24.09, p < 0.001, \eta^2 = 0.52$). As can be seen in **Figure 4**, approaching motion was responded to faster than receding motion, which was in turn responded to faster than static motion targets. This was verified by paired sample t tests with a Bonferroni correction for two comparisons ($\alpha = 0.025$), for approaching targets ($M = 732$ ms) versus receding targets ($M = 761$ ms), ($t[1, 22] = -3.41, p = 0.003, \eta^2 = 0.35$), and receding targets versus static targets ($M = 793$ ms), ($t[1, 22] = -3.82, p < 0.001, \eta^2 = 0.40$).

We also found a significant two-way interaction between set size and motion type ($F[2, 44] = 8.61, p < 0.001, \eta^2 = 0.28$). We calculated search slopes for each motion type and followed this up with paired sample t tests between the search slope for each motion type, using a Bonferroni correction ($\alpha = 0.017$) for three comparisons. Although approaching (17 ms/item) and receding (18 ms/item) motion both showed shallower slopes than static slopes (31 ms/item), ($t[1, 22] = -4.04, p = 0.001, \eta^2 = 0.43$) and ($t[1, 22] = -3.16, p = 0.005, \eta^2 = 0.31$), there was no difference in slope between approaching and receding motion ($t[1, 22] = -0.32, p = 0.755, \eta^2 = 0.01$).

Discussion

The depth singleton did not affect search time results, as evidenced by the lack of significant difference

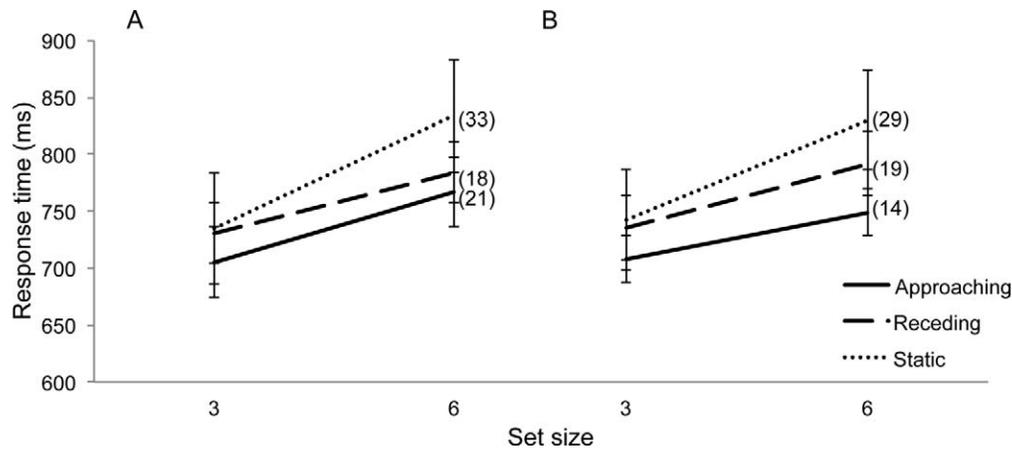


Figure 4. Mean response times to approaching, receding, and static targets as a function of set size from Experiment 2. Slopes are labeled according to target type, with search slope values given in brackets (ms/item). Results are graphed according to depth singleton condition, with (A) singleton and (B) no singleton.

between the singleton and no singleton conditions. We found a main effect of search times shown by an intercept difference for target motion type. The participants found approaching targets faster than receding targets, which were found faster than static targets. Finally, there was a search slope difference, such that both approaching and receding motion search slopes were shallower than the static target search slope; however, no difference was found between approaching and receding target search slopes. The relative effects of approaching and receding motion on visual search remain unclear, with an intercept difference but no difference in search slope. We will explore these results further in the following discussion.

General discussion

This study yielded two new empirical conclusions about the relationship between visual search and targets moving in depth. In Experiment 1, we found that search efficiency varies with how motion in depth is simulated for targets moving in depth compared to static targets. In addition, we are the first to report, through our subjective rating data, that in the context of an irrelevant feature search task, a calibrated combination of changing disparity and size scaling yields a more compelling perception of motion in depth than either of the two cues alone. Motion-in-depth targets presented via a calibrated combination of size scaling and changing disparity produced greater search slope differences than seen in the other depth cue conditions. Our findings contribute to a resolution of contentions among previous studies (Abrams & Christ, 2005; Franconeri & Simons, 2003; Muhlenen & Lleras, 2007; Skarratt et al., 2009). Our data shows that the

variability in results seen among previous studies is due, at least in part, to using different depth cues to simulate motion in depth, which suggests a subjective perception rating might be a useful addition to subsequent studies as a manipulation check. It is important to simulate motion in depth in a way that it is perceptually compelling, and this should be verified with subjective measurements.

In Experiment 2, we show that the potentially confounding depth singleton in Experiment 1 and previous studies (Abrams & Christ, 2005; Franconeri & Simons, 2003; Skarratt et al., 2009) does not affect search results in the irrelevant feature search task. This was surprising because previous research has indicated that unique depth targets can capture attention (Nakayama & Silverman, 1986; Theeuwes, Atchley, & Kramer, 1998), and Franconeri and Simons (2005) observed that participants frequently made eye movements to the depth singleton in their task. On the other hand, O'Toole and Walker (1997) showed that for a subset of their stimuli, targets in the closest depth plane were searched for more efficiently than targets in the further depth plane (but see de la Rosa, Moraglia, & Schneider, 2008). Skarratt et al. (2009) suggested that if items in front are detected faster than targets behind then we should see better performance for receding targets than approaching targets due to their initial starting positions, which is contrary to our findings. We conclude that depth singletons are not interfering with the search results of motion in depth.

Finally, the slopes of the data functions for approaching and receding motion were equivalent in Experiment 2 and significantly shallower than the slope for static targets. One interpretation of the shallower slopes for motion targets is that stimuli moving in depth captured attention more effectively compared to the static targets. In this regard, receding and

approaching objects can be said to be equally efficient in drawing attention. If the ability to draw attention does not differ between approaching and receding motion, how then do we explain the consistently faster response times for approaching motion in both experiments? Our results mirror those of Skarratt et al. (2009), who concluded that the approaching motion advantage may occur outside of attentional selection, passing through the attentional system more efficiently than receding objects, despite showing the same selectional prioritization. Indeed, models of visual search classically describe a two-stage process, such as Treisman's Feature Integration Theory (Treisman & Gelade, 1980), which proposed a parallel, preattentive first stage and a serial, attentive second stage. Wolfe's Guided Search 4.0 (Wolfe, 2007) is similar to Treisman's theory except both stages are described as mostly parallel. Similarly, Signal Detection Theory models of visual search posit a parallel, unlimited-capacity first stage followed by a simple decision rule (J. Palmer, 1998; Verghese, 2001). Despite their differences, these models agree on the basic processes of visual search: visual information is input; once an item reaches a criterion threshold, the item is selected; the selected item is identified and matched to target specifications; and a response is selected and executed. In such accounts positive search slopes can arise from two mechanisms. First, they could arise from an iterative serial search of items, which is expected when targets and distractors cannot be distinguished on the basis of a salient, preattentively available feature, such as color or motion. Second, positive search slopes can also arise from the addition of decision noise to the first stage of the search process discussed above. With increased distractors there is a higher chance that one of the distractors will receive greater stage one activation than the target. Search slopes then can reflect the rate at which distractors can be rejected and the target is selected.

In keeping with the above analysis, our results suggest that approaching and receding motion items have an equal advantage in target selection over static items. Had the distinctiveness of the receding motion been less than that of approaching motion, we would have seen differences in search slopes. From the intercept difference between approaching and receding motion we infer that approaching has an advantage over receding motion in the second stage of attentional processing. Evidence indicating a hard-wired sensitivity to approaching versus receding motion is consistent with the idea that approaching motion preferentially activates response mechanisms (Maier & Ghazanfar, 2007; Zeki, 1974).

A possible explanation for the equivalence in target selection for approaching and receding motion is that participants are being captured by motion onset, rather

than the motion direction, as suggested in Abrams and Christ's (2003, 2005) animacy theory. However, recent evidence has shown that motion itself is able to capture attention without motion onset (Al-Aidroos, Guo, & Pratt, 2010; Franconeri & Simons, 2005). More importantly, the differences we found between approaching and receding motion at later stages of processing indicate that approaching and receding motion are seen as two separate motion directions and not just motion onsets.

Conclusions

We conclude that when motion in depth is simulated via a calibrated combination of size scaling and changing disparity, approaching and receding motion have a selection advantage over static objects, with no difference between the selection of approaching and receding motion. Despite suggestions to the contrary, depth singletons do not affect this relationship. We provide evidence of approaching motion preferentially activating response mechanisms, and this is consistent with the behavioral urgency hypothesis (Franconeri & Simons, 2003) as a prioritized processing of response to approaching over receding motion, even without a selection advantage, fulfills the need for urgent response to potential threat.

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Corresponding author: Nonie J. Finlayson.

Email: nonie.j@gmail.com.

Address: School of Psychology, The University of Queensland, St. Lucia, QLD 4072, Australia.

References

- Abrams, R. A., & Christ, S. E. (2003). Motion onset captures attention. *Psychological Science*, *14*(5), 427–432, doi: 0.3758/BF03206486.
- Abrams, R. A., & Christ, S. E. (2005). The onset of receding motion captures attention: Comment on Franconeri and Simons (2003). *Perception & Psychophysics*, *67*(2), 219–223, doi: 10.1111/1467-9280.01458.

- Al-Aidroos, N., Guo, R. M., & Pratt, J. (2010). You can't stop new motion: Attentional capture despite a control set for colour. *Visual Cognition*, *18*(6), 859–880, doi: 10.1080/13506280903343085.
- de la Rosa, S., Moraglia, G., & Schneider, B. A. (2008). The magnitude of binocular disparity modulates search time for targets defined by a conjunction of depth and colour. *Canadian Journal of Experimental Psychology*, *62*(3), 150–155, doi: 10.1037/1196-1961.62.3.150.
- Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance*, *18*(4), 1030–1044, doi: 10.1037/0096-1523.18.4.1030.
- Franconeri, S. L., & Simons, D. J. (2003). Moving and looming stimuli capture attention. *Perception & Psychophysics*, *65*(7), 999–1010, doi: 10.3758/BF03194829.
- Franconeri, S. L., & Simons, D. J. (2005). The dynamic events that capture visual attention: A reply to Abrams and Christ (2005). *Perception & Psychophysics*, *67*(6), 962–966, doi: 10.1111/j.0956-7976.2005.01528.x.
- Maier, J. X., & Ghazanfar, A. A. (2007). Looming biases in monkey auditory cortex. *Journal of Neuroscience*, *27*(15), 4093–4100, doi: 10.1523/JNEUROSCI.0330-07.2007.
- Muhlenen, A. V., & Lleras, A. (2007). No-onset looming motion guides spatial attention. *Journal of Experimental Psychology: Human Perception and Performance*, *33*(6), 1297–1310, doi: 10.1037/0096-1523.33.6.1297.
- Nakayama, K., & Silverman, G. H. (1986). Serial and parallel processing of visual feature conjunctions. *Nature*, *320*, 264–265, doi: 10.1038/320264a0.
- O'Toole, A. J., & Walker, C. L. (1997). On the preattentive accessibility of stereoscopic disparity: Evidence from visual search. *Perception & Psychophysics*, *59*(2), 202–218, doi: 10.3758/BF03211889.
- Palmer, J. (1998). Attentional effects in visual search: Relating search accuracy and search times. In R.D. Wright (Ed.), *Visual Attention* (pp. 348–388). New York: Oxford University Press.
- Palmer, S. E. (1999). *Vision science: Photos to phenomenology*. Cambridge, MA: MIT Press.
- Pelli, D. G. (1997). The video toolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision*, *10*(4), 427–442, doi: 10.1163/156856897X00366.
- Skarratt, P. A., Cole, G. G., & Gellatly, A. R. H. (2009). Prioritization of looming and receding objects: Equal slopes, different intercepts. *Perception & Psychophysics*, *71*(4), 964–970, doi: 10.3758/APP.71.4.964.
- Theeuwes, J. (1991). Exogenous and endogenous control of attention: The effect of visual onsets and offsets. *Perception & Psychophysics*, *49*(1), 83–90, doi: 10.3758/BF03211619.
- Theeuwes, J. (1992). Perceptual selectivity for color and form. *Perception & Psychophysics*, *51*(6), 599–606, doi: 10.3758/BF03211656.
- Theeuwes, J., Atchley, P., & Kramer, A. F. (1998). Attentional control within 3-D space. *Journal of Experimental Psychology: Human Perception and Performance*, *24*(5), 1476–1485, doi: 10.1037/0096-1523.24.5.1476.
- Treisman, A., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology*, *12*, 97–136, doi: 10.1016/0010-0285(80)90005-5.
- Verghese, P. (2001). Visual search and attention: A signal detection theory approach. *Neuron*, *31*, 523–535, doi: 10.1016/S0896-6273(01)00392-0.
- Wolfe, J. M. (2007). Guided Search 4.0: Current progress with a model of visual search. In W. Gray (Ed.), *Integrated models of cognitive systems* (pp. 99–119). New York: Oxford University Press.
- Yantis, S., & Jonides, J. (1984). Abrupt visual onsets and selective attention: Evidence from visual search. *Journal of Experimental Psychology: Human Perception and Performance*, *10*(5), 601–621, doi: 10.1037/0096-1523.10.5.601.
- Zeki, S. M. (1974). Cells responding to hanging image size and disparity in the cortex of the Rhesus monkey. *Journal of Physiology*, *242*, 827–841.