Title

VISUAL ATTENTION: AN INVESTIGATION OF THE MECHANISMS OF CONTROL, FLEXIBILITY OF ALLOCATION AND THE INFLUENCE OF DISTRACTING INFORMATION

Author

Sterling, Cassidy

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VISUAL ATTENTION: AN INVESTIGATION OF THE MECHANISMS OF CONTROL, FLEXIBILITY OF ALLOCATION AND THE INFLUENCE OF DISTRACTING INFORMATION

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Cassidy P. Sterling

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The Dissertation of
Cassidy P. Sterling is approved:

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Professor Bruce Bridgeman

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Professor Dominic Massaro

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Professor Alan Kawamoto

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Tyrus Miller
Vice Provost and Dean of Graduate Studies

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VISUAL ATTENTION: AN INVESTIGATION OF THE MECHANISMS OF CONTROL, FLEXIBILITY OF ALLOCATION AND THE INFLUENCE OF DISTRACTING INFORMATION

by

CASSIDY P. STERLING

Abstract

This paper summarizes relevant literature on visual attention, beginning with a discussion of how attention is shifted to different locations of focus - both consciously and reflexively. Two experiments investigate the mechanisms controlling attention shifts. Tones perceived to originate from a specific location inside the head were created by manipulating the amplitude of tones presented dichotically through earphones. Evidence of selective attention to these intracranial locations suggests that the premotor theory of attention must be revised. Attention is shown to give rise to a facilitation of processing power for items located within the area of focus. This effect decreases as the area of focus increases. Before any facilitation effects occur attention must select an area or object that will receive the boost in processing power. How this mechanism functions is discussed. The ability to distribute attention flexibly - to multiple non-contiguous locations, areas of various size and shape - appears, in part, due to the influence of distracting information that is present within a visual scene. Studies that have addressed the allocation of attention have, for the most part, utilized impoverished stimuli - letters, numbers or simple shapes displayed on a blank background - ignoring the possible influence a richly detailed scene might have on attentional processes. Two more experiments are run which investigate how attention is allocated to a detailed, photograph quality scene. Participants focused on an object located amongst distractors with all objects set against a photograph quality background. While focused on the object a probe occured briefly at either the target, distractor or background locations and participants responded to the direction of the probe arrow as quickly as possible. Response times were faster for object locations, slower for distractor locations and slowest for background locations. Two possible patterns of inhibition were not found - inhibiting information similar to the target the most or inhibiting information immediately surrounding the target the most. Near background locations were faster than far background locations and all distractor objects, regardless of similarity to and distance from, the target were inhibited equally. The pattern of response times supports a spread of facilitation from the target and inhibition from distractors to surrounding background locations. When a scene is created that better represents the natural world gradients of facilitation and inhibition are still found - the mechanism is not restricted to spreading into blank locations. When a more visually complex scene is viewed participants are able to allocate attentional resources flexibly - different locations within a scene receive different levels of inhibition - based on the demands of the task.

Visual Attention: An Investigation of the Mechanisms of Control, Flexibility of Allocation and the Influence of Distracting Information

Two of the most dominant views of attention - the spotlight model (Posner, Snyder, & Davidson, 1980) and the zoom-lens model (Eriksen, & St. James, 1986) - were originally described by Wilhelm Wundt almost 100 years earlier in 1896, yet, due to difficulties in measuring such a phenomenon, investigation of attention has only recently regained strength. While both of these models assume attention is focused to a single location, and is of a circular shape with a strict boundary that can be moved around in space to facilitate the processing of items within the spotlight, but none of the items that lay outside the spotlight, the zoom-lens model goes a step further, theorizing that the size of the spotlight can be adjusted but, due to limited resources, attention directed to a larger compared to smaller area results in less efficient processing of items located within the spotlight. Importantly, such limitations have been shown to occur due to processing restrictions at the perceptual level (Lupker & Massaro, 1979) where attention is believed to have its effect (Desimone & Duncan, 1995; Yeshurun, Montagna, & Carrasco, 2008).

Attention Shifts

Changing the focus of attention from one location to another can occur reflexively (Jonides, 1981), when attention is captured by luminance-based transients (Franconeri, Hollingworth, & Simons, 2005) such as a brightness change (Enns, Austen, Di Lollo, Rauschenberger, & Yantis, 2001) and motion (Abrams & Christ, 2003) or attention can be directed to a location consciously (Posner et al., 1980).

Initial evidence supported the view that these shifts of attention moved in an analog fashion (Tsal, 1989), processing any stimuli that lay between the start and end locations as the field of attention passed over them. Subsequent experiments, however, tend to favor a discrete movement where attention appears to fade from one location while simultaneously increasing at another (Chastain, 1992a; Chastain, 1992b). For example, if attention moves continuously from a location cued first to a location cued second then at some interval the average accuracy for targets at the two locations should reach a baseline level, when attention is at neither location, but instead moving from one to the other. Chastain (1992b) found that at no point did the average accuracy of the cued locations dip to the level of baseline accuracy (measured as the accuracy found at location two when the initially cued location accuracy was at its highest). In fact, the slope of the average accuracy during the time frame when attention should be moving from location one to location two, was close to zero, indicating very little change in discrimination ability when attention should be at neither location. The results suggest that attention decreases gradually at its initial location while simultaneously increasing at a new location.

Other studies have shown that while attention shifts may not occur instantly, they do seem to occur at a constant rate regardless of distance, both when moving from fovea to periphery (Cheal & Lyon, 1989) and from periphery to fovea (Sperling & Weichselgartner, 1995). Sperling and Weichselgartner had participants detect a target letter at one of three peripheral locations, releasing a button after detection while simultaneously shifting attention to a foveally presented digit stream and then reporting the first four numbers they saw. Identifying the target letter should take more time at peripheral locations further from the fovea, but this differential processing time would be reflected in the time it takes to perform the motor task. By subtracting the time to perform the motor task from the time difference between the presentation of the target letter and the first reported digit, a measure of the time to shift attention, independent of identification time, was obtained. Using this measure the researchers found no difference in response times for the three different distances.

Mechanisms of Control

The mechanisms that control covert attention shifts, however, remain unclear. Premotor theories of attention (Rizzolatti, Riggio, Dascola, & Umilta, 1987) propose that covert attention shifts are a component of a larger program that is created and executed only when a movement to a specific location is planned. Covert attention can shift to a desired location only after motor systems determine the direction and distance required to move to that location. This attention shift occurs regardless of whether the planned action is actually executed. The authors propose that while there is a preference to shift attention within the space encoded by the oculomotor system, the premotor theory is not restricted to vision alone (Rizzolatti, Riggio & Sheliga, 1994). As long as a spatial and motor map exist for a specific modality, then a motor program can be created within that space, resulting in an attention shift to the location of action. Thus, for premotor theories of attention, multiple, independent systems are required. Contrary to this view recent evidence suggests that a single, supramodal system controls attention shifts instead.

Evidence from behavioral studies shows that visual, auditory and tactile attention are strongly linked - when attention is shifted to a location in one modality, responses to unexpected stimuli in the other modalities are also facilitated (Lloyd, Merat, McGlone & Spence, 2003; Spence & Driver 1996, 1997; Spence, Pavani & Driver, 2000, 2004), but some RT cost is always incurred (Turatto, Galfano, Bridgeman & Umilta, 2004) . This result has been found regardless of visual, auditory and tactile cue-target pairings for both reflexively captured and consciously directed attention shifts (Spence & Driver, 2004). Converging evidence from neurophysiological experiments shows a consistent ERP pattern of attentional control - an anterior directing attention negativity (ADAN) and a late directing attention positivity (LDAP) - both within a single modality (Hopf & Mangun, 2000; Nobre, Sebestyen & Miniussi, 2000) and also when directing attention to a location in one modality while anticipating a response in another (Eimer, van Velzen & Driver 2002; Van Velzen, Forster & Eimer, 2002; Eimer, van Velzen, Forster & Driver, 2003; Eimer, Forster, Fieger & Harbich, 2004). Which pattern, the ADAN or the LDAP, reflects the supramodal process of orienting attention has been disputed (Green & McDonald, 2006), but the general consensus is that such a system does indeed exist (Eimer & van Velzen, 2002; Eimer et al., 2002, 2003; Green & McDonald, 2006), controlling attention shifts to specific locations regardless of the modality of the cue or target.

Experiment 1

The supramodal organization of spatial attention combined with the premotor theory of attention implies that when a movement is programmed to a location, attention for all modalities will shift to that location, even when the action is not actually executed. This makes it possible to explain any attentional shifts to external targets using a premotor explanation and, thus, makes it difficult to find a test to disprove the theory. One possibility is to present targets at locations where motor movements cannot physically be directed, such as the space inside one's head. Sounds can be presented through earphones that are perceived to originate at specific locations inside the head (Mills, 1972). If evidence of selective attention is found for these intracranial locations, then motor mechanisms alone cannot be responsible for the spatial orienting of attention.

Method

Twenty University of California, Santa Cruz undergraduates heard two successive tones, a cue (4000 Hz) for 100 ms followed by a 400 ms delay and then a 100 ms target, randomly either a high (4250 Hz) or low (3750 Hz) tone. Throughout the experiment, participants fixated a cross and identified which target tone occurred with a speeded left or right mouse click. Tones were heard at either of two intracranial locations, halfway between the head center and left ear or right ear respectively, by creating intensity differences between the left and right auditory channels. In 80% of trials, cue and target occurred in the same location (valid cue trials). The remaining 20% were shift trials- cue on one side and target on the other. Participants were made aware of the high frequency of valid cue trials and instructed to shift their attention to the location of the cue tone in order to respond more quickly and accurately.

Results and Discussion

Mean reaction times (RTs) for correct trials and response accuracy were analysed in separate 2 (cue: valid, shift) x 2 (location: left, right) x 2 (tone: high, low) within-subjects, repeated measure ANOVAs. Faster RTs for valid (443 ms) versus shift (465 ms) trials, *F*(1, 20)=9.13, *p*=.007, $\square_p^2$ =.33, cannot be accounted for by a speed/accuracy trade off, as both conditions averaged 88% correct responses. A significant tone x cue interaction found faster RTs, *F*(1, 20)=8.98, *p*=.007, and increased accuracy, *F*(1, 20)=4.8, *p*=.04, for valid trial low tones, however, no other effects reached significance, *ps* > .06. The results show that focus on one location yields a RT benefit for subsequent stimuli presented there and a deficit for stimuli presented at another location (see Figure 1), suggesting that attention can be selectively directed to specific locations inside the head.

The finding that shift trials show an increase in response time relative to non-shift trials is explained as an effect of attention, yet the same result may be found if shift trials are simply more difficult to process than non-shift trials. The equivalent accuracy of participants in both conditions suggests differences in difficulty are most likely not the cause of the results. However a second set of twenty participants was run through a control experiment to definitively rule out non-attentional explanations. The control experiment, which changed only the percentage of time that the cue correctly predicted the target, found support for our conclusion. When a cue was presented in the same location as the target on only 50% of trials, the RT difference between valid (525 ms) and shift (534 ms) trials disappeared, F(1,20)=0.856, p=0.367. This result replicates previous findings where a spatially uninformative cue provides no incentive to endogenously shift attention to one location over another (McDonald & Ward, 1999). The failure to find a RT difference in the random cue experiment rules out a possible explanation that the shift condition, with cue and target in different positions, was inherently more difficult than the valid condition, with cue and target in the same position.

Experiment 2

In the first experiment participants heard tones that were presented halfway between the middle of the head and the right or left ear; faster responses were found for target tones on the same side of the head as the preceding cue, presumably because participants directed their attention to the cue location. It is possible, however, that participants were focusing attention to one *side* of the head or the other, depending on which ear received the loudest tone, rather than to the specific locations where the tones were heard. To address this issue a second experiment was conducted which limited the presentation of tones to the right side of the head. If participants cannot attend to specific intracranial locations, then this manipulation - where the right ear is presented with the louder tone on all trials - would yield no difference in RTs for valid versus shift trials.

Method

Prior to the experiment participants were asked to discriminate the location of four tones, presented for 100 ms. at different intracranial locations (panned 80% and 20% to the right of the head center and 10% and 50% to the left of head center), by marking on a top-down line drawing of a head after each tone. Participants were instructed to mark their responses anywhere on the paper, inside or outside of the head, wherever they perceived the sound was coming from. Each tone was repeated five times in succession before a response was given. Instructions for the experiment were then given followed by a short practice session and the experiment of 500 trials. Unlike experiment one, tones were presented at two intracranial locations on the right side of the head only (cue and target tones panned 80% and 20% to the right of the head center). Following the test participants were asked whether they heard these tones in the space outside of their head, inside their head or somewhere else and whether they heard the tones originating from two distinct locations. All other aspects of the experiment followed the same procedure used in experiment one.

Results

Fourteen participants unable to accurately discriminate between the four pretest tone locations - marks made outside the head or outside of a 1.3 cm. diameter circle surrounding the target location - were excluded from analysis. Among the twenty remaining, analysis was restricted to those who reported (post-test) hearing the test tones from two locations inside their head, removing seven more participants. This strict criterion resulted in a large number of excluded participants, but ensured that analysis was restricted to those who could accurately discriminate between tone locations and consistently heard these tones from locations inside their head.

Mean RTs for correct trials and response accuracy were analysed in separate 2 (cue: valid, shift) x 2 (location: left, right) x 2 (tone: high, low) within-subjects, repeated measure ANOVAs. Faster RTs for valid (431 ms) versus shift (443 ms) trials (see Figure 1), *F*(1, 13)=12.47, *p*=.004, η_p^2 =.51, cannot be accounted for by a speed/accuracy trade off, as the percent correct for valid (.98) and shift (.97) trials was not significantly different, *F*(1, 13)=2.47, *p*=.142. A significant tone x location interaction for both RTs, *F*(1, 20)=71.2, *p*<.001, and accuracy, *F*(1, 20)=7.43, *p*=.013 found that low tones near the ear were faster and more accurate than high tones at the same location. This pattern reversed for the location near the head center - high tones were faster and more accurate than low tones. The reversal occurred for both valid and shift trials, resulting in a significant cue x tone x location interaction (*F*(1,13)=6.77, *p*=.023). No other effects reached significance, *ps* > .14.

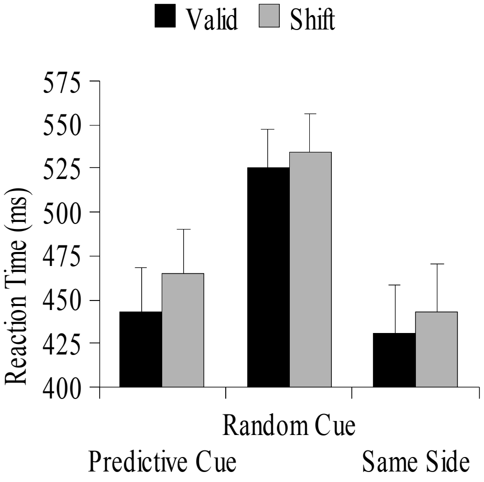

Figure 1. Mean reaction times on valid and shift trials for the predictive cue (80% valid), random cue (50% valid) and same head side experiments. Error bars show SEM.

Discussion

The results from experiment two show that attention can be directed to at least two different intracranial locations on the same side of the head. Focusing attention with such high resolution, as required by this experiment, is difficult but not impossible. Some individuals are better able to focus their attention than others (Hunt, Pellegrino & Lee, 1989) and differences in auditory perceptual acuity is well known; together this could explain why some participants were unable to either accurately or consistently determine the location of the test or pre-test tones. Regardless, multiple individuals could indeed focus their attention to specific intracranial locations; motor mechanisms alone cannot account for this ability.

Conclusion

Participants show a RT benefit on trials where a predictive cue occurs in the same location as a subsequent target, a finding that disappears if the cue location occurs randomly. Furthermore, participants were able to accurately discriminate between multiple different intracranial locations and do so consistently throughout the experiment. The findings of our study suggest that attention can be directed to specific locations inside the head. While attention to a location clearly precedes motor action to that location (Rorden & Driver, 1999), it does not appear that motor planning is required for selective attention, as is posited by premotor theories of attention (Rizzolatti et. al., 1987), because this would necessitate a motor system to calculate co-ordinates to a location where physical action is impossible. Furthermore, as far as the authors are aware, a sensory map on a cortical or subcortical surface for the space inside one's head does not exist; thus, the attentional effects found here cannot be due to shifts of attention to locations on such a map. This decoupling of attentional orienting and motor movements is consistent with recent findings that the frontal eye fields, which control voluntary eye movements, are also involved in covert spatial orienting without eye movements for visual targets in monkeys (Wardak, Ibos, Duhamel, & Olivier, 2006) and auditory targets in congenitally blind humans (Garg, Schwartz, & Stevens, 2007). In conclusion our results indicate that premotor theories of attention are incomplete and that a new theory must be developed to explain how attention is directed to locations where physical action is impossible.

Distribution of Attention

Not only can the focus of attention be shifted to various locations of the visual field, but the size of the area where attention is directed can also be adjusted, depending on task demands (LaBerge, 1983; Castiello & Umilta, 1990; Handy, Kingstone, & Mangun, 1996). Discriminating fine details of a target may require highly focused attention to a small area in order to reduce the influence of nearby distractors, but a larger area would benefit discrimination of gross features for multiple items. LaBerge (1983) found that when a small area of attention was beneficial - discriminating a letter surrounded by two distractors on either side - RT to a probe letter increased as its position from center increased, yet when a larger area of attention was beneficial - determining whether a five-letter word was a noun or not - RT to a probe letter remained constant regardless of distance. The trade-off for distributing attention over a larger area is that the processing power for items within the area of focus is reduced (Castiello & Umilta, 1990). They found that the average RT for detecting a target presented randomly at one of five locations was slower when the focus of attention encompassed all the locations (broad focus) and faster when it encompassed only the central location (narrow focus). The ability to discriminate a target was worse when attention was more broadly focused than when it was narrowly focused. The authors argued that the size of the attentional field was manipulated because in the broadly focused condition RTs were equal for all target locations whereas in the narrowly focused condition RTs were slower for the surrounding four locations and fastest for the central one. Interestingly their findings imply that a narrow focus of attention processes nearby items outside of its focus better than when the same area is broadly distributed but includes those items. The authors explain this finding as providing evidence that attention does not have a rigid boundary, but rather a gradient of attentional processing that tapers off from the center. Subsequent studies have provided support for this view - finding better facilitation near the center of a region of attention and a gradual decrease in facilitation as items appear at more peripheral locations when measuring response time (Downing & Pinker, 1985), discrimination thresholds (Downing, 1988), and distractor influence (Eriksen & St. James, 1986).

Just as the size of attentional focus can be changed, the shape of these gradients can also be adjusted. Gradients for a small center of focus have sharper declines in facilitation than gradients with wider center of focus which tend to have a more gradual decline in facilitation, but less processing power at center (Handy, Kingstone, & Mangun, 1996). In their study the authors manipulated the difficulty of a luminance onset detection task by presenting stimuli at either threshold or suprathreshold level while measuring response time and A` (signal detection). When detection was more difficult, benefits fell quickly from the attended location, showing a sharp gradient of facilitation for both response time and A`. When detection was easier a gradual decrease in facilitation occurred, falling off from the attended location. These results led the authors to conclude that in tasks requiring increased perceptual demands attentional resources are allocated more narrowly, allowing fewer resources to remain elsewhere and causing a steep decline in facilitation from the expected location. Easier tasks do not require as great an amount of resources at the expected location and thus the decline in facilitation is more gradual.

Effects of Attention

Perhaps obviously, attention appears to work as a filter, allowing only a subset of the total amount of information picked up by sensory organs to reach further levels of processing by the system. How it does this is still up for debate. Attention may work by selecting all information within a specific area of space, without regard to what that information actually is. This allows attention to work robustly at a very low, spatial level, but forces later processes to do much of the discrimination and organization of this raw information. Clearly attention can be directed to some area of space while excluding other areas, as has been shown by numerous cuing studies. Faster response times are found for the detection and discrimination of a stimulus when a cue correctly predicts the location of the target than when it does not (Posner et al., 1980). This facilitation at expected locations is not an effect of a response bias, a trade off between speed and accuracy, but rather reflects an increased sensitivity for processing information at the attended location (Downing, 1988; Carrasco, Ling, & Read, 2004; Yeshurun et al., 2008). Downing looked at sensitivity for brightness, orientation and form discrimination as well as luminance detection as a function of distance from initial cue location. A single target and three other non-target stimuli were presented simultaneously either 0, 1, 2, 3, 5, or 7 degrees from the cued location. She measured d' for each condition and found that sensitivity fell quickly from 0 to 1 degree for both orientation and form discrimination and continued to gradually decline as distance increased. A more continuous and gradual decline in sensitivity occurred for brightness discrimination and luminance detection. Participants were best at perceiving differences between stimuli when they were presented at an attended location and this facilitation decreased as the distance of stimuli presentation and the attended location increased.

More evidence that attention improves perception of visual details comes from Carrasco et. al. (2004) who looked at the effect of attention on contrast sensitivity. Each trial began with a neutral or peripheral cue, followed by the simultaneous presentation of a test and standard Gabor patch to the left and right of fixation. Participants reported the orientation (left vs. right) of the Gabor patch they perceived was of higher contrast. In this way the authors were able to determine the point of subjective equality (PSE) between the variable test (2.5%- 16%) and fixed standard (6%) as a function of trial condition. They found that on trials when the test location was cued, PSEs occurred at a lower physical test contrast (3.5%) than both neutral cue (6%) and standard location cue (8%) trials. This is exactly what one would expect if attention to a location increased the contrast sensitivity of stimuli presented there. In summary, attention makes a 3.5% contrast appear equivalent to an unattended 6%

contrast standard and it takes an 8% contrast test to be seen as equivalent to an attended 6% standard. On neutral trials, when attention was presumably at neither location, test and standard contrasts were perceived equal when they were in fact physically equal. These effects are not due to more information being present at the cued locations. A second experiment controlled for attention shifts by using a longer latency between cue and stimulus presentation (500 ms). Since exogenous attention completely decays after approximately 250 ms (Jonides 1981) this should produce effects similar to the results found in the neutral condition, which is indeed what occurred.

Spatial resolution is also enhanced by attention (Yeshurun et. al. 2008). A texture map of congruent angled dashes was shown twice, preceded by either a peripheral, central or neutral cue and followed by a mask. Participants indicated which of the two texture maps contained a target of incongruent angled dashes presented at multiple eccentricities. The proportion of correct responses was calculated and showed that peripheral cues and central cues provided different results. When attention was reflexively oriented to a location with a peripheral cue, accuracy for the target was facilitated compared to neutral trials only for eccentricities greater than 8 degrees and actually decreased accuracy at more central locations. When attention was consciously directed to a location in central cue trials, accuracy was facilitated at all locations. A control experiment to ruled out the possibility that attention was acting to decrease uncertainty at the decision level instead of enhancing the spatial resolution of the attended area. A post cue was added on some trials, which reduced response uncertainty, yet failed to facilitate accuracy to the level of that found when using a pre cue.

Mechanism of Selection

Vecera and Farah (1984) proposed that attention acted by facilitating "grouped spatial arrays" of locations that underlie the area containing an object.This view is similar to the spatial selection view conceptualized by an adjustable spotlight, yet differs in that the shape of attentional focus is much more malleable, working on an area of grouped locations, possibly defined preattentively by gestalt grouping principles (Neisser, 1967; Kahneman, 1973; Driver, & Baylis, 1989). The facilitation of responses for an object within a larger field of attentional focus could result from selecting an object independent of its location or by selecting a "grouped spatial array" of locations directly underlying it.

Kramer, Weber, and Watson (1997) used a post stimulus probe technique (Kim & Cave, 1995) where a red dot appeared on 25% of trials and its detection was responded to as quickly as possible. Two judgments about the same or different objects were made on each trial and directed at either a single location or split between two different locations. Participants were more accurate when making two judgments about the same object than different objects, showing a traditional object facilitation effect of attention. The probe response time data, however, supported the grouped-array theory. On trials where judgments were directed toward a single object, subsequent probes at the same location as that object were responded to faster than if the probe were presented at a location where an object was displayed that required no judgments. According to these results it appears that attention selects the space underlying an object and not the object itself, independent of information about where it was presented.

These grouped arrays are not always formed based on the spatial proximity of stimuli, but can also be formed by grouping items with similar color (Baylis & Driver, 1992) and movement (Driver & Baylis, 1989). Eriksen and Eriksen (1974) found that distractor letters produced less interference on discrimination of a center, target letter as the distance between peripheral distractors and target increased. Using an adapted version of this design Driver and Baylis found that discrimination of a target letter took longer and produced more errors when it shared the same motion as far distractors, even when nearer distractors were present. Conversely near distractors were ineffective at producing interference when they moved but the target remained still. This pattern of results is consistent with grouping by perceptual quality, similar movement, which can supersede grouping by spatial proximity. In purely static displays Baylis and Driver found that, again, grouping by a perceptual quality, color, superseded grouping by location. Discrimination of a target letter took longer and produced more errors for far distractors that shared its color than near distractors that did not. In neither study did Driver and Baylis determine whether attention was selecting from the locations that held the items of similar color and motion as would be predicted by the "grouped spatial array" theory.

To test whether perceptual grouping effects also showed selection of grouped locations, Kim and Cave (2001) used a post display probe presented at either the location of the target or one of three other distractor locations surrounding fixation. To avoid the capture of attention by a feature singleton (Theeuwes, 1991; Theeuwes, 1992) one distractor letter was the same color as the target letter and the two other distractors were of a different color. Response times were faster for probes presented at distractor locations that shared the target color than for locations where the distractor did not share the target color. The authors concluded that this result was evidence in favor of a grouped array selection of attention. Characters of the same color were in fact grouped together, as was also found by Baylis and Driver (1992), however, unlike their study, Kim and Cave explain this effect as occurring because attention was grouping the locations underlying the characters and not due to a perceptual grouping independent of location. If this explanation is true then in the two studies by Driver and Baylis participants were forming groups of locations that either skipped over the near distractor locations or contained them, but inhibited the information presented there. The former would require two separate attention spotlights and the latter a single spotlight with multiple areas of facilitation and inhibition. Both of these conclusions suggest that attention can be allocated to areas in space with much more complexity and flexibility than is suggested by either the spotlight or zoom-lens theories of attention. In fact evidence exists that suggests attention can be directed to an area as complex as a hollow square or rings of different sizes.

Flexibility of Allocation

Sperling and Melchner (1978) used two square shaped letter arrays, one surrounding the other, and had participants detect two target digits. Instruction type was blocked to either give 90% of attention to the inside, or outside square, or to give equal attention to both. The authors calculated attention operating characteristics by mapping the proportion of correct responses for the inside target against the proportion correct for the outside target. They found a tradeoff for instruction type. Participants showed better digit identification for inside square targets with inside attention instructions and this effect reversed when outside attention instructions were given.

Juola, Bouwhuis, Cooper, and Warner (1991) used response time to determine the flexibility of attention to select a target from concentric rings of distractors at three distances. Initially three rings were presented and participants were given a cue to attend to the inside, middle or outside ring area, which contained the target on most trials. If attention must expand to select items that are further apart, encompassing intermediate areas as well, then for middle and outer cues, response time for targets at inner locations should also be facilitated. Somewhat surprisingly Juola et. al. found no evidence for this latter interpretation. Faster response times occurred for congruent-cue target presentations and latency increased as the target was shown at locations further from the cued ring.

One common method in the studies providing evidence for such complex attentional effects is that they all presented targets amongst distractors. The presence of these distractors may influence how attention works compared to when a target is displayed in a blank visual field, which rarely happens outside of a laboratory setting.

When distractors are present attention may not only cause an active facilitation of grouped locations underlying target objects, but may also give rise to an active inhibition of underlying locations for other, non attended objects. This interaction between facilitation and inhibition could explain why some studies yield results that show evidence for such complex and flexible distributions as those found by Juola et al., (1991), Baylis and Driver (1992) and Kim and Cave (2001).

Cepeda, Cave, Bichot, and Kim (1998) conducted a series of experiments to address this issue. They used a post stimulus probe technique that could occur at the location previously occupied by the target, a distractor location, or a blank location between target and a distractor. Participants showed faster response times to probes at target locations than distractor locations, but oddly response times to blank locations between target and distractor were responded to fastest. The authors suggest that an inhibition of return phenomenon could explain the failure for target probes to produce fastest responses. In experiment three the authors controlled for masking effects and found similar results. Their results suggest that selection of a target location is facilitated due to the inhibition of distractor locations, but not inhibition of blank locations surrounding the target. This inhibition appears to apply equally to all distractors regardless of distance from target location, though this was not the case for blank locations, which showed slower response times as distance increased. If an inhibition of return phenomenon was affecting the slower response times to target locations then it appears that the attention effects found in most studies involve a field of both facilitation of target locations and inhibition of distractor locations. If a stimulus appears at a location previously unoccupied then it receives the facilitory benefits of attention, as if it had appeared at a location previously occupied by a target. Cepeda et al. (1998) used only a single target on each trial and thus are unable to determine whether attentional facilitation could be found for locations underlying multiple targets, as would be necessary to explain the Baylis and Driver (1992) result. Yet the possibility of such an effect does not seem too far fetched. If multiple locations can be inhibited, with the left over area appearing to be uniformly facilitated, then perhaps facilitation for multiple target locations could also be achieved.

Mixed results have been found, both supporting (Kramer, & Hahn, 1995; Bichot, Cave, & Pashler, 1999) and denying (Posner et. al., 1980; Hoffman, & Nelson, 1981; Eriksen, & Yeh, 1985) the ability to attend to multiple non-contiguous locations in space. Kramer and Hahn (1995) found that by removing the luminance onset that occurs when displaying stimuli participants were able to direct attention to two noncontiguous locations; when luminance onsets were present however, the distractors captured attention (Jonides, 1981) resulting in a broad focus of attention that included both target and distractor locations. Participants determined whether the two letters in the far left and far right locations were the same or different and distractors in the middle were either the same letters as the target or different. Response accuracy was affected by distractor type only in the condition when luminance onsets were present.

In multiple experiments, Bichot, Cave, & Pashler (1999) also found results supporting an ability to split attention between two non contiguous locations. Their most convincing experiment had participants first determine whether two shapes of the same color, surrounded by distractors, were the same or different. A subsequent probe task presented letters at all locations for 60 msec and, after a mask, asked participants to identify as many letters as possible. They found that accuracy in the probe task was highest at the location of one of the target locations and lowest at all distractor locations. They also found that the probability of a correct response at the second target location was higher than for all other distractor locations. The authors argue that, since there is not enough time to shift attention between the two target locations and that accuracy for intervening distractor locations is lower than for two non-contiguous target locations, attention must have split between the two targets. The results are similar to those found by Baylis and Driver (1992) who found no intervening distractor influence on selection of multiple color targets.

Evidence against the ability to split attention between non-contiguous locations also exists. Unlike the studies mentioned above, Eriksen and Yeh (1985) used a precue with its validity varied across three conditions, 40%, 70% or 100%. In the 40% valid condition the target occurred at the cued location 40%, the opposite location 40% of the time and at the two other locations 10% each. If attention could be split between the equally likely cued location and secondary location then response time for targets at each should be similar and faster than to targets at either of the two remaining locations. Eriksen and Yeh found no evidence for this, with fastest response times occurring for the primary cued location and no difference between the secondary and low probability locations. A neutral trial condition, with all four locations having equal probability of containing a target, found similar response time as those for the non-primary target location. The authors concluded that attention could not be split between non-contiguous locations, arguing that the results showed a facilitation at cued locations and an equal attention shift to any location when the cue was incorrect.

More support for this view comes from a dual task experiment that did not use cues. Hoffman and Nelson (1981) had participants search for a target letter and determine the orientation of a 'U' either presented at the same time or successively and either at the same or different locations. POC curves were calculated for each condition, which varied the emphasis for the two tasks. They found that when target letter and symbol occurred at different locations, there was extensive tradeoff in performance for the two tasks. When attention was directed completely to one task, the other resulted in near-chance performance. When both targets were presented at the same location, both tasks show above chance performance, even when full attention should be directed to one task over the other. The authors argued that this shows that attention to a single location enhances processing of all stimuli presented there. They go on to conclude that the extensive performance tradeoff for the two tasks when presented at different locations shows that attention cannot be split between two non-contiguous locations.

Given the mixed results on this issue it is reasonable to assume that in some conditions attention can be split between two non contiguous locations while in others it cannot. In both the studies that failed to find evidence for split attention at least one target location was uncertain. If attention cannot sustain focus on one location while performing a search for a second target location then no evidence for split attention would be found in these experiments. When the two target locations remain predictable, however, evidence shows that attention can be split between the two locations (Kramer & Hahn, 1995), without interference from distractors in between. Interestingly Bichot et al., (1999) did use a search task where target locations were uncertain yet still found evidence supporting an ability to attend to two non-contiguous locations. In their task, however, the two targets were of the same color compared to the distractors and thus presumably popped out (Treisman & Gelade, 1980), and were grouped together (Baylis & Driver, 1992). The stimuli in the search task used by Hoffman and Nelson (1981) contained no common features that would allow for perceptual grouping. In conclusion it appears that in order to split attention between two non contiguous locations one must either know where the two targets will be or the targets must share some common feature that allows them to be grouped together.

Natural Settings

In order to gain a complete and accurate understanding of visual attention, research must be conducted using procedures that more accurately mimic how attention is used in natural, day-to-day situations (Kingstone, Smilek, Ristic, Kelland & Eastwood, 2003). Most experiments on attention utilize impoverished stimuli - letters, numbers or simple shapes displayed on a blank background - presented for fractions of a second and with restricted eye movement; participants must usually maintain fixation at a central location while trying to focus attention on items located in the periphery. Attention processes are likely to respond differently when a richly detailed and contextually informative scene, one that more accurately reflects the natural environment, is used.

Friesen and Kingstone (1998) found that, contrary to a previous finding that covert attention does not shift for non-predictive central arrow cues (Jonides, 1981), a non-predictive central cue that included eyes instead of arrows *did* show evidence of covert attention shifts in the direction of the eye gaze. The authors argue that eye gaze direction in common human interaction is such a powerful predictor of another's attention that it produces a reflexive attention shift regardless of whether the cue is informative for completing an experimental task or not. Thus, the previously held belief that central cues must be spatially informative in order to produce an attention shift was shown to be false when a more socially significant stimulus was used. In fact, social significance appears to be an important factor influencing the attention system. Eastwood, Smilek and Merikle (2001) found that emotional faces can capture attention in a visual search task. Specifically, they found that sad faces were particularly effective at guiding attention, as shown by shallower search function slopes, when compared with happy faces. The specific, differential components of the two faces could not account for the results because the effect disappeared when faces were inverted. The authors conclude that meaning can be gathered from the parallel processing of a stimulus outside the focus of attention. Such a result refutes the prominent feature-integration theory (Treisman & Gelade, 1980) which claims that attention is necessary to bind individual features together; a conclusion formed after numerous studies provided evidence in its favor. Yet none of those studies utilized stimuli complex enough to have any intrinsic meaning of their own, most manipulating simple shapes, letters and different colors only. Thus, it appears that complex stimuli can be processed outside of attention to some extent, yet most likely there must be a clear socially significant aspect associated with it.

The purpose of the following two experiments is to investigate how attention is distributed to a visual scene; specifically a scene that includes a detailed background and contextually relevant target and distractor objects. Previous studies have found that attention could be distributed flexibly - hollow squares (Sperling & Melchner, 1978) and rings (Juola et al., 1991) - when other distracting objects were also present in the scene. A separate study found that the facilitation effect of attention bled into the blank area surrounding a target while an area of inhibition bled into the blank areas surrounding distractors (Cepeda et al., 1998). Together, these studies imply that the interaction between distractors and targets influences where attention resources are distributed when viewing a scene. Importantly, however, in the natural environment, there is not simply one type of distractor, but many and there is rarely blank space surrounding each item.

Experiment 3

The perceptual system may allocate fewer processing resources to locations where information competes with the target in an effort to increase discrimination of the target from its surroundings. With fewer perceptual resources available the information at these locations is inhibited and processed less efficiently. The third experiment looks to investigate whether adding a background - adding a field of distracting information surrounding both target and distractor objects that more accurately mimics the natural environment - will cause the facilitation effect surrounding a target to shrink and not spread to the background area surrounding it. This would be the effect one might observe if the perceptual system were inhibiting the information surrounding the target in order to boost processing of the target. It is possible that the background and the distracting objects will not differ in their effects on attention - yielding a facilitation of the target and equal inhibition of all other locations; the alternative being that some locations, perhaps those containing information that interferes with the target more, will undergo greater inhibition than other locations. This would result in different levels of inhibition based on differing amounts of attentional resources being allocated to different locations.

Method

Participants

Twenty five University of California, Santa Cruz undergraduates participated in this study as a part of their research requirement for the Introduction to Psychology class. All who participated had normal hearing and vision.

Apparatus and Stimuli

All stimuli were presented on a standard 2005 Dell computer with a 15" monitor using a display resolution of 1280 x 1024 pixels and running at a refresh rate of 60 Hz. A single 1280 x 1024 greyscale, background image was used throughout the entire experiment (Figure 2). On a given trial four objects -- three green distractor objects and one red target object -- were superimposed on top of the background image at locations determined by a 22.5° leftward rotation from the four cardinal directions on a 60 mm. (6° visual angle) centered, invisible circle. Each object was an image of an apple with the right side cut off, yielding a final size of 10 x 8 mm. (1° x 0.8° visual angle). On each trial the target and distractor apples were rotated randomly so that the missing side was oriented toward one of the four cardinal directions, with the restriction that each direction was represented on each trial. Black, square probes (5 x 5 mm, 0.5° x 0.5° visual angle) with either a white, left-facing arrow ('<') or right-facing arrow ('>') imbedded within were displayed randomly at one of eight locations. Enclosing the arrow stimuli with a black square ensured that the immediate background surrounding the probe was the same for all trials. A discrimination task was chosen to control for any preattentional effects that could occur with the use of a simple detection task. The probe was equally likely to be presented at the target location, one of the three distractor locations or one of four locations between the target and distractor locations (a 22.5° rightward rotation from the four cardinal directions on the invisible circle). A desk mounted eye tracker was used to monitor participants' eye movements throughout the experiment. Accuracy of the eye tracker was improved by having participants use a bite-bar to reduce head movement during trials.

Figure 2. Example of one of the scenes participants saw during experiment three. The green apple is the target; participants answering correctly would respond that the left side of the apple was cut off. The three red apples were the distractor objects. Target could occur at any of the four locations (indicated by an apple). Probes could occur at any of the four object locations or at a background location halfway between any two of the object locations (a 22.5 degree rotation from an object location along the invisible circular boundary that defined where objects and probes were placed).

Procedure

Participants were seated 57 cm. from the computer screen and given instructions for the experiment. The eye tracker was then calibrated - participants fixated a center cross and when instructed made a saccade to one of the four target locations on the computer screen. The corresponding location on the eye tracking monitor was recorded and the procedure was repeated for all four locations. A boundary was established halfway between the four target locations and the fixation location on the eye tracking monitor - all trials where a saccade was made that crossed over this boundary were removed from evaluation. Before each trial participants rested their right index finger on the 'K' key and their right middle finger on the 'L' key in preparation for the response time task. A trial consisted of the presentation of a central fixation cross for 600 ms, followed by the stimulus image (background image with the target and distractor objects) for 90 ms. After a 60, 90 or 120 ms delay a left-facing or right-facing probe was displayed for 60 ms, randomly at one of the eight possible locations. Participants determined which arrow was presented and pressed the 'K' key for a left-facing arrow or the 'L' key for a right-facing arrow as quickly as possible. A question then appeared on the screen asking participants to determine which side of the target object had been removed: top, bottom, left or right. This question was untimed. The sequence of events in this experiment is designed to measure where attentional resources are allocated when one attends to an object and how this distribution can be affected by distracting information. Participants must first focus their attention on the target object; the time it takes to respond to the subsequent probe measures the amount of attentional resources that were distributed to the probe location - faster responses implying more resources.

Participants controlled the speed of trial presentation by pressing the space-bar to begin each trial. All participants were required to take a 2 minute break at the end of each block of 256 trials, of which there were three. Trials were randomized within the constraint that each probe condition was run eight times for each block - collapsing across target orientation - and that all conditions were run equally once the entire experiment was completed. A condition was broken down as follows. The target could occur at each of the four locations and at each of the four orientations, yielding 16 combinations. These 16 combinations could have a probe occur at any of the eight probe locations, yielding a total of 128 different probe, target location, and target orientation combinations. A short practice session was run prior to the experiment.

Results

Participants were excluded from analysis if their target or probe accuracy fell below 90%. Thus, three participants were removed for responding to the target incorrectly on more than 10% of trials and one was removed for responding incorrectly to the probe on more than 10% of trials. Participants were also excluded if they were unable to maintain fixation on more than 5% of trials, resulting in one further participant being removed. For the remaining twenty participants 2.15% of trials, on average, were removed due to eye movements, 5.13% were removed due to inaccurate target identification and 3.75% were removed due to inaccurate probe identification.

Three separate within subjects, repeated measure ANOVAs were run on probe response time, probe accuracy and target accuracy comparing participant responses for target, distractor, near-background and far-background locations. A significant main effect of location on probe response time was found, $F(1, 19) = 9.02$, $p=.008$, $\eta_p^2 =.334$. Post-hoc analysis revealed faster RTs for probes presented at target locations (570 ms) compared to near (601 ms, $p =.001$) and far (595 ms, $p = .021$) background locations but not compared to distractor locations (567 ms, $p = .712$). RTs were also faster for distractor locations compared to both near and far background locations ($p = .001$). Background locations were not significantly different ($p = .553$). A significant main effect of location on probe accuracy was also found, $F(1,19) =$

5.76, $p = .028$, $\eta_p^2 = .253$. Post-hoc analysis revealed more accurate responses for probes at target locations (97.8% correct) compared to near (94.8% correct, $p =.016$) and far (95.1% correct, $p = .017$) background locations but not compared to distractor locations (97.5% correct, $p = .731$). Accuracy was also better for probes at distractor locations compared to both near ($p = .019$) and far ($p = .018$) background locations. Background locations were not significantly different ($p = .614$). No main effect of location on target accuracy was found, $F(1,19) = .530$, $p = .476$, showing that participants responded equally to the target regardless of where the subsequent probe was displayed.

Discussion

The results show that Near and Far background locations were responded to with equal accuracy and speed but were less accurate and slower than responses to probes at target and distractor locations. No difference in speed or accuracy was found between target and distractor locations. It is possible that there were different levels of inhibition to background and distractor locations compared to the target, but that an inhibition of return phenomenon obscured this fact by slowing down responses to probes presented at the previously attended target location. As they are, the results suggest that participants were able to distribute their attention equally to all locations where the target might occur. This finding extends the evidence that attention can be directed to multiple, noncontiguous locations (Kramer & Hahn, 1995; Bichot et al., 1999) and suggests that the ability results from inhibition of the areas surrounding the locations of focus. For this study it is not clear how participants were grouping the multiple locations of focus together. All colored objects could have been grouped together, resulting in a facilitation of both target and distractor items but not the background. Participants could have grouped by location, attending to the four static locations where the target could occur, or possibly grouping was done based on top-down information - attending to all apples. Facilitation of target locations was not found to bleed into surrounding areas, nor was there a spread of inhibition as was found by Cepeda et al. (1998) when blank locations were used to separate target and distractor items. Perhaps the lack of surrounding distracting information is necessary for the spread of inhibition and facilitation to occur; in this study there was no place for spread to occur. It could also be the case that the facilitation of multiple locations washed out any effect of a spreading inhibition.

Experiment 4

The aim of the fourth experiment was to make it more difficult for participants to attend to multiple locations by integrating the target and distractors with the background. This makes it more difficult to distinguish the target from the background and participants will need to focus more attentional resources to the target location (Handy et al., 1996) to aid in discrimination. The resulting scene will also look more natural than the one used in the third experiment, which emphasized increasing the ability for participants to discriminate the target and distractors from the background in an effort to closely approximate previous studies that had no background. The fourth experiment will also address whether different types of distracting information lead to different levels of inhibition by adding a distractor object that is different from the target and other distractors. One explanation for why the background locations were inhibited equally in experiment 3 is because the entire background was dissimilar from the target and thus could be treated as a single object, with an equal amount of attentional resources distributed throughout. An alternative explanation for the equal inhibition of the background could be due to task demands - the target could never appear at a background location - thus participants could inhibit information based on location. By adding a distractor that is dissimilar from the target one can determine whether it is the difference from the target which causes inhibition, which would result in the dissimilar object receiving equal inhibition as the background, or if it is due to the demands of the task, which would lead to the dissimilar object receiving inhibition equal to the other distractor objects.

Method

Participants

Thirty University of California, Santa Cruz undergraduates participated in this study as a part of their research requirement for the Introduction to Psychology class. All who participated had normal hearing and vision.

Apparatus and Stimuli

All stimuli were presented on a standard 2005 Dell computer with a 15" monitor using a display resolution of 1280 x 1024 pixels and running at a refresh rate of 60 Hz. A single 1280 x 1024 color, background image was used throughout the entire experiment (Figure 3). On a given trial four objects -- three distractor objects and one target object -- were superimposed on top of the background image at locations determined by a 22.5° leftward rotation from the four cardinal directions on a 60 mm. (6° visual angle) centered, invisible circle. On each trial the task was always to identify the single purple flower, which came in three different varieties. Two of the distractors - a white flower and a yellow flower - were similar to the target (similar-object-distractors) and did not change throughout the experiment. The third distractor was a bee (dissimilar-object-distractor) - contextually related but different from the other three objects. Each object was 10 x 8 mm. (1° x 0.8° visual angle) in size. Black, square probes (5 x 5 mm, 0.5° x 0.5° visual angle) with either a white, left-facing arrow ('<') or right-facing arrow ('>') imbedded within were displayed randomly at one of eight locations. Enclosing the arrow stimuli with a black square ensured that the immediate background surrounding the probe was the same for all trials. The probe was equally likely to be presented at the target location, one of the three distractor locations or one of four locations between the target and distractor locations (a 22.5° rightward rotation from the four cardinal directions on the invisible circle). Probes displayed at background locations between the target and the nearest distractor to the left and right were defined as near-background locations. The remaining two background locations farthest from the target were defined as far-background locations. A desk mounted eye tracker was used to monitor participants' eye movements throughout the experiment. Accuracy of the eye tracker was improved by having participants use a bite-bar to reduce head movement during trials.

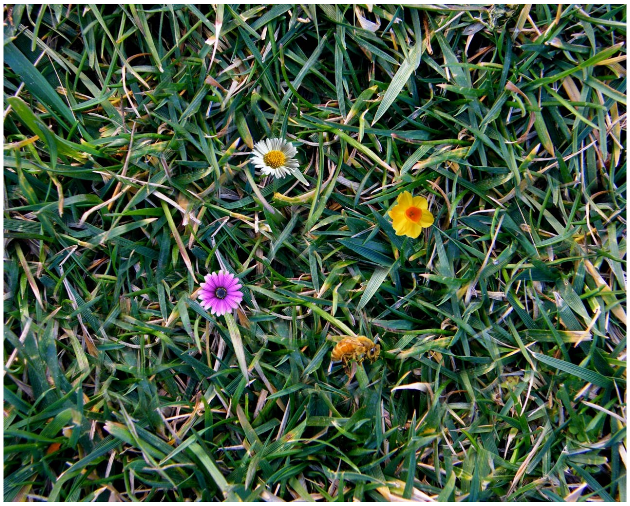

Figure 3. Example of one of the scenes participants saw during experiment four. The purple flower is the target; participants identified which target flower, out of three options, chosen randomly, was presented on each trial. Two similar object distractors (non-target flowers) and one dissimilar object distractor (bee) were displayed on each trial. Target could occur at any of the four object locations. Probes could occur at any of the four object locations or at a background location halfway between any two of the object locations (a 22.5 degree rotation from an object location along the invisible circular boundary that defined where objects and probes were placed).

Procedure

Participants were seated 57 cm. from a computer screen and given instructions for the experiment. The eye tracker was calibrated as described above. Before each trial participants rested there right index finger on the 'K' key and their right middle finger on the 'L' key in preparation for the response time task. A trial consisted of the presentation of a central fixation cross for 600 ms, followed by the stimulus image (background image with the target and distractor objects) for 90 ms. After a 60, 90 or 120 ms delay a left-facing or right-facing probe was displayed for 60 ms, randomly at one of the eight possible locations. Participants determined which arrow was presented and pressed the 'K' key for a left-facing arrow or the 'L' key for a right-facing arrow as quickly as possible. A question then appeared on the screen asking participants to determine which of the three possible target flower types was shown for that trial. This question was untimed. Prior to the experiment participants were shown the three different target flowers and were asked to memorize which key, 'A', 'S' or 'D' corresponded to which flower type. Participants were reminded of this key-target pairing during the practice if they forgot. Participants controlled the speed of trial presentation by pressing the space-bar to begin each trial. All participants were required to take a 2 minute break at the end of each block of 288 trials, of which there were four. Trials were randomized within the constraint that each probe condition was run three times for each block - collapsing across target type - and that all conditions were run equally once the entire experiment was completed. A condition was broken down as follows. The target could occur at each of four locations and for each of the three target types. The bee distractor could occur at any of the remaining three locations and the probe could occur at any of eight possible locations, yielding a total of 288 target type, target location, bee location and probe location combinations. A short practice session was run prior to the experiment.

Results

Participants were excluded from analysis if their target or probe accuracy fell below 90%. Thus, two participants were removed for responding to the target incorrectly on more than 10% of trials and two were removed for responding incorrectly to the probe on more than 10% of trials. Participants were also excluded if they were unable to maintain fixation on more than 5% of trials, resulting in three further participants being removed. For the remaining twenty participants 3.53% of trials, on average, were removed due to eye movements, 3.2% were removed due to inaccurate target identification and 1.6% were removed due to inaccurate probe identification. The high accuracy (96.8% correct) of responses to the target suggests that participants were shifting their attention to the target flower.

To determine whether responses to a probe differed as a function of probe location two separate within subjects, repeated measure ANOVAs were run comparing participant responses for five locations: target, similar-object-distractors (SOD), dissimilar-object-distractor (DOD), near-background (NB) and far-background (FB). A third ANOVA was also run to determine whether responses for the target differed as a function of probe location. A significant main effect of location on probe response time was found, $F(1, 22) = 17.02$, $p<.001$, $\eta_p^2 =.448$ (see Figure 4). Post-hoc analysis revealed faster RTs to probes presented at target locations compared to all other locations (see Table 1). Responses for SOD and DOD locations were not significantly different, suggesting that participants treated all object distractors equally. Participants did, however, respond faster to probes presented at object distractor locations (SOD and DOD) than to background locations - both NB and FB. A significant main effect of location on probe accuracy was also found, $F(1,22) = 6.72$, $p = .017$, $\eta_p^2 = .242$ (see Figure 5). Post-hoc analysis showed no difference in response accuracy for target, SOD or DOD probes (see Table 2). Target, SOD and DOD locations were, however, more accurate than both NB and FB locations. No difference in accuracy between background locations was found. A main effect of location on target accuracy was found, $F(1,22) = .4.63$, $p = .002$, $\eta_p^2 = .$

181. Post-hoc analysis revealed the main effect was due to more accurate responses for the target when the probe occured at the target location (98.2% correct) compared to when it did not. No difference in target accuracy was found when probes occured at SOD (97% correct), DOD (96.4% correct), NB (96.6% correct) or FB (95.8% correct) locations.

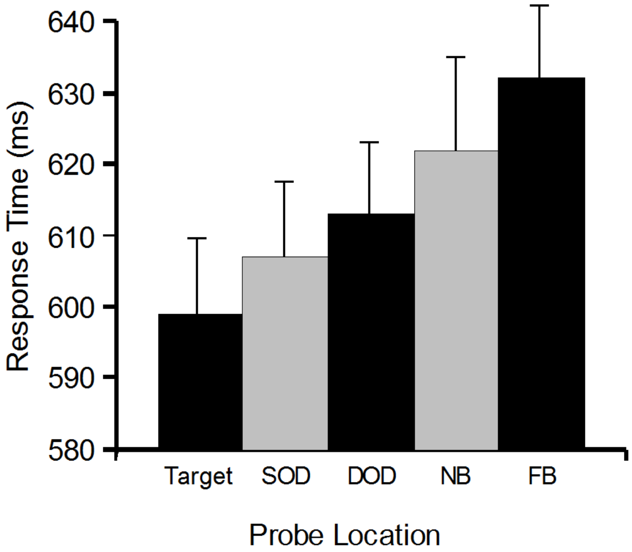

Figure 4. Response times to probes displayed at target, similar object distractor (SOD), dissimilar object distractor (DOD), near background (NB) and far background (FB) locations for Experiment 4, measured in milliseconds. SEM is shown for n = 25 participants.

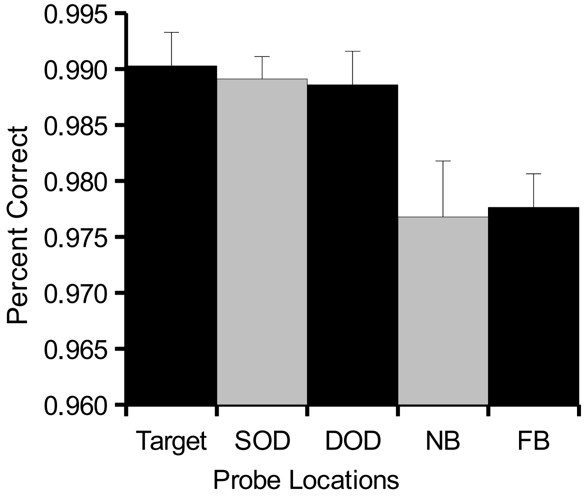

Figure 5. Accuracy of responses *to probes displayed at target, similar object distractor (SOD), dissimilar object distractor (DOD), near background (NB) and far background (FB) locations for Experiment 4. SEM is shown for n = 25 participants.*

Table 1

Post-hoc analysis of response times by condition

	Response Time			
Location	Target	SOD	DOD	NB
Target				
SOD	0.026			
DOD	0.010	0.172		
NB	<.001	0.003	0.076	
FB	<.001	<.001	0.001	0.017

Note. Tukey's LSD post-hoc test compares response time for one condition with response time for all other conditions. SOD: similar object distractor. DOD: dissimilar object distractor. NB: near background. FB: far background.

Table 2

Post-hoc analysis of accuracy by condition

	Accuracy			
Location	Target	SOD	DOD	NB
Target				
SOD	0.649			
DOD	0.624	0.793		
NB	0.01	0.021	0.021	
FB	<.001	0.002	0.004	0.819

Note. Tukey's LSD post-hoc test compares accuracy for one condition with accuracy for all other conditions. SOD: similar object distractor. DOD: dissimilar object distractor. NB: near background. FB: far background.

Discussion

Participants were fastest when responding to probes presented at the target location and equally slower when responding to probes at any of the distractor locations. The decrease in discriminability of the target from the background may have decreased the ability of participants to focus on multiple locations - resulting in the facilitation of the target location found here. Both sets of background locations were responded to slower than the distractor object locations, with the far-background locations receiving the slowest response times. Previous studies using a similar successive task method have generally found responses to locations between objects to be faster than responses to distractor object locations (Klein, 1988; Kim & Cave, 1995; Cave & Zimmerman, 1997; Cepeda et al., 1998). One can conclude that this pattern is likely due to their use of blank white space that surrounded the objects. When distracting information surrounds the objects in a scene, as is the case in our set of experiments, slower response times are found at locations between objects. Perhaps the information contained in the background, being less relevant to the participant's task than the distractor objects, is thus inhibited to a greater degree. The distractor objects, regardless of their top-down similarity to the target, were inhibited less - due to the possibility that these locations could contain the target. Since reaction time to the dissimilar-object-distractor was equal to the similar-distractor-objects, and not the background, inhibition did not occur based on the similarity of the distracting information to the target. This further supports the conclusion that the amount of inhibition an area receives increases as the relevance of the information for the specific task at hand decreases. An analogy would be that when one is searching their refrigerator for a can of coke, the food, oddly shaped jars and bottles receive the most inhibition as they constitute the background. Other cans - beer, ginger ale, pepsi - or an item in a location where the coke is usually located receive less inhibition due to their relevance to the task of finding a can of coke.

Unlike in the third experiment there was evidence of spreading inhibition from distractor objects and spreading facilitation from the target in this experiment. Near-background locations were responded to faster than far background locations, possibly due to the interaction of the facilitation spreading from the target and inhibition spreading from the near distractor objects. The slowest response times for the far background locations would be explained due to the lack of any facilitation influence and a summation of the inhibition from the surrounding distractor objects. The spread of facilitation from a target location (Downing & Pinker, 1985; Eriksen & St. James, 1986; Downing, 1988) and a spread of inhibition from distractor locations (Cepeda et al., 1998) was previously found when blank, white space surrounded all items. Evidence from this study, which also finds a gradient of both facilitation and inhibition, shows that this effect is not a bi-product of viewing a highly controlled scene where distracting information is sparse. Rather, gradients of facilitation and inhibition most likely occur when viewing more natural scenes as well - ones where distracting information of varying relevance to the target is distributed throughout the scene.

General Discussion

Attention, when focused on a target object, facilitates the processing of the object and the facilitation extends into surrounding blank areas (Downing & Pinker, 1985; Downing, 1988; Eriksen & St. James, 1986). To increase the ability to discriminate the target from distracting objects the perceptual system also inhibits the processing of information at locations containing distracting information and this inhibition has also been found to extend into blank areas surrounding the distractors (Cepeda et al., 1998). Two experiments were run to determine what effect a background would have on these two processes. Considering that when viewing the natural world there are very few objects surrounded only by blank space, this study is measuring how attentional processes behave in the real world. Participants focused on an object located amongst distractors with all objects set against a photograph quality background. While focused on the object a probe occured briefly at either the target, distractor or background locations and participants responded to the direction of the probe arrow as quickly as possible. Response times were faster for object locations, slower for distractor locations and slowest for background locations. The proximity of the background information to the target should have produced a good amount of interference when processing the target. This could explain why near background locations were slower than distractor locations, but it does not explain why far background locations were responded to the slowest. Facilitation from the target and inhibition from the near distractors could both have bled into the near background locations. The far background locations would not have received any facilitation from the target, only receiving inhibition from the far distractors. The spread of both a facilitation and inhibition gradient would explain why the far background locations were responded to the slower than the near background locations. This implies that the background as a whole was inhibited more than the distractor objects, otherwise the distractor objects would have been responded to the slowest. It appears that participants were able to allocate attentional resources based on the demands of the task and not necessarily by bottom up processes alone. Since the target could never occur at a background location, the background received the fewest amount of attentional resources, leading to the slowest responses. More resources were allocated to locations where either the target or distractors could occur and most directed to the location where the target appeared. This occured even when one of the distractor objects was changed to be dissimilar from the target. If it was the similarity of the distractor objects to the target alone that was causing the specific level of attentional resource allocation then this manipulation should have led to the dissimilar object mimicking the background, which was not found to be the case. In conclusion, when viewing more realistic images participants treated information irrelevant to the task as a single object and allocated the fewest amount of attentional resources to those locations. Areas in the image that could contain the target received a greater proportion of resources. Proximity of distracting information to the target does not appear to predict the level of inhibition, nor does similarity of the distractor objects to the target. Rather, the relevance of the location to the task asked of participants determined the level of resource allocation - areas that could not contain the target were ignored, while areas that could were facilitated equally.

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