MUCH ADO ABOUT NOTHING: GRADIENT DISCONTINUITIES AND ATTENTION

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ABSTRACT

The research described in this thesis was conducted to determine whether a gradient discontinuity (a gap) in an array of stimuli would also capture attention. A novel task was created to study this; an array of stimuli was presented for a brief period and then removed, a tilted-line target appeared at the gap location or elsewhere. Participants then made a speeded response about the target's orientation which was found to be faster at gap locations than non-gap locations. The results of this research suggest that a gap discontinuity in a regular array of stimuli can capture attention, and can also serve as a location cue. Moreover, its capacity to do so may differ from that of other types of discontinuitie. These findings indicate that studying the operations involved in the visual analysis of gaps may help us to understand, more generally, how stimuli capture our attention.

Keywords: attention, location cueing, attentional capture.

DEDICATION

To those that taught me that hard work is best rewarded with more hard work.

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1: INTRODUCTION

William James once said that everyone has a sense of what attention is. On the surface level, the act is intuitively understood. However, attention has been an elusive concept to understand and define. This may be because it does not refer to a single action or operation. Instead, it appears to be an umbrella term that is used to describe a number of operations such as expecting, filtering, and spatial orienting. It has really only been about 20 years since researchers began to understand the physiological basis of different attentional operations and this breakthrough has allowed us to gain a new appreciation of the complexity of paying attention.

Three attention-related phenomena that researchers have spent a great deal of time studying since the 1970s are orienting, visual search, and attentional capture. Orienting is the alignment in space of the attentional focal point with objects or perceptual stimuli (lights, sounds, touches). We orient our attention in space when we visually search for items of interest. And so the knowledge we have gained from studying attention orienting has helped us to understand the nature of the operations involved when we search for items that are difficult to find. Sometimes items are so easy to find that they seem to grab our attention, whether we are intentionally searching for them or not. This attentional capture is intriguing because the conditions required for it to occur remain unclear (see Theeuwes, Olivers and Belopolsky, 2010). But, like orienting, it is an integral part of visual search. The experiments described in this thesis are related to each of these attentional phenomena, and they are described in more detail in the following sections.

1.1 Location cueing and covert orienting

One of the first empirical studies of attention was conducted by Helmholtz in the mid-1800s. He was able to show that some items in the visual field can be looked at but not paid attention to, while others can be paid attention to but not looked at; which is, in other words, the separation of visual and attentional focus. Helmholtz is thought to be the first to formally demonstrate that we are able to shift our attentional focal point independently of where our visual focal point is directed (Wright & Ward, 2008, pp. 3-6).

Attention shifts that occur in synchrony with head, eye, or body movements are referred to as *overt* attention orienting. Attention shifts that occur independently of head, eye, or body movements are referred to as *covert* attention orienting. Helmholtz's work demonstrated the process of covert orienting.

Covert attention orienting is usually studied with some variant of a task in which a location cue precedes, by a fraction of a second, a target that requires a response from observers but no overt eye movement. In some cases, cue presentation facilitates or inhibits target responses in a way that suggests that an attention shift was initiated to the cued location prior to target onset. This task has been used to study the nature of attention orienting to visual stimuli.

Posner and colleagues are generally credited with the developing and refining the location cueing task (e.g., Posner, 1978; Posner et al., 1980), and it has been used so often over the past 30 years that it has come to be known in the attention literature as the *Posner task*. A typical Posner task usually has a small fixation point in the centre of the display screen that observers are required to direct their gaze toward (i.e., foveate) throughout each experimental trial. Then a location cue is presented, usually 100 to 300 ms before the onset of a target that observers must respond to. A common finding is that the cue will facilitate target response time and accuracy. It has been suggested that cue effects on target responses may be due to attention orienting.

One of the Posner task's strengths is its simplicity. Another is the ease by which the task can be varied. In some experiments, for example, the cue indicates the impending target's location with a high degree of probability. In other experiments, the cue might provide no useful information about where the target will appear. This is referred to as *cue validity*; simply is the cue predictive or unpredictive. Another important variable is the delay between cue and target onset, or *cue-target onset asynchrony* (CTOA). Both cue validity and CTOA are variables in the research conducted for this thesis.

One reason why cue validity is varied is to determine whether or not a location cue will affect target responses. To elaborate, trials on which the target and cue location coincide (spatially but not temporally) are referred to as valid-cue trials or predictive cue trials. Trials on which a cue and target locations do not coincide are referred to as invalid-cue trials. Neutral trials, which are sometimes included in experiments to serve as a baseline measure, involve an uninformative cue that does not indicate any potential target, and only provide a warning signal about the target's impending onset. If a cue is valid, it may allow an observer to respond to targets appearing at its location faster and more accurately than would be the case on neutral-cue trials. In contrast, if a cue is invalid, it may cause an observer to respond to targets appearing at its location slower and less accurately than would be the case on neutral-cue trials. The latter is called the cost of invalid cueing on target responses, and the former is called the benefit of valid cueing on target responses.

Many researchers avoid the use of neutral-cue trials because the baseline measure they provide for cost/benefit analysis is often unreliable (see Jonides & Mack, 1984; Wright, Richard, & McDonald, 1995). Use of an improper neutral cue, for example, can lead to overinflated response-time costs and underestimated benefits. As discussed in the experimentation section of this thesis, cueing effects that are determined by comparing mean valid- and invalid-cue responses are not subject to this unreliability.

Cueing effects depend, in part, on the type of location cue. A symbolic location cue is usually a centrally presented arrow symbol that points in the direction of the impending target's probable location. Because it is a symbol, processing this cue requires cognitive operations. The observer must interpret the symbol as denoting a particular location and then must choose whether or not to generate an expectancy about the target on the basis of this information. Symbolic cue use is voluntary and, because cognitive processing is involved, this type of location cue is usually not effective unless the CTOA is roughly 300 ms or more. Therefore, cueing effects do not usually occur with low-validity symbolic cues, and with symbolic cues that precede the onset of targets by less than 300 ms.

A direct cue appears at or near the probable location of the impending target. It is usually a vertical or horizontal line close to this location, or an outline box surrounding it. No cognitive interpretation is required, and direct-cue effects occur even with non-predictive cues. Unlike symbolic cues, direct cues are most effective when the CTOA is roughly 100 ms, and their effect can dissipate when this delay is increased to 300 ms or more (or, when CTOA is increased, can lead to a negative effect called inhibition of return; Posner & Cohen, 1984; Posner et al., 1985). Cueing effects produced by direct location cues are more closely related to sensory processing than cueing effects produced by symbolic cues.

1.2 Attention and visual search

Attention orienting occurs whenever we search the environment for items of interest. For this reason, visual search has been one of the most intensely studied topics in psychology over the past 30 years. The research on location cueing and covert orienting described in the previous section has helped us to gain a better understanding of the operations involved in visual search.

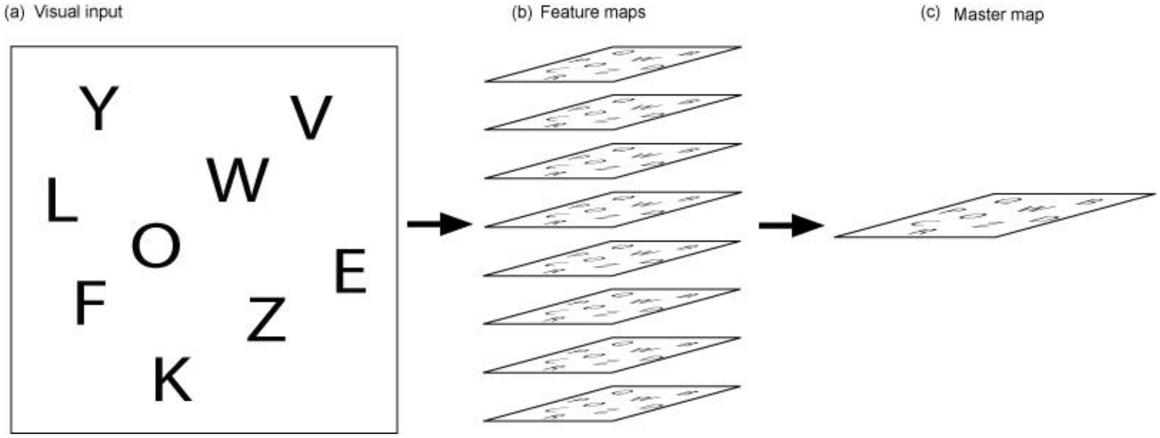
Neisser (1963, 1964) was among the first to conduct a systematic investigation of the relationship between attention and visual search. He is often credited with being the first to formally demonstrate that items are easier to find if they have a unique feature that surrounding items do not possess. Observers in his experiments typically were required to search through an array letters and to determine, as quickly and as accurately as possible, whether a target letter was present among them. Target present/absent responses were made quickly when the target letter was visually distinct from the others. For example, a circular letter (e.g., O, C) stands out within an array of non-circular letters that possess a line (e.g., X, Z) and vice versa. When the target letter did not stand out from the others, target present/absent responses were slower. It may be that more attention and effort is required for this type of visual search.

Neisser also demonstrated that when searching for a target that is difficult to find, a *set-size effect* occurs. That is, as the number of non-target items (distractors) in the stimulus array is increased, the time required to make a target present/absent response also increases. There is no set-size effect, however, when searching for a target that is easy to find. This type of target has a unique feature that causes it to pop out from the surrounding items. When the relationship between set size and response time is plotted graphically, a target that is distinct from other items in the array pops out and subsequently has a flat search slope. A target that is not distinct from the other items in the array does not pop out, and has a steep search slope.

Based on this discovery, Neisser proposed that search for hard-to-find targets requires serial attentional analysis. Each item must be attended to in sequence to verify whether it is the target or not. He proposed that search for easy-to-find targets that pop out does not require serial attentional analysis. Instead, he suggested that all items in the search array are processed in parallel, but in a manner he called *preattentive*. The serial-parallel visual search dichotomy was compelling and, in the 1980s, it influenced the development of more elaborate visual search models. More recently, however, it is generally accepted among attention researchers studying visual search that processing is not strictly serial or parallel.

One visual search model that built on and was a refinement of Neisser's visual search proposal is feature-integration theory (Treisman & Gelade, 1980). This model preserved the serial-parallel search dichotomy and it accounted for the two types of search in terms of a spatial map based architecture. Serial attentional analysis was said to occur within a master location map. This master map is a representation of space that the attentional focal point was said to move within, as discussed in the previous section on attention orienting. Parallel non-attentional analysis was said to occur within a set of feature maps. These are also representations of space but each one was said to contain only information about one type of feature (e.g., colour, orientation, size). Information in all of the feature maps was said to be accessible to processing carried out within the master map, but only by moving focused attention from one master map location to the next. In Treisman's terms, focused attention in the master map served to integrate information in all feature maps at a particular location, as though it was "gluing" it together. This is why the model is called feature-integration theory (Figure 1).

Figure 1 ***Outline of feature integration theory***



Note. Map-based architecture of feature-integration theory. Visual input is processed in a number of different feature maps, each responsible for the processing of specific visual elements (orientation, colour, intensity etc.). These feature maps provide input to the master map. At the master map level, attention binds features together into objects.

Feature-integration theory holds that parallel search and rapid target localization is initiated by processing within the feature maps. For example, suppose that an observer is searching for a red target, and it is easy to find because it has a unique colour and therefore pops out from the surrounding distractors. The model holds that the colours of all items in the search array are processed in parallel in the colour feature map. The presence of a single red item in the colour map provides a clue about where to search first. More specifically, the colour map sends a signal to the master map about the presence of the single red item and this, in turn, guides focused attention to the corresponding location of the item within the master map. Thus, attention is not operating within individual feature maps. This occurs only within the master map. In the case of easy-to-find targets that pop out, the master map receives input from feature maps about items with unique features.

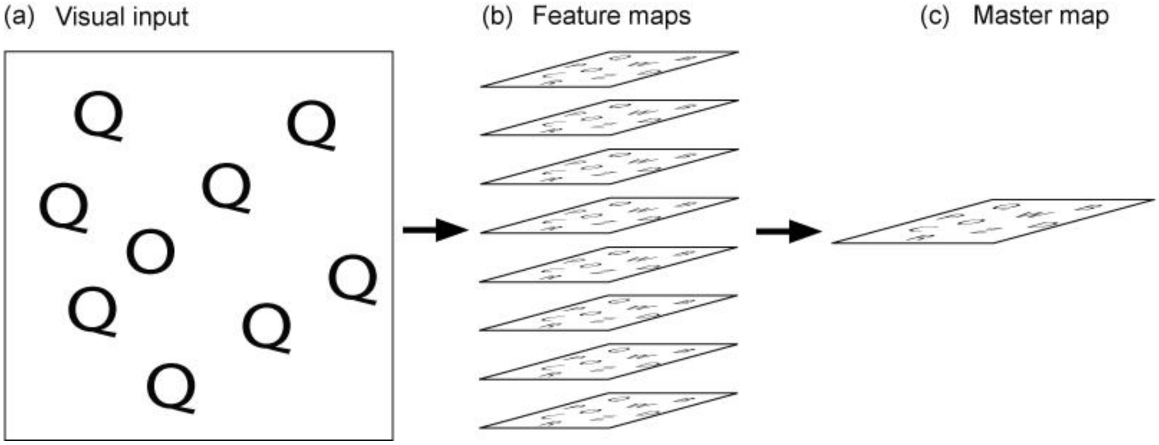
The initial version of feature-integration theory was based on assumptions that were not consistent with the results of subsequent research. For example, Treisman and Gelade (1980) stated that features are represented independently of their locations, and that location information is used only to bind an object's features together. More recent research, however, indicated that feature information often includes location (e.g., Cohen & Ivry, 1989). Treisman (1998) acknowledged that the disassociation between "what" and "where" in feature processing is not as extreme as originally proposed by Treisman and Gelade (1980) and went on to revise her original proposal. Other research indicated that the serial-parallel search dichotomy that the initial version of the model is based on appears to be overstated (e.g., Duncan & Humphreys, 1989, 1992), and that it may be more accurate to describe visual search as being more or less efficient rather than serial or parallel.

Feature-integration theory is provocative because it yields several testable predictions. One of them is related to the experiments described in this thesis. In particular, the model holds that a target will not pop out if it lacks a feature that all distractors possess. One type of visual search task is the *odd-man-out task*. Observers do not know what type of target they will be searching for, and their task is to determine whether one of the items in the search array is different from the others. An odd-man-out target will pop out if it has a unique feature that the surrounding distractors do not. On the other hand, an odd-man-out target will not pop out if it is unique because it is the only item in the search array that lacks a particular feature (e.g., the only circle that is not bisected by a vertical line). In other words, the presence of a unique feature at one item location within the search array is salient. But the absence of a feature at one location that is present at all other item locations is not salient. This is sometimes referred to as a *search asymmetry*, and it has been found in several experiments (e.g., Treisman & Gormican, 1988; Treisman & Souther, 1985; see also, Rauschenberger & Yantis, 2006; Wolfe, 2001). According to feature-integration theory, a search asymmetry should occur because, when a target possesses a unique feature, the associated feature map will send a signal to the master map about its presence and location. But when a target is unique by virtue of lacking a feature, the associated feature map cannot do so because the feature in question is present at many feature map locations.

The experiments described in this thesis involved a modified Posner task. The location cue was not a single stimulus. It was, instead, an array of stimuli like that in a visual search experiment. The stimuli were arranged in a regular pattern and, when one of the stimuli was absent from the array, this resulted in a gap. One research question was whether or not this gap was salient enough to capture attention. The feature-integration theory account of search asymmetries holds that when an object at a location is unique by virtue of the absence of a particular feature, this does not cause attention to be captured at that location (Figure 2). One difference between the current experiments and search -

asymmetry experiments is that, in the current experiments, there is no object at the gap location. Therefore, according to feature-integration theory, no signal should be sent to the master map about a unique feature at that location. In other words, the gap should not pop out because there is nothing at that location within feature maps. This issue is discussed in more detail in the General Discussion.

Figure 2 ***Feature-integration theory account of asymmetric search***



During normal pop-out search, a single feature map can signal the location of the pop-out item. In asymmetric search, there is no single feature map capable of signalling the location of the ‘O’. The theory holds that pop-search only occurs when there is a feature difference that is additive.

1.3 Attentional capture

What is it that captures our attention and how does it do so? In the 1600s, Descartes speculated about why attention might be involuntarily drawn to objects of interest. In the 1800s, James proposed that, in his words, if a stimulus is very intense or sudden, it may capture attention and this may involve the adjustment of sensory organs; and in the early 1900s, Koffka talked about attentional capture in terms of a force going from an object to the self (Wright & Ward, 2008, pp. 9-11). Like James, Titchener (1908, p. 192) also proposed that if a stimulus appears suddenly and abruptly, it can capture attention.

Attentional capture is often studied with a visual search task. Yantis and colleagues conducted some of the first experiments of this type (e.g. Yantis & Hillstrom, 1994; Yantis & Johnson, 1990; Yantis & Jones, 1991; Yantis & Jonides, 1984, 1990). Typically, in their experiments, search arrays contained two types of targets. One type had a gradual onset. In particular, when the search array was first presented, a gradual-onset target appeared initially as a placeholder stimulus resembling a rectangular figure eight. After the placeholder was visible for roughly one second, some of its component lines were removed like camouflage to reveal the target letter. It was a gradual-onset target in the sense that another object (the placeholder) was already present at its location, and this object was transformed into the target. The other type of target had an abrupt onset relative to the items in the search array. More specifically, this type of target was quite noticeable because the visual search array would appear first. Then, after a brief delay, the target would appear at a previously empty location. Therefore, relative to gradual-onset targets, its onset was abrupt. The general finding was that when these two types of targets were used in visual search experiments, abrupt-onset targets popped out and gradual-onset targets did not. On this basis, Yantis and colleagues concluded that abrupt-onset stimuli can capture attention.

After this research was conducted, it was thought that an abrupt onset is required for attentional capture (Jonides & Yantis, 1988). But the results of subsequent experiments indicated that other properties of objects can also capture attention. Yantis and Hillstrom (1994), for example, proposed that it is not the abrupt onset of an object that captures attention, but rather the fact that it is a new object. The appearance of new objects in their experiments was not, they argued, accompanied by changes in luminance that occur with abrupt onsets. The new-object proposal is controversial, and some researchers have argued that luminance changes are required to capture attention (e.g., Theeuwes, 1995; see also, Ruz & Lupianez, 2002).

When attention is captured by an abrupt-onset stimulus, this is triggered reflexively in a stimulus-driven (bottom-up) manner. However, capture is not solely a reflexive operation. In particular, attention is not always captured by an abrupt onset if it is actively engaged at another location (Lamy & Tsal, 1999; Theeuwes, 1991; Yantis & Jonides, 1990). Attentional capture can be contingent upon the observer's perceptual goals. In one study, for example, when a task involving targets defined by a unique colour was performed (e.g., red target & green distractors), abrupt-onset distractors did not interfere with performance and therefore did not capture attention (Folk, Remington, & Johnston, 1992). When distractors shared the same colour as the target, their presence did interfere with task performance and did capture attention. Conversely, when targets were defined by their abrupt onset, unique-coloured distractors did not interfere and did not capture attention. Only abrupt-onset distractors did so. In other words, attentional capture depended on current perceptual goals, and this attentional set could override stimulus-driven capture. The contingent attentional capture proposal is controversial, and there are other milder versions (see Burnham & Neely, 2008; Ruz & Lupianez, 2002; Turatto & Galfano, 2001; Yantis & Egeth, 1999).

One alternative to the contingent capture proposal is that top-down control of attentional capture is limited by temporal and spatial factors (Stigchel, Belopolsky, Peters, Wijen, Meeter, & Theewues, 2009). In particular, Stigchel et al. argue that rapid target localization is due to the influence of target foreknowledge on post-selection processes rather than speed of attentional deployment. If true, then attentional capture by these targets would be due to bottom-up priming rather than top-down control.

It has also been proposed that attentional capture may be mediated by a concept called dimensional weighting. When performing an odd-man-out task, for example, the exact nature of the target is not known because it varies from one trial to the next. According to the dimensional weighting proposal, the attention system gives greater weight to the dimensions that the target might have, and less weight to other dimensions. These weightings are continuously modulated in a top-down manner. One indication that a process like this may underlie contingent capture is that there appears to be a cost associated with switching weights, as indicated by ERP analysis and modulation of N2pc (Graman, Todlner, Krummenacher, Eimer, & Muller, 2007). The dimensional weighting proposal raises questions not only about what captures attention, but about when and by what means.

1.4 Location cueing with attentional capture stimuli

Aspects of the location cueing and visual search tasks have been combined to determine whether or not cueing affects visual search performance (e.g., Briand & Klein, 1987; Shiu & Pashler, 1994; Treisman, 1986; Treisman & Gelade, 1980). The results of these studies indicate that it depends on the type of location cue presented, and the type of target being searched for. Location cues only facilitate the search for hard-to-find targets, and not those that pop out. In addition, this response facilitation occurs only if a direct cue is used. Symbolic location cues, normally, do not affect visual search performance. Woodman, Arita, and Luck (2009) show that symbolic cueing can affect visual search if the symbolic cue is indicating an object and not a location. Therefore, it is possible to use a symbolic cue to affect performance in a visual search task but only when the symbolic cue is present with the search array or the symbolic cue precedes the search array but all possible item locations have corresponding placeholders. Regardless, if a direct location cue is presented 100 ms before the onset of the visual search array, and if the cue is at the location of a hard-to-find target, then the target present/absent response may be facilitated.

The order of presentation of stimuli in these experiments is a single stimulus (location cue) followed by a visual search array. The order of presentation of stimuli in the current experiments is the reverse of this. That is, an array of stimuli typical of a visual search display is presented first, and is followed by a single stimulus (target). It is similar to the stimulus presentation used to study a phenomenon that some call inhibitory tagging (e.g., Klein, 1988). Typically, in these experiments, an array of stimuli appears briefly and then a target is presented. Observers are required to detect the target as quickly as possible. The array of stimuli that precedes it sometimes contains a singleton that sometimes pops out and sometimes does not. The general result of this type of experiment is that the initially-presented stimulus arrays sometimes facilitate target detection response times.

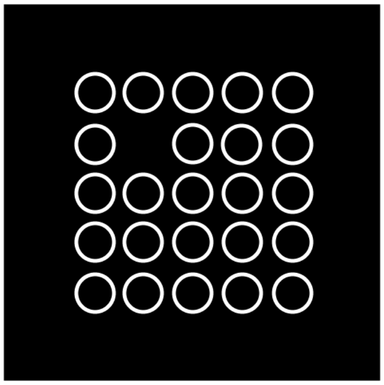
The task used in the current experiments also involves the presentation of a stimulus array, followed by a single target stimulus. It is essentially a modified Posner task. One of the primary research questions was the following: If attention is captured by one of the elements within the array of stimuli, can this element serve as an effective location cue and facilitate responses to targets as in a standard Posner task?

1.5 The gap and the goal

The stimulus array used in the current experiments was a regular arrangement of circles (5 rows & 5 columns). In some cases, a circle was missing and this created a gap in the texture of the pattern. A gradient discontinuity is a “break” in a known pattern. This can be a simple feature discontinuity, such as colour or shape, or it can be semantically complex like a word or number discontinuity. It can be as simple as an “odd ball” letter in a string of letters such L, L, L, L, R, L, L. Researchers have manipulated the distinctiveness of discontinuities to explore the mechanisms of attention (e.g., Treisman, 1986).

A *gap discontinuity* can be thought of as a type of feature discontinuity. Unlike other feature discontinuities, a gap discontinuity is the absence of a feature or object in a known pattern (see Figure 3). If we consider an object as being the collection of features (e.g., Treisman, 1986) then there is “nothing” at the gap’s location. A growing body of research suggests, however, that illusory objects and contours may have the same attentional properties as normal objects (see Martinez, Teder-Salejarvi, & Hillyard, 2006; Martinez, Ramanathan, Foxe, Javitt, & Hillyard, 2007). As well, questions remain about what counts as a visual object (e.g., Scholl, Pylyshyn, & Feldman, 2001). Is a gap discontinuity an object, or perhaps an illusory object? And will it capture attention like other types of objects? These questions are addressed in more detail in the General Discussion.

Figure 3 ***Example of gap discontinuity used in the current experiments***



Note. Above is an example of a gapped array.

From a visual search perspective, perhaps a gap in this type of regular pattern is also a singleton. An initial goal of this research was to determine whether or not the discontinuity in the pattern would capture attention. A number of studies have demonstrated that boundaries between different regions of patterns will pop out when searched for. For example, the boundary between upright and tilted letter Ts pops out because of the difference in their orientation (Treisman, 1986). This demonstrates that if the target item differs from the rest of the items in the display within one dimension of feature (orientation), then it will pop-out. But will pop out also occur if a region is unique because it is the only location, within a regular pattern, that is lacking a stimulus?

It could be argued that a gap discontinuity is not, in fact, a region that lacks a stimulus. The visual system is finely tuned for edge detection and extremely sensitive to contrast differences (Hubel & Wiesel, 1979). And our capacity to process gap discontinuities has been studied in a variety of experiments on, for example, visual integration, iconic memory, and visual masking (e.g., Di Lollo, 1977; Kinnucan & Friden, 1981). But there has been only one attempt that I know of to determine whether or not a gap discontinuity can modulate attentional processing (Kiss & Eimer, 2009, June). As mentioned in the General Discussion, it could be argued that the results were limited by the nature of the stimulus presentations. A primary goal of the current experiments was to determine whether or not this type of gap will capture attention.

2: TESTING THE GAP

2.1 Experiment One

The first experiment was conducted to determine whether or not a gradient discontinuity in the form of an empty region (gap discontinuity) in array of circular stimuli would capture attention; and, if so, whether the attentional capture by this odd-man-out location associated with the empty region would be sufficient to facilitate responses to targets subsequently appearing there. A variant of the Posner task was used. Whereas the typical location cue in Posner-task experiments is a single stimulus (underline or bar marker), the location cue in this experiment was an array of stimuli of the type that is often used in visual search and attentional capture experiments. In some cases, a location cueing effect on responses to targets is more likely if there is a high probability that the target will appear at the cued location, and if the delay between cue and target onset is long enough for observers to voluntarily orient their attention to the cued location before the target appears. Therefore, in order to increase the likelihood that gap discontinuities would facilitate responses to targets in this experiment, the location cue information conveyed by the gap was 100% valid; and a relatively long (300 ms) delay between cue and target onset was used. In sum, the first experiment was conducted to find out if, using parameters that were initially believed to be most likely to produce response facilitation, a gap discontinuity can serve as a Posner-task location cue.

2.1.1 Method

Participants. Thirteen Simon Fraser University students were given course credit for taking part in the experiment. All participants had normal or corrected-to-normal vision, and none reported any vision difficulties.

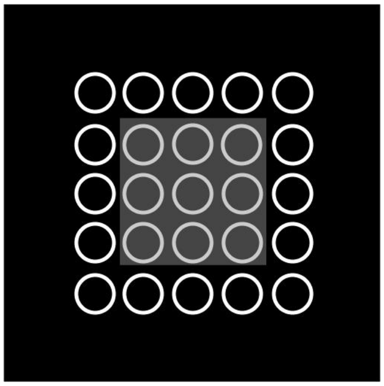
Apparatus: A microcomputer (PC) controlled the experiment timing and stimulus presentation. Stimuli were displayed on a 19-inch LCD monitor (Samsung SyncMaster 932BF) with a 2 ms response time. Responses were recorded with a custom-built button box interfaced with the computer. Participants were tested in a dimly lit room to minimize reflections, and an adjustable chin rest was used to maintain head position at a distance of 60 cm from the computer monitor.

Stimuli: All stimuli were presented on a black (unlit) background. A small white ellipse (0.86 x 1.06 degrees) in the centre of the display served as a fixation point, and remained visible for 1000 ms before the beginning of each trial. The offset of the fixation point was followed by 25 white circles (5.47 x 7.29 degrees) that were equidistant of one another and arranged in a 5 x 5 array. The array was rectangular and subtended 29.84 x 39.57 degrees in the centre of the display. On some trials, the 5 x 5 array contained only 24 circles and one randomly selected “empty” location (gap discontinuity). And, on these gap trials, the gap only appeared within the inner 3 x 3 portion of the cue array. Figure 4 illustrates the *gap* discontinuity. After the offset of the cue array, the display remained blank for 200 ms. This temporal interval was long enough to preclude the possibility of forward masking of the target by the array (e.g., Breitmeyer, 1984; Kahneman, 1968), as did the size of the empty region (6.98 x 9.86

degrees) relative to that of the smaller target. Then, a white diagonal line (3.17 x 4.1 degrees) was presented at one of nine locations associated within the inner 3 x 3 array of the complete 5 x 5 array. This was the target stimulus. The target was tilted either to the left (on 50% of trials) or to the right (on 50% of trials) at a 45 degree angle.

Procedure. Participants were instructed to direct their eyes toward the fixation point throughout the experiment, to determine the orientation of the target, and to press one of two response buttons. The left button was for left-tilted target responses and the right button was for right-tilted target responses. Participants were also told that before the target appeared, they would see the cue array for a brief period. Then, after it disappeared, the target would appear with equal likelihood at one of the nine locations corresponding to the interior 3 x 3 array of locations of these circles (see Figure 4). This occurred on half of the trials (the neutral trials). On the other half of trials, only 24 circles were presented in the cue array and one of the locations in the 3 x 3 stimulus array was empty (the gap trials). Participants were told to expect this; and that when it occurred, the target would always appear at the empty location. In other words, the empty region always indicated the impending target's location, and therefore it was a 100% valid cue. Order of presentation of trial types was completely randomized. Reaction time data were collected in a 35-minute testing session that was divided into three blocks of 360 trials with a brief rest period following each block.

Figure 4 ***Example of cue array and possible target locations used in all experiments***

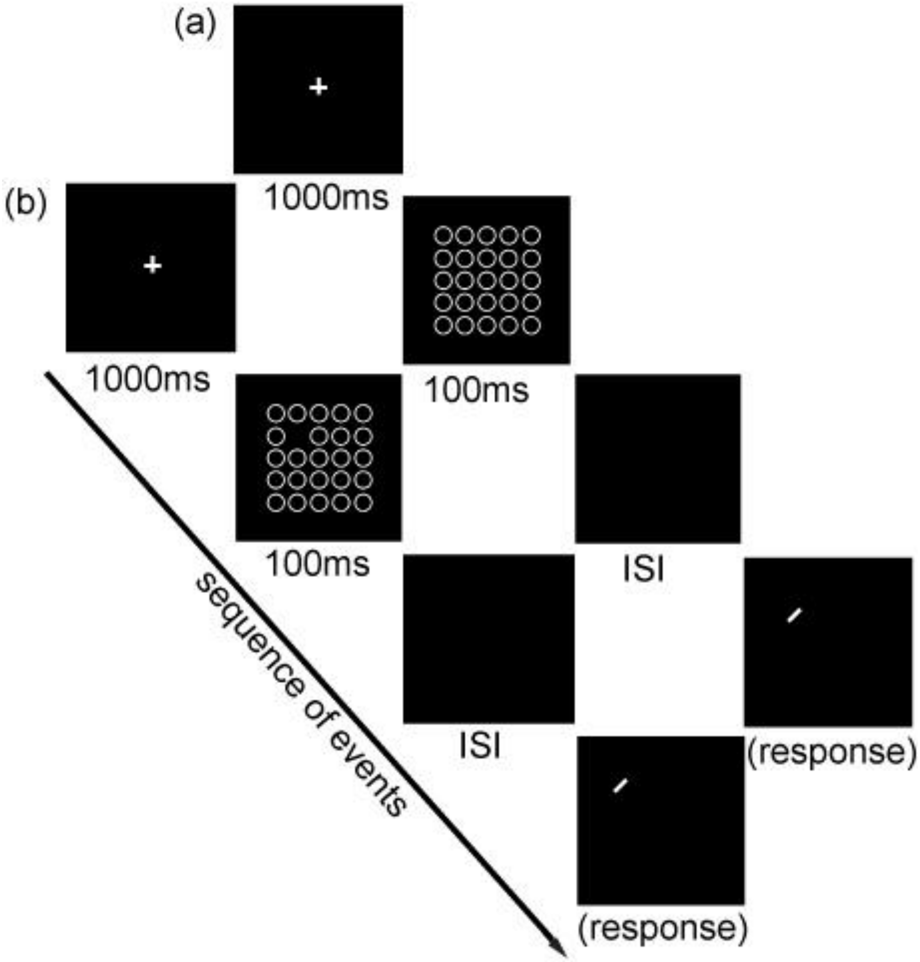


Note. This figure shows a 5x5 array. The light grey shaded area indicates the interior 3 x 3 array corresponding to the 9 possible target locations.

As seen in Figure 5, each trial began with a 1000 ms interval, during which the fixation point was visible. Then the cue array was presented for 100 ms and was followed by a 200 ms blank field. Thus, the cue-target onset asynchrony (CTOA) in this experiment was 300 ms. The target remained visible until a response was made. Participants were told to make their responses as quickly but also as accurately as they could. Response times were measured as the interval between the target onset and the button press. When the target was extinguished following the subject's response, this marked the end of the trial.

Design: There were 540 neutral trials and 540 gap trials, for a total of 1080. In the neutral condition, the target appeared at nine possible locations (Figure 4) and there were 60 trials for each location. In the gap condition, the discontinuity appeared at the same nine possible locations, there were 60 trials for each location, and the target always appeared at the gap location.

Figure 5 ***Sequence of stimulus presentation in Experiment 1***



Note. Examples of a neutral trial (a) and a gap trial (b).

Data Analysis. In all experiments, before any statistical analyses were carried out, response times less than 150 ms and greater than 1500 ms were excluded as errors. After outlier removal, paired comparisons or Analyses of variance (ANOVAs) were conducted to determine whether or not speed-accuracy trade-offs occurred. These results are not reported in this or other results sections because no significant trade-offs occurred.

2.1.2 Results and Discussion

The mean target-discrimination response times for the whole array and gapped array conditions were 487 and 442 ms respectively. A t-test indicated that the responses were faster on gap trials than on neutral trials ($t_{(12)} = -6.41$, $p < 0.001$). One interpretation of this finding is that the gap facilitated target orientation discrimination by causing attention to be captured at target locations prior to their onsets. Another more conservative interpretation, however, is that responses were faster on gap trials than on neutral trials because some aspect of the gap provided a more effective warning signal about the impending target's onset than occurred neutral trials. Thus, it is unclear whether the gap facilitated responses by serving as a location cue or by serving as a strong warning signal about target onset.

If it is assumed that the gap can serve as a location cue, one limitation of the first experiment was that the cue validity was 100%. Therefore, determining whether or not a cueing effect (as opposed to a warning-signal effect) occurred was not possible. In order to do so, both valid and invalid gap-cue trials would be required. If such an experiment was conducted and there was a response-time "cost" of invalid cueing relative to neutral and valid cueing, this would indicate that attention may have been misdirected to invalid-cue locations rather than to where the target ultimately appeared. And, therefore, differences between neutral trial and gap trial mean response times may not be due simply to a facilitative warning effect induced by onset of the array containing an empty space.

Some researchers (e.g., Wright & Ward, 2008) have stated that when the Posner task is used and the CTOA is 300 ms, eye movements should be monitored because this delay is long enough for participants to initiate a saccadic eye movement after cue onset but before target onset (Fischer & Weber, 1993). Therefore, on gap trials in the current experiment, it was possible for a saccade to have been initiated from the central fixation point to the gap location prior to the target appearing there. Because this is a possibility, it is unclear whether or not the response facilitation produced by the gap discontinuity was due, in part, to saccadic eye movement programming and execution.

When the Posner task was first used in the 1970s to determine whether or not observers could orient attention covertly, one condition that had to be satisfied was that the effect of cueing on responses could not be due to overt attention orienting (e.g., eye movements). The goal of these early studies was to demonstrate that cue-induced effects on responses were due to attention shifting independently of eye movements. This finding has since been replicated consistently and there is now an overwhelming consensus among researchers that attention can be oriented to cued locations covertly, and can facilitate responses to targets appearing there.

Controlling for eye movements in these early experiments was necessary to prove that covert orienting is possible. And it continues to be part of the recommended procedure for those using the Posner task to study attention orienting when the CTOAs involved are greater than saccade latency (220 ms). One could argue, however, that 30 years of replications have left little doubt that location cueing effects can occur without contributions by oculomotor operations. And some researchers have stated that the need to demonstrate that location cueing effects are due to purely covert attention may be overblown. Findlay and Gilchrist (2003), for example, argue that there is a close linkage between ocular focus and attentional focus; that attentional processing is rarely carried out at locations other than the direction of our gaze; and that the importance of covert orienting for understanding attentional analysis of visual stimuli is overstated. Instead, they claim that most attentional analysis of visual stimuli is closely related to eye movements.

This has been tacitly accepted by researchers studying visual search over the past 30 years. Eye movements are usually not monitored during visual search experiments; and when it is done, its purpose is usually to better understand the scan paths of attentional processing. Eye movement monitoring is not viewed by these researchers as a requirement for studying attention orienting, even when examining the effects of location cueing on visual search efficiency (e.g., Treisman & Gelade, 1980). And when this type of experiment is conducted, they do not feel that they must demonstrate that attention orienting during visual search is purely covert.

Despite some limitations, the first experiment does indicate that trials with a gap discontinuity had a different effect on target-orientation discrimination responses than trials without one. Liberal design parameters are often implemented in the first of a series of experiments in order to determine whether or not a particular effect is possible. In the experiments that follow, design parameters are made more conservative to test specific aspects of the gap-cueing hypothesis.

2.2 Experiment Two

The second experiment was conducted to determine whether or not a gap discontinuity in an array of circular stimuli could elicit a location cueing effect on target-orientation discrimination responses if, in addition to neutral cues, both valid and invalid cues were used. Thus, Experiment 2 was a replication of the first experiment with the exception that targets on gap trials occurred at cued locations at the chance level. If the mean response time on invalid-cue trials was longer than those on neutral- and valid-cue trials, then this would indicate that the differences were not simply due to a cue-onset induced warning signal. In particular, warning signals typically prepare an observer for a target stimulus and *decrease* the time required to respond to it; not increase it. In sum, the second experiment was carried out to determine whether gap cues would produce location cueing effects.

2.2.1 Method

Participants. Ten Simon Fraser University students were given course credit for taking part in the experiment. All participants had normal or corrected-to-normal vision, and none reported any vision difficulties.

Stimuli and Procedure. The stimulus displays and procedure were the same as those of Experiment 1 with the following exception: In the first experiment, on gap trials, the target always appeared at the same location as the empty region of the previous cue array. In this experiment, on gap trials, the target was equally likely to appear at any of the nine locations corresponding to the interior 3 x 3 array of the larger 5 x 5 array (Figure 4). Therefore, in this experiment, on gap trials, the empty region was uninformative about the impending target’s location. Participants received the same instructions as those in Experiment 1, with exception of the information about how useful the empty region’s location would be for predicting the target location. In particular, they were told that the empty region of the cue array did not predict the location of the target that followed any better than chance (11.1% cue validity). Also, in Experiment 1, there were an equal number of neutral and gap trials. In this experiment, 80% of trials were gap trials and 20% were neutral trials. Participants were told to expect that on most trials, in the inner 3 x 3 array there would be an empty region. Reaction time data were collected in a 35 to 50 minute testing session. The session was divided into ten blocks of 108 trials, for a total of 1080. A brief rest period followed each block. Order of presentation of trial types was completely randomized.

Design: There were 180 neutral trials and 900 gap trials, for a total of 1080. In the neutral condition, the target appeared at nine possible locations and there were 20 trials for each location. In the gapped array condition, the discontinuity appeared at the same nine possible locations and there were 100 trials for each location. As stated previously, the target in the gap condition appeared at these nine locations with equal probability and the gap did not predict the impending target’s location.

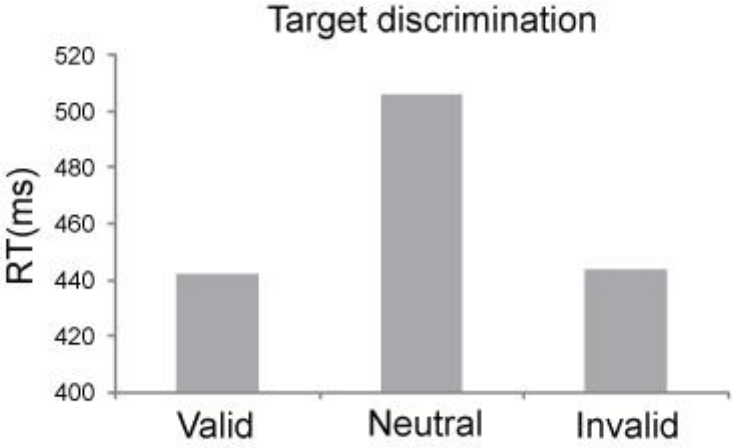
2.2.2 Results and Discussion

Whole arrays were used for neutral cueing, and gapped arrays were used for valid and invalid cueing. A 1 x 3 repeated-measures ANOVA indicated that there was a significant main effect of Cue Validity ($F_{(1,9)} = 9.88$, Mse = 2717.9, $p < 0.025$). Paired comparisons indicated that whereas the differences between the mean neutral cue response time (506 ms) and the mean valid (443ms) and invalid cue (442 ms) response times were both significant ($p < .005$), the difference between mean valid and invalid cue response times was not (see Figure 6). In other words, even with the inclusion of invalid-cue trials in this experiment, the near equivalence of the mean valid-cue and invalid-cue response times suggests that responses may have been faster on gap trials only because the gap produced a more effective warning signal than a whole array.

Experiment 2 was intended to be a nearly exact replication of the first experiment, in part, to establish the finding that response times on gap trials are faster than on neutral trials. There are, however, some reasons why a cue effect may not have occurred. In particular, targets appeared with equal probability at cued and uncued locations on gap trials, and participants were told that the gap location was not an informative location cue and that it could be ignored. Presumably they did so. As result, no symbolic (endogenous) cueing effect should have been expected. When uninformative cues are used, typically only a direct (exogenous) cueing effect will occur because observers will have no reason to voluntarily process a cue that does not predict the impending target's location. Moreover, a direct cueing effect should not have been expected in the current experiment and the previous experiment because of the relatively long (300ms) delay between cue and target. Direct cues are most effective with shorter (100 to 200 ms) CTOAs. So perhaps one reason why a cueing effect was not found in Experiment 2 was that an inappropriately long CTOA was used instead of one that was optimal for direct cueing.

In summary, the current experiment served only to replicate the Experiment 1 finding that response times on gap trials were faster than those on neutral trials. The near equivalence of the mean valid-cue and invalid-cue response times was consistent with the warning signal account of the results. But a gap cueing effect may be possible if experimental parameters (particularly CTOA) are adjusted to be optimal for direct cueing rather than symbolic cueing.

Figure 6 ***Experiment 2 mean response times***



Note. Valid refers to gap trials on which the target appeared at the gapped location. Invalid refers to gap trials on which the target appeared at an uncued location.

2.3 Experiment Three

The third experiment was conducted to determine whether or not a gap discontinuity would produce a cueing effect if a cue-target delay shorter than 300 ms was used. Experiment 3 was a replication of the second experiment with the exception that there were three different CTOA conditions. If the results support the hypothesis that a cueing effect will occur when this delay is shorter (200 ms) but not when it is longer (300 & 400 ms), it would indicate that, like direct cueing, cueing with a gap discontinuity is most effective at shorter CTOAs. And the occurrence of a cueing effect would indicate that the differences between mean responses times for gap and neutral trials are not due only to a cue-onset induced warning signal.

2.3.1 Method

Participants. Eighteen Simon Fraser University students were given course credit for taking part in the experiment. All participants had normal or corrected-to-normal vision, and none reported any vision difficulties.

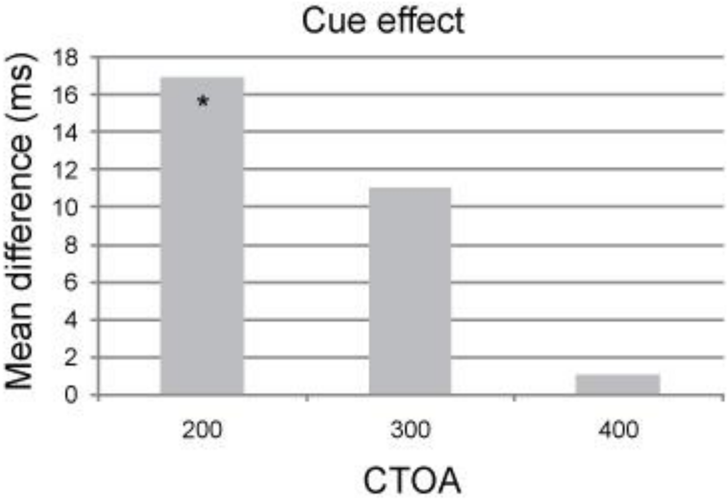
Stimuli and Procedure: The stimulus displays and procedure were the same as those of Experiment 2e with the following exception. In the previous experiment, the delay between cue-array onset and target onset was 300 ms. In this experiment, the blank field was presented at 100, 200, or 300 ms. Thus, in the current experiment, the CTOA was 200, 300, or 400 ms. Order of presentation of trial types was completely randomized. Reaction time data were collected in a 35 to 50 minute testing session that was divided into ten blocks of 108 trials with a brief rest period following each block.

Design: There were 108 neutral trials and 972 gap trials trials, for a total of 1080. For each of the three CTOAs, there were 10 neutral trials and 324 gap trials (36 valid, 288 invalid) for each target location. As in Experiment 2, cue validity was set to chance level.

2.3.2 Results and Discussion

A 3 x 3 repeated-measures ANOVA indicated that there were significant main effects of Cue Validity ($F_{(2,34)}$ = 11.9, MSe = 18669, $p < 0.001$) and CTOA ($F_{(2,34)}$ = 4.12, MSe = 1594, $p < 0.025$). There was no significant interaction between these factors. Paired comparisons showed that, at the 200 ms CTOA, there was a significant difference ($t_{(17)} = 3.191$, $p < 0.005$) between the mean valid-cue (492 ms) and the mean invalid-cue (509 ms) response times. None of the other differences between valid-invalid pairs were significant. As seen in Figure 7, this indicates that there was a cueing effect at the 200 ms CTOA, but not at the 300 and 400 ms CTOAs. This suggests that gap cueing, like direct cueing, is stimulus-driven (exogenous). And it supports the hypothesis that a gap cueing effect is more likely to occur with a 200 ms CTOA than with longer CTOAs like the one used in the previous experiment. The mean neutral-cue and invalid-cue response times were also significantly different ($t_{(17)} = 3.0$, $p < 0.01$) when the CTOA was 300 ms. As mentioned previously, however, there are several concerns about the use of neutral cues as a baseline for determining the costs and benefits of location cueing. And a location cueing effect is considered more reliable when based on a valid-cue/invalid-cue comparison as opposed to an invalid-cue/neutral-cue comparison. This is probably also the case in the current experiment, given the small proportion of neutral-cue trials in the current experiment (10%).

Figure 7 ***Experiment 3 cue effects***



Note. Cue effects are the difference between mean response times on valid and invalid trials at each CTOA. Significant differences are highlighted (*).

2.4 Experiment Four

The fourth experiment was conducted to determine whether the procedure used to elicit a cueing effect by a gap discontinuity would also elicit a cueing effect by a colour discontinuity (unique-colour singleton). The previous experiment indicated that, at shorter CTOA (200 ms), attention can be captured by a gap discontinuity and facilitate target orientation response times. The discontinuity in that experiment was equivalent to an odd-man-out stimulus in a visual search display. Another type of odd-man-out that has been shown to capture attention is a stimulus with a different colour than that of the surrounding stimuli (e.g., Folk et al., 1992). Experiment 4 was a replication of the third experiment, but with the addition of a colour singleton cue condition. If both types of cues have a similar effect on target discrimination response times, then this would indicate that gap discontinuities share some of the same attentional capture properties as other types of feature discontinuities.

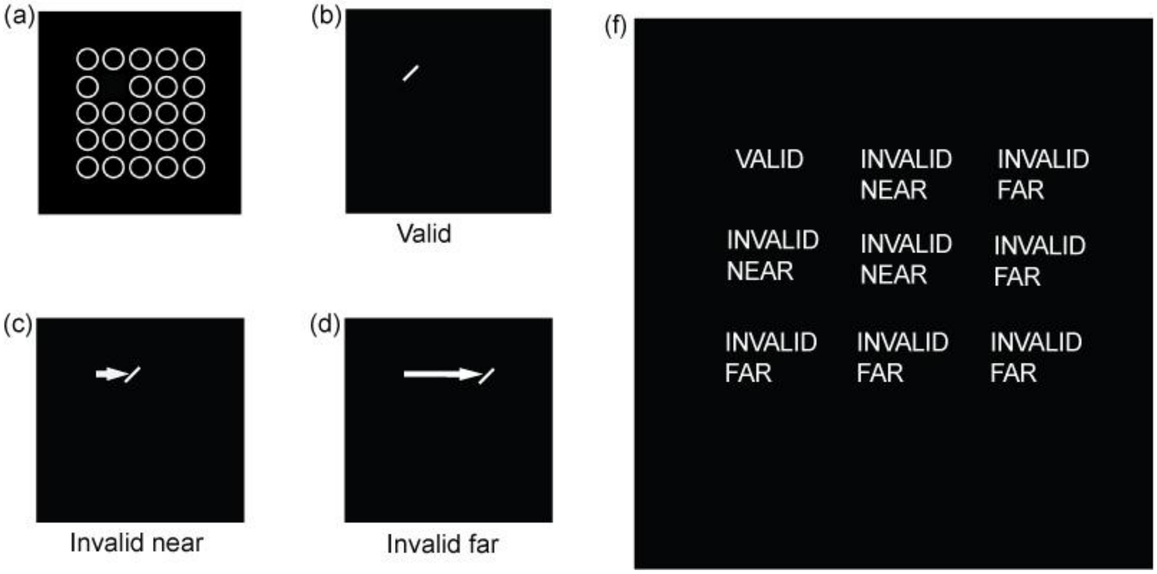
2.4.1 Method

Participants. Twenty-four Simon Fraser University students were given course credit for taking part in the experiment. All participants had normal or corrected-to-normal vision, and none reported any vision difficulties.

Stimuli and Procedure. The stimulus displays and procedure were the same as those of Experiment 3 with the following exception: In the previous experiment, all of the circular stimuli in the cue array were white. In this experiment both a gap discontinuity and a colour discontinuity (green) were presented in the cue array. Like in Experiment 3, the gap discontinuity was presented by omitting a single circle from the cue array. The feature discontinuity was presented by changing the colour (white-to-green) of one of the circles within the array. Approximately 89% of trials contained either a gap discontinuity or a colour discontinuity. The remainder of trials contained no discontinuity (neutral trials). On all trials, the target was equally likely to appear at any of the nine locations corresponding to the interior 3 x 3 array of cue field locations (Figure 4). Participants were informed that a discontinuity (gap or colour) would appear on the majority of trials and that neither type of discontinuity predicted the target's location any better than chance. Order of presentation of trial types was completely randomized, and reaction time data were collected in a 35 to 50 minute testing session.

Design: There were 54 neutral trials, 486 colour (colour discontinuity) trials in which one of the 25 circles was green, and 486 gap (gap discontinuity) trials, for a total of 1026. In each condition, the target appeared at the same nine possible locations as in the previous experiments. For each of the discontinuity types, and for each of the three CTOAs, there were 54 valid-cue trials and 216 invalid-cue trials. In addition, there were two types of invalid trials. Invalid-near trials were those on which the target appeared at the location directly adjacent to the discontinuity's location. Invalid-far trials were those on which the target appeared at a location that was on the opposite side of the 3 x 3 array (see Figure 8).

Figure 8 ***Experiment 4 invalid-cue trials***



Valid

Invalid near

Invalid far

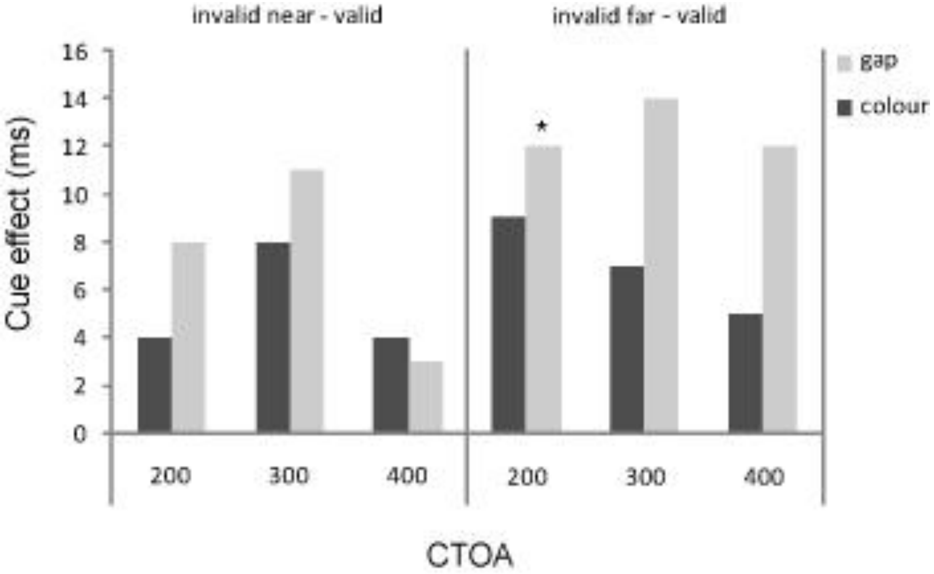
Note. An example of a (b) valid-cue, (c) invalid-near, and (d) invalid-far trial. After the offset of an array with a discontinuity, target onset could occur at the same location, appear directly adjacent to the discontinuities location, or appear at the opposite side of the 3 x 3 array. All discontinuity trials had this cue-target location coding (f).

2.4.2 Results and Discussion

As in the previous experiment, trials without a discontinuity were used for neutral cueing. But there were only a small number of trials of this type in this experiment, and their inclusion served, in part, as catch trials. Whereas comparisons of mean neutral-cue and valid-cue response times can indicate whether or not a cue-induced warning signal has affected responses, it will not indicate, with certainty, the occurrence of a cueing effect. As discussed in Experiment 2, a cueing effect occurs if there is a significant difference between valid- and invalid-cue responses. Therefore, neutral trials were not included in the analyses. As previously stated, there were two types of invalid-cue trials (Figure 8). Invalid-cue trials were differentiated in order to determine whether or not there would be an invalid-cue/target distance effect.

A 2 x 3 x 3 repeated-measures ANOVA was carried out with two levels of the Discontinuity Type factor (gap & colour), three levels of the Cue Validity factor (valid, invalid-near, & invalid-far), and three levels of the CTOA factor (200, 300, & 400 ms). There was a main effect of Discontinuity Type ($F_{(1,23)} = 4.955$, Mse = 325, $p < 0.05$), Cue Validity ($F_{(2,46)} = 8.5$, Mse = 525, $p < 0.001$), and CTOA ($F_{(2,46)} = 25.958$, Mse = 1039, $p < 0.05$). And there were no significant interactions. Paired comparisons showed that, at the 200 ms CTOA, there was a significant difference ($p < 0.05$) between the mean valid gap cue (464 ms) and the mean invalid-far gap cue (476 ms) response times. None of the other differences between means were significant. Figure 9 shows the cueing effect observed at the 200 CTOA on gap trials. There were no cueing effects at any of the CTOAs in the colour-singleton condition.

Figure 9 ***Experiment 4 cue effects***



Note. Cue effects are the differences between mean response times on invalid-near and valid trials, and the differences between mean response times on invalid-far and valid trials. Significant differences are highlighted (*).

There was a significant gap cueing effect only when it was based on the difference between mean valid-cue response times and mean invalid-far response times. In other words, the effect occurred only when the distance between target and gap was separated by one item location in the cue array (invalid-far). It did not occur when the target and gap were at adjacent locations (invalid-near). This suggests the possibility that the response-time cost of invalid cueing may occur only when there is a clear separation between the target and the cued location. On the other hand, when the region occupied by the target is at the boundary of the region occupied by the gap, then this valid-cue / invalid-cue separation may not be distinct enough to indicate that a cueing effect occurred.

The results also suggest that the gap discontinuity, at least for the current experimental parameters, is a more effective location cue than the colour discontinuity. Some researchers have argued that the attentional capture produced by colour-singletons is contingent upon the task that is being performed (e.g., Folk et al., 1992; Yantis, 1993). In contrast, perhaps attentional capture by a gap discontinuity is less contingent upon task performance and more reflexive.

While the results of Experiment 4 seem to replicate the findings of Experiment 3, there are statistically non-significant findings that are hard to ignore. While there was no statistically significant cueing effect found at the 300 or 400 ms CTOA condition, the mean difference between valid and invalid trials between all CTOAs was similar (12ms ± 1). Figure 9 shows the mean difference between valid and invalid trials for all conditions. While the means are similar, the responses for the 300 and 400 ms CTOA conditions have greater variability than that of the 200 ms CTOA condition. This will be addressed further in the General Discussion.

3: GENERAL DISCUSSION

The results of these experiments indicate that a gap discontinuity in a regular array of stimulus items can capture attention and, in turn, serve as a location cue that facilitates target orientation responses. The first two experiments showed that these responses were faster when preceded by a gapped cue array (gap trials) than by a full cue array (neutral trials). It was unclear, however, whether response facilitation in these experiments was due to a location cueing effect or to a cue-induced warning signal.

In the first experiment, the gap indicated the impending target's location with 100% validity. That is, there were no invalid trials. Without invalid trials, it could not be determined whether response facilitation in this experiment was due to a cueing effect or to a warning signal that was stronger on gap trials.

In the second experiment, invalid-cue gap trials were included on which targets appeared at non-gap locations. As in the first experiment, responses were faster when preceded by a gap array than by a neutral array. Mean valid-cue and invalid-cue response times in the gap condition were not significantly different. This indicated that the faster response times on gap trials compared to neutral trials were not due to a location cueing effect. This would only have been the case if the mean response time on valid-cue trials was significantly faster than that of invalid-cue trials. This finding therefore suggested that, in Experiment

1, responses were faster on gap trials than in the neutral trials because the former elicited a more effective warning signal.

The failure to find a location cueing effect in Experiment 2 may have been due to the use of a CTOA (300 ms) that was too long for it to occur. In order to test this possibility, a shorter CTOA was used in Experiment 3. The results indicated that a gap cueing effect did occur when the CTOA was 200 ms. The mean target orientation response time on valid-cue trials was significantly faster than that on invalid-cue trials. This suggests that a gap cueing effect may not have occurred in Experiment 2 because the CTOA was too long for direct location cues to be effective.

The fourth experiment was a replication of Experiment 3. Experiment 4 included a colour-singleton cue condition. The question addressed by this experiment was whether gap cues and colour cues would yield the same pattern of results. Significant location cueing effects (as measured by the difference between mean valid and invalid response times) occurred only with gap cues. This suggests that, at least with the design parameters of the current experiments, gaps capture attention and colour singletons do not.

In the fourth experiment, mean differences in the 300 and 400 ms CTOA conditions were almost equal to that of the 200ms CTOA condition. While these differences were not statistically significant, they do suggest a cueing effect at the 300 and 400 ms CTOA. What could have caused this result? One difference between Experiment 3 and 4 was the nature of the analyses of invalid-cue responses that were used to determine the cueing effect. In Experiment 3, all invalid gap trials were designated as invalid in the analysis. In Experiment 4, however, invalid gap trials were separated into two categories. These were based on the spatial relationship between gap and target locations (Figure 8). This categorization of invalid-near and invalid-far trials was intended to provide a more precise indication of the effect of distance between gap and target on response times. Gap cue effects occurred in Experiment 4 only on invalid-far trials. Again, invalid-cue trials were not broken down into invalid-near and invalid far in Experiment 3. Perhaps this more conservative criterion for determining a gap cue effect is why differences arose between Experiment 3 and 4.

Another possible reason why the results of Experiments 3 and 4 differed is that the former involved only one type of location cue whereas the latter involved two. In Experiment 4, approximately 47% of trials involved a gap cue and 47% involved a colour cue. These trials were presented in a randomized order, which may have led to a continuous switching of attentional control settings. Perhaps rapidly switching between control settings leaves attention vulnerable to be captured by a salient but irrelevant stimulus. If so, this may be related to the differences observed between Experiment 3 and 4. (see, however, Lien Ruthruff, & Johnston, 2010).

Work by Luck, Fan and Hillyard (1993) suggest that the cueing effect observed in Experiment 4 might actually be expected. Participants in their study performed a visual search task; on some trials, a probe was presented for 50 ms. The probe was a simple rectangle that fitted around the items of the search array without occluding them. On some trials, the probe would appear at the target location and on others it appeared at an irrelevant item location. On trials where the probe and target appeared at the same location, the ERP's associated with processing were more pronounced than on trials where the probe appeared at irrelevant item locations. It is thought that the N2pc component, associated with attention, enhances the processing of the probe stimulus (Eimer, 1996). The task used in this thesis is similar to the Luck et al (1993) task. Participants were presented with a cue array and then a single target. While the probe used in the Luck et al study was irrelevant to task, the target in this study was relevant, and perhaps its processing was enhanced due to attention being engaged at that location. They report their N2pc component at 250ms. It may be that the cueing effect observed in Experiment 4 at 200 and 300ms is related to the time course of the N2pc component.

Attentional Capture by Gaps. In order for a gap in a stimulus array to serve as a location cue, it must draw attention to its location. The occurrence of a gap cueing effect in Experiments 3 and 4 indicates that gaps did capture attention. Given that there was no relationship between the gap discontinuity and task demands (line orientation discrimination), participants had no reason to strategically attend to the gap location because it would not improve performance. This suggests that the gap discontinuity captured attention in a bottom-up or stimulus-driven manner.

The failure to find a colour singleton cueing effect is consistent with the results of previous studies (e.g., Folk et al., 1992). The contingent capture hypothesis states that capture is, in part, contingent upon the task being performed. Perhaps if target responses were colour-related, then the colour-singleton cues would have captured attention in a contingent manner because both cue and target would be associated with colour.

Typically, when contingent attentional capture is studied, trials are blocked by condition. This leads to the creation of an attentional set about the type of feature (e.g., colour, abrupt onset) that is relevant for task performance. In Experiment 4, however, gap-cue and colour-cue trials were presented in a randomized order. And therefore perhaps contingent capture by colour singletons was less likely than if gap-cue and colour-cue trials were presented in separate blocks. The fact that gap cues still captured attention, despite the intermixing of gap-cue and colour-cue trials, may be another indication that this capture was bottom-up and reflexive.

As mentioned in the introduction, another attempt has been made to determine whether or not a gap discontinuity will capture attention (Kiss & Eimer, 2009, June). This experiment made use of a circular stimulus array and multi-sized cues and targets. They found capture affects only on trials where size was relevant to task. As well, they found capture effects to the gap regardless of task set. Their results suggest that the gap discontinuity might capture attention in a bottom-up manner.

Using Search Arrays as Location Cues. As mentioned in the introductory section, other researchers have combined visual search and location cueing tasks. Unlike the task used in the current experiments, however, a single stimulus served as the location cue that preceded the onset of an array of stimuli.

The results of Experiments 3 and 4 provide further evidence that these tasks can be combined in the reverse order as well (see Klein, 1988). That is, an array of stimuli containing an odd-man-out that is typical of visual search experiments can also be used as a location cue.

The occurrence of a gap cueing effect at the 200 ms CTOA, but less reliably at the 300 ms CTOA suggests that a pattern cue may be more effective when the delay between cue and target onset is within the 100 to 200 ms range. Direct location cues are also most effective at this range. So perhaps when an array of stimuli is used as a Posner-task location cue and the resulting cueing effect is due to attentional capture by an odd-man-out within the array, the cueing effect is reflexive like that of a direct cue.

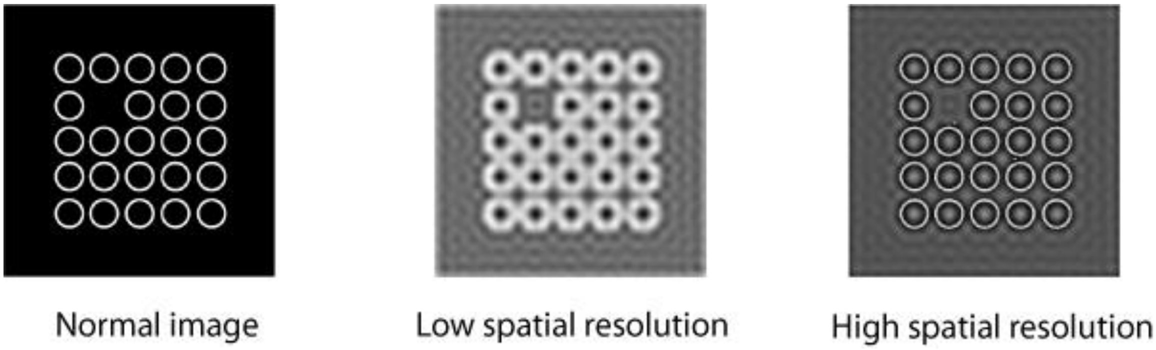
A gap cueing effect occurred in Experiments 3 and 4 even though cue validity was at the chance level. This is another indication that gap cueing may be reflexive as opposed to goal-driven and voluntary like symbolic cue use. Observers tend to ignore uninformative cues, and especially when told beforehand, as in the current experiments, that these cues are not useful and do not need to be attended to. Thus, although the current experiments were not designed to test this question and a strong claim cannot be made, the results suggest that the location cueing effects were stimulus-driven rather than goal-driven.

The results of Experiment 4 also suggest that if a gap in a pattern is used to cue an impending target's location, then the response-time difference between mean valid-cue and mean invalid-cue trials will be greatest if targets appear at uncued locations that are not adjacent to the boundary of the “empty” region. A number of Posner-task studies were conducted in the 1970s and 1980s to determine whether or not manipulating the distance between invalid-cue and target locations would affect the magnitude of response-time costs (Wright & Ward, 2008, p. 40). The results were equivocal. Some researchers found that changing the invalid-cue/target distance affected response times (Shulman et al., 1979; Tsal, 1983), and some did not (Kwak et al., 1991; Sagi & Julesz, 1985; Skeleton & Eriksen, 1976). Those studies were conducted to determine whether the attentional focal point is shifted from the invalid-cue location across the visual field to the target location in an analogue or in a discrete manner. A location cueing effect occurred in the fourth experiment only when mean valid-cue response times were compared to mean invalid-far response times; and not when they were compared to mean invalid-near response times. This invalid-cue/target distance effect is probably not related to the analogue versus discrete attention shift debate, however. It is more likely the case that the invalid-cue locations that were immediately adjacent to the gap were simply not distinct enough from the valid-cue location in the centre of the gap region to provide an accurate measure of invalid-cue response times. If future research is conducted to study the nature gap location cueing, then invalid-cue locations should be clearly separate from valid-cue (gap) locations.

Is a Gap Discontinuity Just an Empty Location? The gap discontinuity in the current experiments was the only location in the stimulus array at which there was no white circle. Instead, there was only the uniformly black background colour. It is sufficient to describe the gapped region as the only part of the stimulus array that lacked a circle when reporting the methodology used. But when discussing the operations that mediate attentional capture by a gap discontinuity, this is probably an oversimplification.

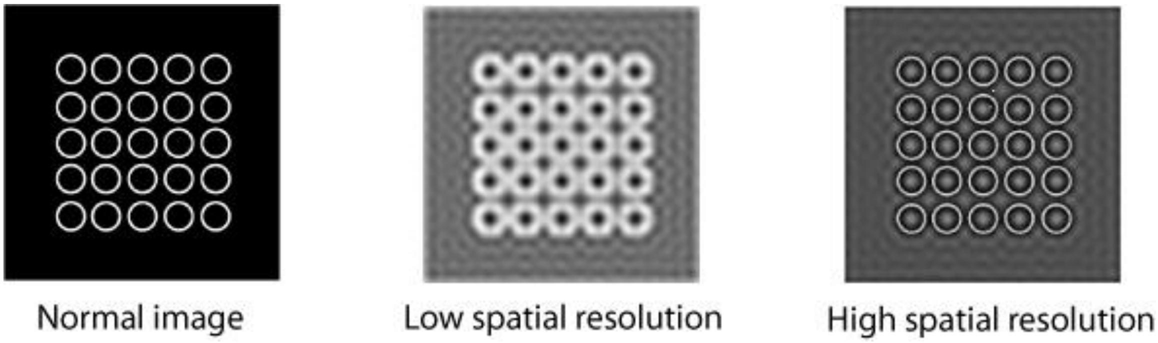
It is unclear, when considering a gap as the complete absence of features, how attention could be captured at that location. In particular, the absence of any discernible features presumably means that there is nothing at that location that could generate the type of signal within a spatial map that attracts attention. This is the dilemma to be faced if a gap is thought of merely as an empty region; it is probably not the case, however. To elaborate, if the figure-ground relationship of the circles and the background is looked at differently, it could be argued that the gaps in the stimulus array did in fact have discernible features. Viewed from this perspective, the gaps resembled black, X-shaped objects comprised of illusory contours at the boundaries of eight neighbouring circles. These boundaries are simple contrast differences that the visual system is sensitive to, particularly when only low spatial frequency information about the stimulus array is available (see Figures 10 & 11).

Figure 10 Gapped array at high and low spatial resolution



Note. These images were created using Fourier transform lab ©JCrystalSoft 2009. The above is the results of low and high pass filtering of the cue array containing a gap discontinuity.

Figure 11 Whole array at high and low spatial resolution



Note. These images were created using Fourier transform lab ©JCrystalSoft 2009. The above is the results of low and high pass filtering of the neutral array.

It could be argued that the gap is an object, but one comprised of illusory contours. There is some evidence that objects with illusory contours can capture attention (Martinez, Teder-Salejarvi, & Hillyard, 2006; Martinez, Ramanathan, Foxe, Javitt, & Hillyard, 2007). In particular, the stimuli in the Martinez, Teder-Salejarvi, & Hillyard (2006) experiment were two Kanisza “inducers” that produced the perception of a bar with illusory contours. The two components also denoted potential target locations. One finding was that when a location cue directed attention to one of the two components, responses to targets were facilitated when they appeared at this location, and when they appeared at the location of the other component. Given both components were part of a common perceptual object comprised of illusory contours, this suggests that attention directed to one part of such an object will spread to other parts. This finding is also consistent with the proposal that objects comprised of illusory contours can capture attention.

Models of Attentional Capture. The current experiments raise questions about how attention is captured by a gap discontinuity. Many proposals about the physiological instantiation of stimulus-driven capture involve a spatial representation called a *salience map.* Koch and Ullman (1985) were among the first to speculate about this. They stated that items in the salience map compete for attention, and that a winner-take-all algorithm determines which item will be attended to.

There is an emerging consensus among researchers that attentional capture operations are carried out within a representation like a salience map, and that a number of these maps are distributed throughout the brain. Each of them, in turn, provides input to a *master salience map* (e.g., Bundesen et al., 2005; Shipp, 2004). It has been suggested that, like information about objects in the master map component of feature-integration theory described by Treisman and Gelade (1980), information about objects in this master salience map is "featureless" (Fecteau & Munoz, 2006). More specifically, it contains no specific information about, for example, the colour or size or shape of objects. It contains only information about the locations and magnitudes of activation associated with each object. The object with the highest level of activation is the most salient, and most likely to capture attention.

There is some agreement about the nature of master salience map operations, but little agreement about its location. Some researchers have claimed that it is located in the frontal eye fields, the parietal cortex, the visual cortex, and in the brain areas associated with the oculomotor system (e.g., Bundesen et al., 2005, p. 300; Fecteau & Munoz, 2006; Gottlieb, 2007; Treue, 2003). Shipp (2004) proposed that it is in the ventral pulvinar region of thalamus. One reason why the ventral pulvinar is a good candidate for the master salience map location is that it has many connections with other cortical and subcortical areas. In particular, it has efferent and afferent connections to the structures associated with the ventral visual pathway (V1, V2, V4, TEO, & TE). These visual areas have projections to the frontal eye fields and the parietal cortical areas involved in the attention shifting; and to the superior colliculus, which also plays an important role in attention shifting. In addition, there are many projections from the superior colliculus to the ventral pulvinar, which presumably contribute to salience determination. Presumably, as well, the projections from the frontal cortical areas serve to influence saliency determination in a top-down manner. It remains to be determined, where the master salience map is located (or even if there is one; see Serences & Yantis, 2006); but the ventral pulvinar is a strong candidate.

It has been proposed that the salience maps do not contain information about the relevance of objects to current task performance, and therefore that this relevance does not affect salience (e.g., Fecteau, Bell, & Munoz, 2004; Fecteau & Munoz, 2006). In other words, salience map operations are stimulus-driven and are not influenced by top-down factors such as the observer’s goals. Fecteau and colleagues argued that while this can account for stimulus-driven, reflexive attentional capture; it does not account for capture that is contingent upon the task being performed. Contingent attentional capture occurs when both object relevance (top-down) and salience (bottom-up) influence the selection of the object. According to Fecteau et al., object relevance and salience are combined in a higher level representation called a *priority map*. In other words, while stimulus-driven salience and attentional capture can be triggered by salience map operations, contingent attentional capture requires the combined operations of the salience and priority maps, with the former providing input to the latter.

One model that combines these operations is a modified version of LaBerge's activity distribution proposal described by Wright and Ward (2008, pp. 81-85). It is a model of attention orienting to cue and target locations. In particular, the onset of each stimulus triggers, at its location within a spatial representation, the formation of a sensory activity distribution. If one of the stimuli triggers an activity distribution that is greater than the distributions triggered by other stimuli, and if the magnitude of this distribution exceeds a criterion threshold, then a channel of attention is opened at that location within a higher level spatial representation. In other words, attention is captured by the stimulus that is associated with the largest activity distribution if it exceeds the threshold level for attentional processing at that location. Capture, in this case, is purely stimulus-driven.

In addition to the representation containing stimulus-driven, sensory activity distributions; there is an intermediate-level representation containing activity distributions that can be modulated by goal-driven input in accordance with the task being carried out by the observer (e.g., cue validity information).

The representation containing the sensory activity distributions is analogous to the salience map described by Fecteau et al., and the intermediate-level representation is analogous to the priority map. Wright and Ward (2008, pp. 67-68) proposed that when a target appears at a direct cue location within 100 to 200 ms of cue onset, residual sensory activity associated with the cue can combine with target-triggered sensory activity at that location. The result will be an activity distribution that is greater in magnitude than would be the case if the target appeared at an uncued location. This is how sensory activity distributions combine to produce a location cueing effect. This is reflexive and will therefore occur in a stimulus-driven manner; even with cues that are uninformative about probable target location. If a high-validity cue is presented that observer knows is a good predictor of the impending target's location, then goal-driven input can sustain and enhance an activity distribution at the cued location within the intermediate-level representation (Wright & Ward, 2008, pp. 84-85).

The model, as described by Wright and Ward, accounts for location cueing effects yielded by the Posner task. But it can also account for contingent attentional capture. Consider the case of a red colour singleton that does not capture attention reflexively, but does produce contingent capture when a colour-associated task is performed. Each item in the stimulus array would trigger, in the lower-level representation, the formation of sensory activity distributions of roughly equal magnitude, regardless of colour. And none would be sufficiently greater in magnitude than the others or would exceed the criterion threshold for stimulus-driven capture. The activity distribution within the intermediate-level representation at the location of red singleton would be enhanced, however, by goal-driven input about the importance of colour. As a result, the magnitude of the activity distribution at the red item's location within the intermediate-level representation would grow to exceed the criterion threshold and a channel of attention would open up at that location within a higher level spatial representation.

The results of Experiment 4 indicate that gap discontinuities captured attention and also produced a location cueing effect, even though they did not predict target locations. Colour singletons, on the other hand, did neither. In terms of the Wright and Ward model, this suggests that on gap-cue trials, the gap discontinuity triggered the formation of a sensory activity distribution that exceeded criterion threshold and caused a channel of attention to open at its location. On colour-cue trials, the colour singleton did not trigger the formation of an activity distribution that exceeded this threshold and, therefore, a channel of attention did not open at its location. The results of previous research, however, indicate that if the colour cue was a useful predictor of target location, then it would have produced a cueing effect (Richard, Wright, & Ward, 2003). In terms of the Wright and Ward model, on colour-cue trials, the activity distribution within the intermediate-level representation at the location of green singleton would be enhanced to the level required to open a channel of attention.

The results of the current experiments may also be consistent with Shipp's (2004) model. In particular, the model holds that a master salience map in the ventral pulvinar pools spatial information from salience maps in several other brain areas. When all of the salience values from these other maps are summed within the master map, neural activity peaks at the most salient location and attention is focused there. Wright and Ward (2008) compared this process to an activity distribution surpassing a criterion threshold. When this location is selected, a signal is sent from the pulvinar to the frontoparietal components of an attention orienting network (e.g., Corbetta & Shulman, 2002) in order to initiate a shift of the attentional focal point to the object in question. On gap trials, in the current experiments, analysis of the stimulus array by areas in the ventral visual pathway would indicate the gap locations. And perhaps it would yield lower level sensory information about the gap such as its relative darkness compared to adjacent regions, and how the size of these dark areas associated with gaps are larger than any other uniformly dark area in the arrays. This, in turn, may cause gaps to have the most salience in the master map.

Like most studies that involve a novel task, the results of the experiments raise several additional empirical questions that could be tested. Some obvious possibilities for future experimentation include use of a shorter CTOA (e.g., 100 ms) to determine whether or not the cueing effects are even more pronounced when the delay between cue and target onsets is within the range that is optimal for direct cues. And if gap cue is shown to function like a direct cue, can it also be used to produce IOR? In addition, the stimulus arrangement of the cue arrays could be altered to determine whether or not manipulating gap size and shape influences the magnitude of cueing effects. Also, given that gap discontinuities in the current experiments appeared to capture attention in a stimulus-driven, reflexive manner; a variant of a contingent attentional capture experiment could be conducted to determine whether or not the onset of irrelevant gap stimuli would interfere with the performance of a task involving colour singletons. A variant of Experiment 4 could be done in which cue validity is manipulated to determine whether or not colour singletons would yield significant cueing effects if the cue was a useful predictor of target location. If so, then this would raise more questions about the relationship between cue validity and contingent attentional capture that could be investigated.

Another possible experimental manipulation is to vary the spatial frequency of cue arrays (from low resolution to high) to determine whether or not this would affect capture. As can be seen in Figure 10, at low spatial frequencies, each item in the array seems to blend into the other so that the contrast difference created by the gap is quite salient, whereas at high spatial frequencies, each item has clearly defined boundaries. This may make the gap discontinuity less salient. Perhaps there is a range of spatial frequencies at which the gap discontinuity best captures attention. If so, then this may provide a hint about the neurological structures mediating capture.

As with any research project that is exploratory in nature and that involves a novel task, conclusions about the findings are tempered somewhat by limitations of the methodology. These findings do not, for example, tell us much about the differences between gap discontinuities and colour singletons other than that, in the current experiments, gaps were more effective location cues. But they show that the Posner task can be modified so that, rather than a single location cue stimulus, an array of stimuli can be used as the location cue. This a good first step toward the study of contingent attentional capture and location cueing. And there are many possibilities for future research.

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