Title

Non-predictive cueing improves accuracy judgments for voluntary and involuntary spatial and feature/shape attention independent of backward masking.

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Publication Date

2013

Peer reviewed|Thesis/dissertation

Non-predictive cueing improves accuracy judgments for voluntary and involuntary spatial and feature/shape attention independent of backward masking.

By

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A dissertation submitted in partial satisfaction of the

requirements for the degree of

Doctor of Philosophy

in

Vision Science

in the

Graduate Division

of the

University of California, Berkeley

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Spring 2013

Abstract

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Doctor of Philosophy in Vision Science

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Many psychophysics investigations have implemented pre-cues to direct an observer's attention to a specific location or feature. There is controversy over the mechanisms of involuntary attention and whether perceptual or decision processes can enhance target detection and identification as measured by accuracy judgments. Through four main experiments, this dissertation research has indicated that both involuntary and voluntary attention improve target identification and localization accuracy even when cues are non-predictive. The first experiment was conducted to assess the validity of the mask-dependent cueing hypothesis and to determine if involuntary attention improves target identification accuracy. A two-alternative force choice experimental procedure using the method of constant stimuli was conducted using non-predictive cues and both masked and unmasked target stimuli. The results indicated that involuntary attention improved target identification accuracy for unmasked stimuli across the entire Weibull psychometric function. The second experiment introduced multinomial modeling of observed data to assess the extent of response bias which has been shown to confound cueing experiments. In a seven-alternative force choice experiment, observers reported both the location and identification of masked stimuli presented across a range of temporal parameters spanning the time course of both voluntary and involuntary attention. The multinomial modeling removed the response bias and the results indicated a strong cueing effect for both voluntary and involuntary spatial attention.

The third experiment used the same multinomial modeling technique to remove response bias, but stimuli were unmasked and 6 stimulus contrast levels were tested ranging from 19% to 100% contrast. Results indicated strong cueing effects across the entire psychometric function. The fourth experiment was a six-alternative force choice feature-attention task in which observers reported the identity and location of target stimuli following a feature cue. The results indicated that under both involuntary and voluntary attention, response accuracy was increased. The combined results indicate that accuracy is enhanced with voluntary and involuntary attention for both feature-based and visuo-spatial attention using non-predictive cues.

Table of Contents

Introduction

A long standing debate about the distinction and mechanisms of involuntary and voluntary attention has existed in the scientific community since the late 19th century with early scientists such as Hermann Helmholtz and Wilhelm Wundt. There is some agreement now that there are two orienting systems and that voluntary attention is characterized as a voluntary and controlled orientation of visual attention while involuntary attention is a transient, involuntary and reflexive orienting of visual attention in response to a stimulus (ideally of high salience). Differentiating and characterizing these two systems has been a very difficult endeavor and is still debated today. The attention systems are often experimentally investigated using cueing paradigms. In a cueing task, a cue stimulus precedes a target stimulus (or in some cases, follows), and thereby influences the perceptual processing of the target stimulus, leading to an improved response performance or a detriment depending on whether the cue is validly predictive of where the forthcoming target is going to appear (leading to enhancement) or if it is invalid and does not appear at the same spatial location (causing a performance decrease as attention is drawn to a different spatial location or feature as the target).

Instructional cues preceding the appearance of a visual target have been experimentally used to study the covert allocation of visual attention for many years. The most common experimental technique is to use a variation of the Posner cueing task (Posner, 1980). In this task, a peripheral target with or without distractors is pre-cued for the possible location of the upcoming target. The observer is required to maintain fixation at a fixation point in the center of the display, and must covertly (without eye movements) attend to the peripheral stimuli. Task performance is measured as reaction time or as an accuracy judgment for which subjects report the location and/or identity of the target stimulus.

Visual spatial attention is a well-documented ability by which observers can selectively focus on a region of space in the visual field, placing extra emphasis and processing to visual stimuli or regions of interest. Similarly, feature-based attention can be directed to a particular feature of a stimulus of interest. Improved target identification and/or localization from attention allocation can be experimentally measured as faster response times to a stimulus onset, an improvement in an accuracy judgment, or a combination of both (Egly, Homa, 1991; Henderson, 1991; Yeshuran & Carrasco, 1999). Evidence supporting faster response times for identifying target stimuli under conditions of involuntary attention allocation is substantial, but evidence supporting improved accuracy judgments from involuntary attention allocation is less abundant and controversial. While it is well known that voluntary covert attention allocation enhances the perceptual information at the attended location, resulting in faster response times (Jonides, 1976; Jonides, 1980; Jonides, 1981; Joseph & Optican, 1996; Pashler, 1988; Prinzmetal, McCool & Park, 2005; Theeuwes, 1991; Theeuwes, 1992) and improved visuospatial sensitivity (Carrasco, Ling, & Read, 2004; Carrasco & Yeshuran, 2009; Giordano, McElree, & Carrasco, 2009), there is a substantial degree of skepticism that transient involuntary attention can enhance visual perception for stimulus accuracy judgments, and different mechanisms have been proposed for voluntary and involuntary attention to account for this. It has been proposed that voluntary attention can influence a perceptual representation of a stimulus and hence will show cueing effects for both accuracy and reaction time judgements, but that involuntary attention does not influence the perceptual representation and only shows cueing effects for reaction time judgments (Prinzmetal, McCool, & Park, 2005; Prinzmetal, Park, & Garrett, 2005). Similarly, it has been stated that non-predictive cues do not always improve perception, whereas predictive cues do (Kerzel, Zarian, & Souto, 2009; Kerzel, Gauch, & Buetti, 2010; Prinzmetal, McCool, Park, 2005; Prinzmetal, Park, Garrett, 2005). It has also been stated however, that this generalization may not always hold true and that there are some experiment conditions that may produce cueing effects with involuntary attention such as when set size is large or when a mask is used (Prinzmetal, Park, & Garrett, 2005; Prinzmetal, McCool, & Park, 2005). The current investigation examines the timings and contrasts of cues, targets, and masks to demonstrate that transient, involuntary attention does facilitate accuracy judgments of both identifying where a target was among many distractors (even under conditions of spatial uncertainty), and also in enhancing the ability to recognize the identity of the target. The first three chapters investigate cueing effects with spatial attention while the fourth chapter investigates feature-based cueing effects with involuntary and voluntary attention.

Involuntary attention enhances identification accuracy for both masked and unmasked stimuli using non-predictive peripheral cues

Abstract

There is controversy whether or not involuntary attention improves response accuracy at a cued location when the cue is non-predictive. Various mechanisms of perceptual and decisional performance enhancement have been proposed, such as the mask-dependent cueing hypothesis (Smith et al. 2009) which states that involuntary attention only improves accuracy with backward masked stimuli. The mask creates a limit on the amount of time available to attend to a stimulus after the stimulus is no longer visible (via iconic memory), and with a cue directing attention to the stimulus there is a more efficient transfer of visual information into visual short term memory. Herein we review a recent report of mask-dependent accuracy improvement with low contrast stimuli and question the validity of this hypothesis by demonstrating that previous experiments contained stimulus artifacts whereby the cue impairs perception of low contrast stimuli. Our experiments corrected these artifacts by implementing an isoluminant cue and increasing its distance relative to the targets. The results demonstrate that cueing effects are robust for masked and unmasked stimuli presented in the periphery, resolving some of the controversy concerning cueing enhancement effects from involuntary attention. Unmasked low contrast and/or short duration stimuli as implemented in these experiments may have a short enough iconic decay that visual short term memory functions similarly as if a mask were present to constrain access to short term memory and thereby lead to improved accuracy with a valid cue.

1. Introduction

Cueing paradigms have been implemented as a means of measuring many aspects of visuo-spatial attention. A target stimulus is presented with some probability near to or away from a pre-cue which attracts attention to a spatial location or feature. The observer is required to maintain fixation in the center of the display while covertly attending to the peripheral visual field in search of the target stimulus (Posner, 1980). Attention can be directed voluntarily or involuntarily and there is controversy over the mechanisms by which each form of attention influences the perceptual and decisional processing of attended stimuli.

Some researchers have proposed that cueing effects result from more efficient transfer of visual information into visual short-term memory (Smith et al. 2009; Smith, Ratcliff, & Wolfgang, 2004; Smith & Wolfgang, 2004, 2007; Smith, Wolfgang, & Sinclair, 2004). To compensate for the presence of the mask, attention accelerates information accrual by improving the efficiency of information transfer into visual short term memory, leading to improved task performance at the attended location. The mask dependent cueing hypothesis states that this mechanism only occurs with masked stimuli, since cueing effects were only found with masked stimuli in the experiments by Smith and colleagues. There are however numerous reports of perceptual enhancement from involuntary attention with unmasked stimuli (Cameron, Tai, & Carrasco, 2002; Carrasco, Giordano,& McElree, 2006; Henderson, 1996; Lu & Dosher, 1998), with some studies reporting perceptual enhancement with both masked and unmasked stimuli using the same task (Carrasco, Penpeci-Talgar, & Eckstein, 2000; Carrasco, Williams, & Yeshuran, 2002; Hendersen, 1991; Yeshuran & Rashal, 2010). It has been argued that some previously reported cueing effects with unmasked stimuli are confounded by spatial uncertainty (Gould, Wolfgang, & Smith, 2007), but recent research has argued that spatial uncertainty alone is not sufficient to produce cueing effects (Kerzel, Gauch, & Buetti, 2010), and that cueing effects with unmasked stimuli still occur with spatial uncertainty constrained (Baldassi & Verghese, 2005; Cameron, Tai, & Carrasco, 2002; Luck et al., 1994). Since there are reports of signal enhancement with unmasked stimuli arguably not due to spatial uncertainty reduction, there must be a mechanism of involuntary attention other than that presented in the mask-dependent cueing hypothesis and mask dependent cueing results may reflect other critical methodological parameters. The present experiments were conducted to examine such potential mechanisms and to determine whether or not cueing effects are exclusively a result of spatial uncertainty reduction.

In a recent publication Kerzel, Gauch, & Buetti (2010) used non-predictive cues and target letters which were either unmasked and low contrast or masked and high contrast. Positive cueing effects were only observed for high contrast masked stimuli, arguing in favor of the mask-dependent cueing hypothesis. Interestingly, with unmasked low contrast targets observers performed worse with a valid cue that with an invalid cue. They hypothesized that crowding contributed to the backward cueing effects and conducted an experiment where the stimuli were presented in the parafovea. They observed significant cueing effects with unmasked stimuli, but only when stimuli were presented in the parafovea. We hypothesized that it is the high contrast of the cue stimulus combined with the close proximity to the cue and target that interfered with perception of the low contrast target letters. As such, we predicted that a reduction in the cue contrast and an increase in the distance between the cue and target would produce significant positive cueing effects in the peripheral visual field where Kerzel, Gauch, & Buetti (2010) previously did not obtain cueing effects using their stimulus parameters. To obtain support for our hypothesis that cueing effects occur in the periphery with unmasked stimuli, we lowered the contrast of the cue and kept the stimuli in the periphery. A cue with a lower contrast, more appropriately suited for low contrast targets, may produce cueing effects with unmasked stimuli. We also tested the effects of the high contrast cue on low contrast targets with masked stimuli, an important condition not investigated in Kerzel, Gauch, & Buetti (2010).

We tested this hypothesis in four experiments with low visibility letters and non-predictive cues. Robust cueing effects were observed with unmasked stimuli using a low contrast cue in two experiments with different temporal parameters. These cueing effects were obtained across a full range of contrast levels covering performance levels from chance guessing to near 100% accuracy. Two additional control experiments demonstrated that spatial uncertainty reduction does not completely account for the results, and this is discussed further. The results indicate improved accuracy judgment performance from involuntary attention capture at two different temporal durations, not dependent on backward masking. This suggests that a mechanism of performance enhancement exists beyond that presented in the mask dependent cueing hypothesis, and not attributable to spatial uncertainty reduction.

2.1. Experiment 1: Letter discrimination with full contrast cue

The first experiment was conducted to verify that cueing effects are absent with the stimulus parameters utilized in the 5th experiment of Kerzel, Gauch, & Buetti (2010). We conducted the same task but used the method of constant stimuli rather than a staircase procedure to test for cueing effects across a range of target contrasts since some researchers have argued that cueing effects only occur near detection threshold (Kerzel et al., 2010; Kerzel, Zarian, Souto, 2009; Schneider, 2006). It was hypothesized that no cueing effects would be observed using a full contrast cue in close proximity to the low contrast targets as reported in Kerzel, Gauch, & Buetti, (2010).

2.2. Methods

2.2.1 Participants

In each of the experiments reported here, subjects were recruited from the local public community, consisting of students and non-students alike. Recruitment and experimental procedures were approved by the University of California affiliated Institutional Review Board ethics committee. Six subjects (3 male and 3 female; ages ranged from 19 to 32) participated in the experiments, five of which were naïve observers, and one was the primary author. All participants signed an informed consent and were financially compensated for their time.

2.2.2 Apparatus

In all experiments, stimuli are generated, presented, and responses recorded using the WinVis Psychophysical Testing platform, a toolbox for Matlab. Stimuli were presented on a 17 inch Sony Trinitron CRT monitor at a refresh rate of 100hz. The display resolution was 1024x768 pixels. The background was grey with an approximate luminance of 13 cd/m^2. Subjects were positioned in an Eyelink II eye tracker with a chin and forehead rest. Subject's eyes were positioned 50cm from the display resulting in 2.1 x 2.1 min square pixels. Subjects were told that eye movements were being recorded during each trial and to avoid making eye movements during a trial. The experiment was conducted in moderate brightness indoor lighting conditions.

2.2.3 Stimuli

Monitor luminance linearity was achieved using an 8 bit gamma correcting look up table. A 25% contrast fixation circle 0.2° in size was presented at the center of the screen at the beginning of each trial (Figure 1). The duration of the fixation circle was randomly selected from 1.5-3.0 sec for each trial to prevent the subject from being able to predict the cue onset. The fixation target was removed during target presentation, whereas in Kerzel, Gauch, & Buetti (2010), the fixation stimulus was a plus sign and remained displayed throughout the entire experiment. We do not believe that these differences in the fixation stimulus contribute to our differing results. The cue was a full contrast black horizontal line (1.23° x 0.27°), presented 9.7° from fixation. In Kerzel, Gauch, & Buetti (2010) two cue sizes were tested, but the results were identical with significantly higher accuracy for invalid cue trials than valid cue trials. In similarity, we presented the same cue stimulus characterized as “large” in their experiments and the target stimulus was also presented at 9.7° and 0.45° (edge to edge) above the cue. The target letters were each 1° x 1° in size. Following the offset of the fixation point, the cue was displayed for 100ms, and followed by the presentation of the target for 70ms. After the target offset, there was 100ms of blank screen, after which the subject was prompted, “What was the target letter?” The contrasts tested in this experiment were 6.3%, 7.8%, 9.2%, 10.6%, and 12.1% (relative to the background luminance). Pilot studies indicated that the range of 6-12% contrast covered chance guessing to near 100% correct letter identification.

2.2.4 Procedure

Subjects were instructed to complete the task at their own preferred pace, and to take breaks between each 40-trial run as often as desired to maintain a consistent attentive state. After each stimulus presentation, the subject used a keypad to indicate the observed letter, either an ‘O’ or an ‘X’. A response initiated the next trial.

Each run consisted of 40 trials (lasting 2-3minutes) with 50% of the trials having valid cues and 50% with invalid cues. Each data collection session lasted 1 hour, and each subject participated in a total of 4 hours per experiment. Since data collection is self-paced, there is some slight variation in the amount of data collected per subject, but the average number of trials completed by each subject is 3500 trials per experiment. In experiment 1, an average of 440 trials were conducted on the lowest and highest contrast levels, and 880 trials were conducted at each intervening contrast covering the middle of the psychometric function. The subjects are initially familiarized with the task by completing 3 runs with moderately high contrast targets, having low task difficulty. The data from these training runs are not included in the final analysis. The contrast levels were fixed within each run.

Subjects were informed of the presence of the cue as a precursor to the target stimulus, but not about the reliability of the cue. In some previous published research, subjects were specifically instructed to ignore the cue since it did not reliably predict the forthcoming target location (Jonides, 1981; Kerzel, Zarian, Souto, 2009). While there is some evidence that observers cannot completely ignore a salient peripheral cue (Jonides, 1981; Muller & Rabbitt, 1989; Warner, Juola, Koshino, 1990), specifically instructing a subject to ignore the cue will activate top-down control systems that will likely decrease the saliency of reflexive attention capture and weaken any cueing effects. To avoid any potential confounds from decision processes related to the subjects' intentions when attending to the cue, we withheld specific instructions about the cue other than informing the subjects that it would be presented before the target.

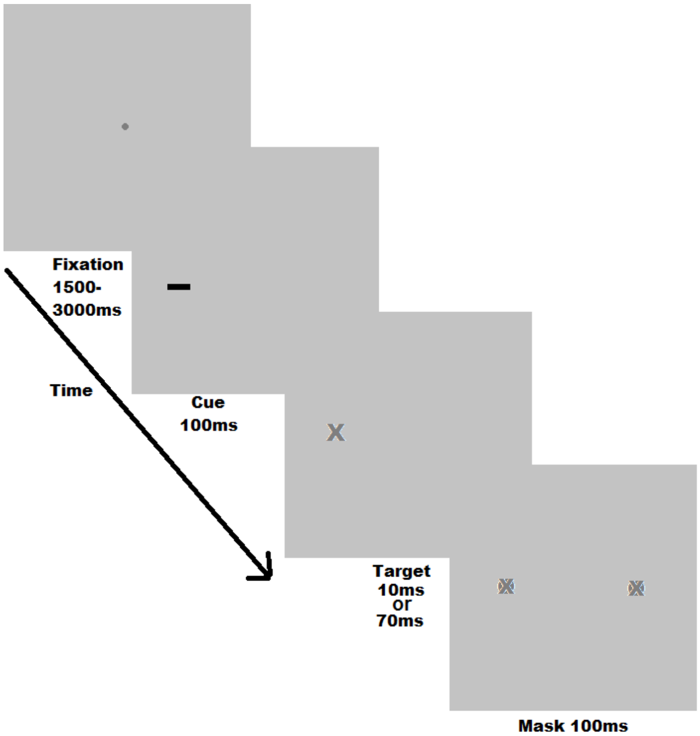

Figure 1. The sequence of stimuli in a single trial. A valid cue trial is shown. After a fixation period, the cue is presented for 100ms and immediately followed by a 70ms, low contrast letter target stimulus. The target stimulus is presented in isolation and unmasked (in experiments 1, 2, and 4). After the target offset, the subjects reported the target identity in response to a text prompt. The observer's task was to report the identity of the low contrast letter. The peripheral cue was non-predictive of the forthcoming target location, having 50% predictability. Observers report their response by pressing either 1 or 2 (for O and X respectively). A mask was displayed only in the third experiment, but it shown here for illustrative purposes.

2.3. Results

Accuracy was measured as the percentage of trials that the observer correctly identified the target letter. In Figure 2 accuracy is plotted as a function of stimulus contrast for each subject. Psychometric functions were fitted to each subject's valid and invalid cue data using the Weibull function. The parameters of this function are the upper asymptote (a) fixed at 97%, the floating exponent or slope (β), and the threshold definition (k) of 75% or d'=1, where $p(c)$ is the percent correct at a given contrast level (c) for the psychometric function from 50% chance guessing up to 100% correct: $p(c) = a - (a - .5) * .5\hat{}((\frac{c}{k})^{\beta})$

Standard error was calculated using Binomial statistics where p is the probability of a correct response, and n is the total number of trials: $\sqrt{p(1-p)/n}$

The upper asymptote parameter was fixed at 97% accuracy, while the exponent parameter (slope) was allowed to float. Analysis of the proportion correct indicates that in general valid cue trials produced lower accuracy performance than invalid cue trials, though not all data points are statistically significant. The goodness of fit (chi square, χ^2) is shown in the figure for each subject. Parameter values for the Weibull function fit are shown in Figure 3 for each experiment. The χ^2 values representing the goodness-of-fit are shown in the plots. Given that the degrees of freedom (df) = N_{data} - $N_{parameters}$ = 6, the expected value of χ^2 = df ± $\sqrt{2\,df} = 6 \pm 3.5$. The t-values shown in Table 1 were calculated as t = (ratio-1)/SE.

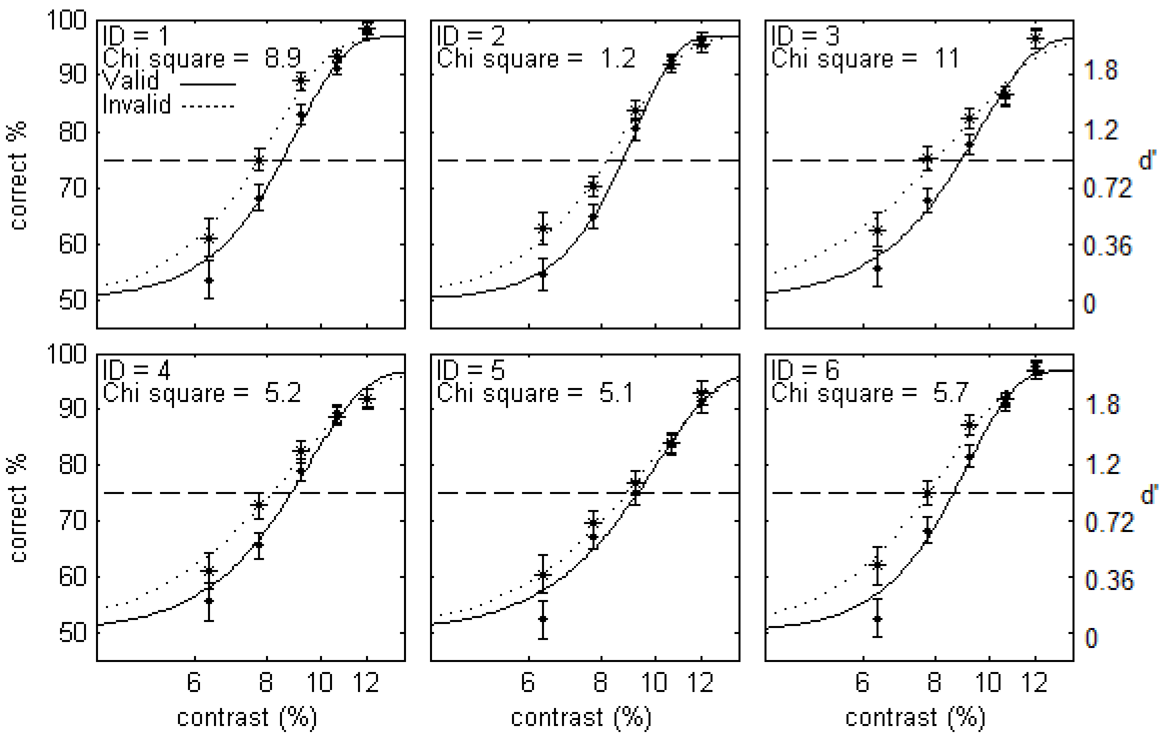

Figure 2. Accuracy (percent correct) as a function of target contrast for unmasked, low contrast targets with a full contrast cue. A Weibull function was fit to each individual subject's accuracy performance from Experiment 1. The error bars are +/- one binomial standard. The Weibull fit of performance with a valid cue is shown as the solid line, while performance with an invalid cue is shown by the dotted line. d' values are plotted on the right vertical axis. The threshold contrast of 75% correct is plotted as the horizontal dashed line. The IDs are subject identification codes, which are the same across all 4 experiments.

In figure 3, the fit parameter values for each individual subject are plotted with each subject ID on the horizontal axis against the specified parameter on the vertical axis. The first subplot shows the contrast thresholds across the first 3 experiments for valid cue trials. The second subplot shows the ratio of the contrast thresholds for invalid and valid cue conditions. A threshold value above 1 indicates a higher threshold with invalid cue trials than valid cue trials, while a value less than 1 shows the opposite. In the third subplot, the exponent (slope) for the valid cue trials is shown. In the fourth subplot, the invalid to valid ratios of the exponent (slope) is shown. A ratio larger than 1 indicates that the valid cue condition has a shallower slope than the invalid cue condition, while a ratio smaller than 1 indicates the opposite.

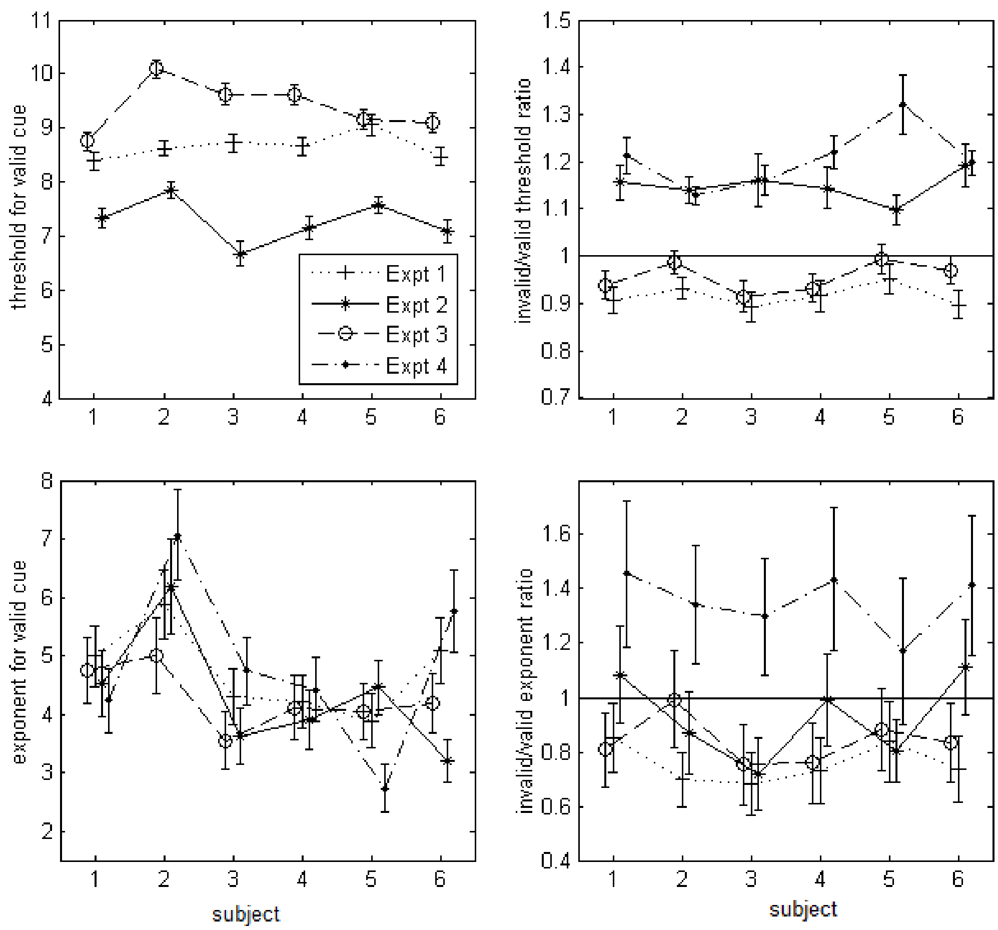

Figure 3: Plots of the parameter values of the Weibull function fit. The first subplot is of threshold parameter values for each experiment across each individual subject. The second subplot indicates the ratio of the thresholds of invalid and valid cue trials. The third subplot indicates the exponent (slope) of valid cue data. The fourth subplot indicates the exponent ratio between invalid and valid cue trials. The data point alignment along the x axis is jittered to prevent overlapping error bars.

As shown in Table 1, the group averaged threshold ratio was 0.916, indicating that the threshold of the cued target was significantly increased $t(5) = -9.211$, $p<0.001$. We attribute this increase to masking by the cue. The group averaged exponent ratio was 0.757, indicating that the psychometric function for the cued stimulus with the increased threshold has a significantly increased slope $t(5) = -8.37$, $p<0.001$. The goodness of fit (χ^2) of the Weibull function was 9.5. The general finding in all the four experiments is that the stimulus condition (cued or uncued) with the higher threshold will have the steeper slope. Our hypothesis is that whatever factor contributes to the threshold elevation, such as stimulus uncertainty, or masking by the cue, will affect low contrast targets more than high contrast targets. The stimuli with lower strength will be more degraded by factors such as stimulus uncertainty or masking by the cue.

	Experiment 1	Experiment 2	Experiment 3	Experiment 4
Exponent Ratio	0.757 +/- 0.029	0.929 +/- 0.065	0.838 +/- 0.037	1.358 +/- 0.045
t	-8.37	-1.09	-4.394	8.1
p-value	0.0004	0.3255	0.0071	0.0005
Threshold Ratio	0.916 +/- 0.009	1.148 +/- 0.012	0.957 +/- 0.013	1.207 +/- 0.027
t	-9.2107	11.9342	-3.3353	7.7451
p-value	0.0003	0.0001	0.0207	0.0006
Chi Square χ^2	9.5	8.7	17.9	5.6

Table 1: Analysis of group averages of exponent and threshold ratios for each experiment as well as the goodness of fit (χ^2) of the Weibull function to the averaged data. Only the exponent ratios of experiment 2 were not significantly different from 1.0.

2.4. Discussion

As shown in figure 3, across all 6 subjects there was a consistent contrast threshold between 8 and 9 percent, indicating fairly equal performance and task difficulty across all subjects. The threshold ratio was consistently below 1.0 for each subject, and the mean threshold ratio (Table 1) indicated a significant decrease in performance with the valid cue compared to the invalid cue. The Weibull function exponents, corresponding to the slopes of the psychometric function for valid cue trials varied between 4 and 6, and the exponent ratios of invalid to valid cue data were less than 1.0, indicating a shallower slope of the invalid cue fit compared to the valid cue fit. Overall, the subjects performed worse with a valid cue than with an invalid cue, suggesting that the presence of the high contrast cue in close proximity to the targets impaired perception of the low contrast target stimuli, confirming our hypothesis of a cue stimulus confound. While this experiment is not an exact replication of Kerzel, Gauch, & Buetti (2010), the results are in general agreement with theirs. While the results indicate that the cue used is impairing perception, further experiments were conducted to provide additional evidence to support this hypothesis.

3.1. Experiment 2: Letter discrimination with an isoluminant cue

The purpose of Experiment 2 was to determine if changing the parameters of the cue results in better performance with a valid cue than an invalid cue, thereby suggesting that the absence of cueing effects for unmasked stimuli as previously reported is actually due to the cue disrupting perception of low contrast targets rather than being related to mask-dependent cueing effects. To test our hypothesis that the cue stimulus used in Experiment 1 was interfering with perception of the low contrast target letters, we changed the cue color and made it approximately isoluminant with the background and increased the distance between the cue and the target from 0.45° to 0.9°.

3.2. Methods

The same 6 subjects from experiment 1 were recruited to participate in experiment 2. The stimuli are identical to those used in experiment 1 except for changes in the features of the cue. The cue was an isoluminant green horizontal line spanning 1.23° x 0.27°, presented 9.7° away from fixation and 0.9° (edge to edge) below the target location. Cue luminance was set to 13 cd/m^2 using a photometer so that the green cue color was isoluminant with the background. Subjects were given the same task instructions as in Experiment 1 but were informed that the cue would now appear as a light green line, rather than black. Data analysis is the same as in Experiment 1.

3.3. Results

In Figure 4 accuracy is plotted as a function of stimulus contrast for each subject. Analysis of the proportion correct indicates that across all six participants, task performance was higher with a valid cue than an invalid cue. As shown in Table 1, the group averaged threshold ratio was 1.148, indicating that the threshold of the cued target was significantly decreased $t(5) = 11.934$, $p<0.001$. The group averaged exponent ratio was non-significant at 0.929, indicating no change in slope $t(5) = -1.09$, $p>0.05$. The goodness of fit (χ^2) of the Weibull function was 8.7.

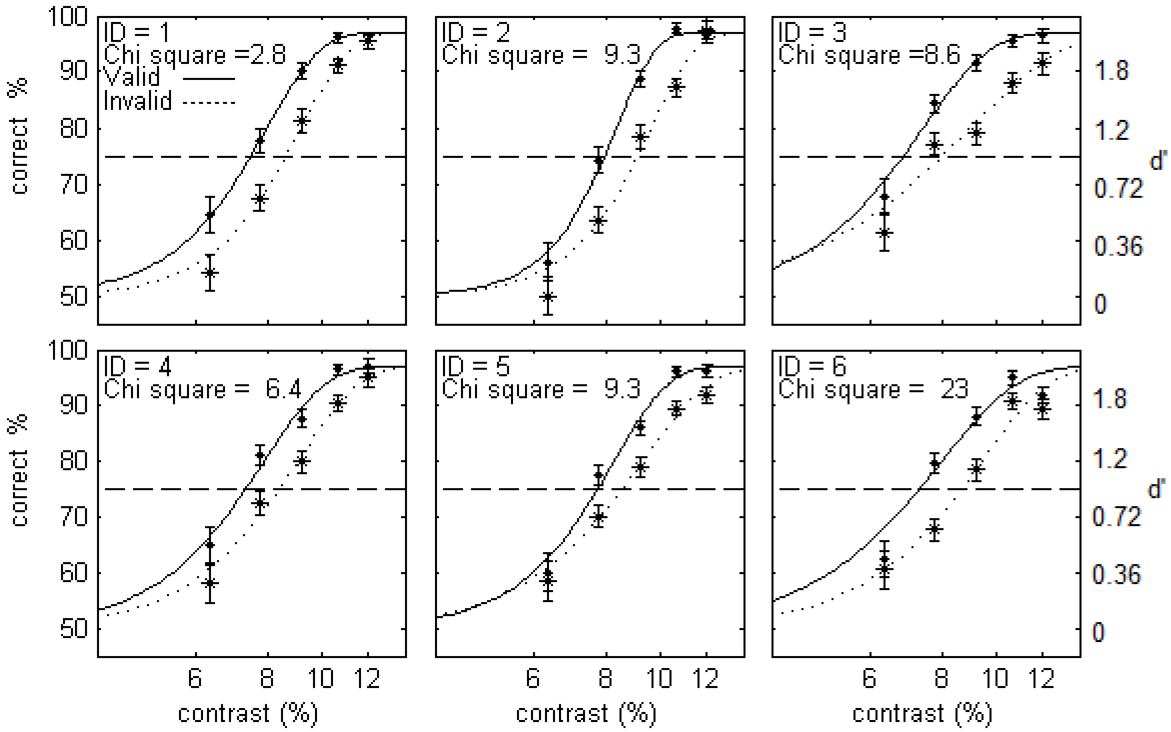

Figure 4: Accuracy (percent correct) as a function of target contrast for unmasked, low contrast targets with a green cue isoluminant with the background. A Weibull function was fit to each individual subject's accuracy performance. The error bars are +/- one binomial standard error. The fit for the valid cue condition is shown as the solid line, while the invalid cue condition is shown as the dotted line. d' values are plotted on the right vertical axis. The 75% contrast threshold is plotted as the horizontal dashed line.

3.4. Discussion

As shown in figure 3, the contrast threshold for the valid cue condition varied between 6 and 8 percent, while the threshold ratio was above 1, indicating the invalid cue trials had a higher threshold than the valid cue trials, corresponding to a leftward shift of the psychometric function. This is also indicated by the group averages as shown in Table 1. The exponent of the valid cue fit ranged from 3 to 5 for all subjects except subject 2 who had an exponent of 6.18. Three subjects had an exponent ratio less than 1, indicating a steeper slope with valid cue trials, while two subjects had a steeper slope with valid cue trials, but across all six subjects there was not a uniformly significant change of slope above or below 1. The averaging of the data from all 6 subjects also indicated no significant change in slope. This has significance to spatial uncertainty reduction and signal detection theory as will be discussed in the general discussion section. The results from Experiment 2 confirm our hypothesis that the previously reported absence of cueing effects with unmasked low contrast target letters was due to disruption from the high contrast cue positioned in close proximity to the target. By making the cue isoluminant with the background and doubling the distance between the top of the cue and the bottom of the target stimulus, accuracy improved at cued locations compared to uncued locations.

These results bring into question the validity of the mask-dependent cueing hypothesis since there are statistically significant cueing effects with involuntary attention and unmasked stimuli in this experiment. To provide additional evidence that the changes we made to the cue stimulus were actually the determining factor in why we observed strong cueing effects and others have not with the same task, a third experiment was conducted using the original high contrast cue parameters, but with masked stimuli. Kerzel, Gauch, & Buetti (2010) did not test for cueing effects with masked stimuli using the same cue that was used with unmasked stimuli, overlooking a critical factor in their experiments. We hypothesized that the high contrast cue would create the same perceptual disruption with masked stimuli as unmasked stimuli.

4.1 Experiment 3: Low contrast letter Discrimination with masked stimuli

In order to reiterate the fact that the cue stimulus parameters used in Kerzel, Gauch, & Buetti (2010) lowered discrimination of the low contrast target stimulus thereby leading to backward cueing effects, we conducted a third experiment using the same cue parameters but with masked stimuli. In their previously reported results, Kerzel, Gauch, & Buetti (2010) did not examine if cueing effects were present with masked low contrast targets using their cue stimulus. Only full contrast targets were implemented with the mask. Since their experimental conditions are therefore different between the masked and unmasked conditions, it is unreasonable to conclude that cueing effects are observed with masked stimuli, but not unmasked stimuli. In the third experiment reported here, we wanted to determine if cueing effects were present for masked stimuli when targets are low contrast and a full contrast cue is presented in close proximity to the target stimulus. Since the two previous experiments demonstrated that the cue contrast and proximity were the confound leading to backward cueing effects with unmasked low contrast stimuli, we wanted to test if the same interference occurs with masked stimuli. If there is an absence of positive cueing effects, then it confirms our hypothesis that the cue stimulus parameters are a confound, and challenges the mask-dependent cueing hypothesis.

4.2 Methods

The same 6 subjects from experiments 1 and 2 were recruited to participate in experiment 3. The stimuli and task are identical with the first experiment except that the low contrast target is followed immediately by a 100ms mask consisting of an X and O target stimulus superimposed and presented on both sides of fixation. In each trial, the contrast of the mask is the same as that of the targets. In the previous two experiments, there was a 100ms duration of blank screen following the offset of the target during which iconic memory was undergoing decay. In the masked experiment, the mask is presented for the duration of the 100ms, maintaining the same time interval between the target offset and question prompt. The difference is that with the mask, the iconic memory decay is now interrupted instead of gradually decaying.

4.3 Results

In Figure 5 accuracy is plotted as a function of stimulus contrast for each subject. The Weibull function was fit to the valid cue and invalid cue data. Analysis of the proportion correct indicates that task performance was not significantly different between cue conditions, though some data points indicate worse performance with a valid cue than an invalid cue. As shown in Table 1, the group averaged threshold ratio was 0.957, indicating that the threshold of the cued target was significantly increased t(5) = -3.3, p<0.05. The group averaged exponent ratio was significant at 0.84, indicating an increased slope for the valid cue trials t(5) = -4.39, p<0.01. The goodness of fit (χ^2) of the Weibull function was 17.9.

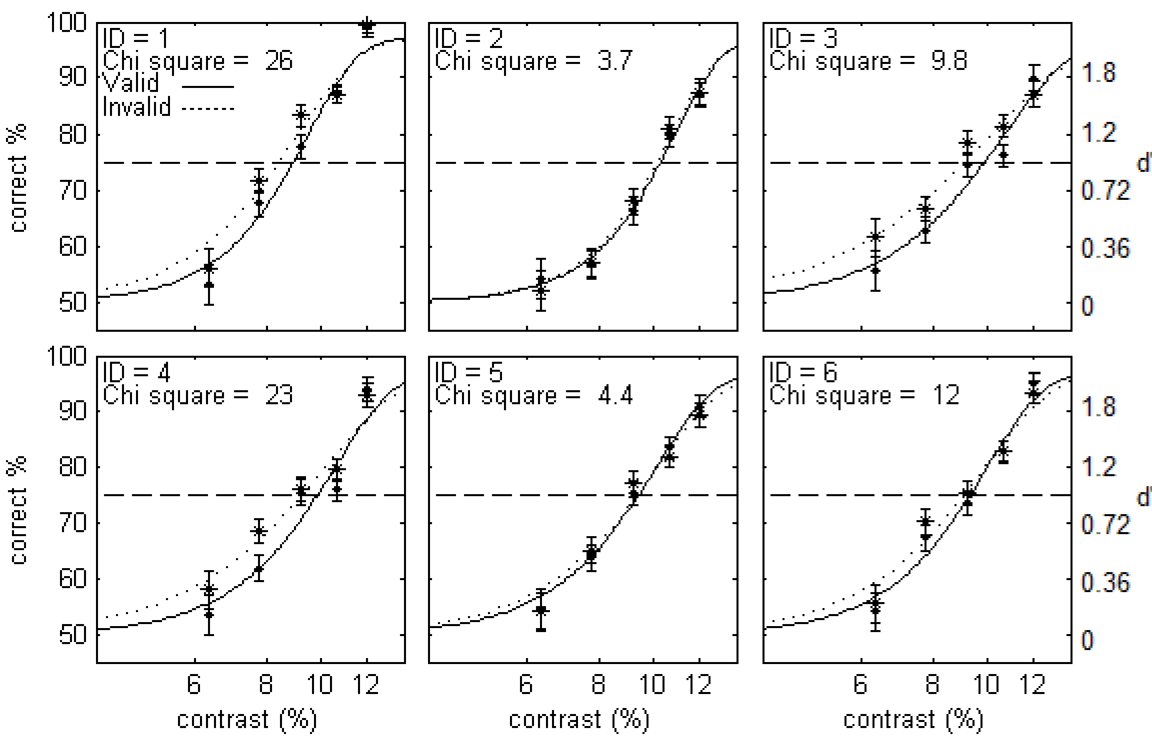

Figure 5: Accuracy (percent correct) as a function of target contrast (percent) for masked, low contrast targets with a high contrast cue. A Weibull function was fit to each individual subject's accuracy performance. Valid cue data is illustrated by the solid line, while invalid cue data is illustrated by the dotted line. d' values are plotted on the right vertical axis. The threshold value is plotted as the horizontal dashed line.

4.4 Discussion

As shown in figure 3 by the dashed lines with circular data points, thresholds for valid cue data were higher in Experiment 3 than in Experiments 1 and 2, ranging from 8.6 to 10. Threshold ratios were less than 1, but not all individually statistically significant. Averaging the data across all 6 subjects indicated a statistically significant increase in the threshold ratio (Table 1). The Weibull fit exponents ranged from 3.5 to 6 while the exponent ratios were less than 1, though not all were statistically significant. Averaging across all 6 subjects resulted in a statistically significant reduction of the exponent ratio, producing a shallowing of the slope of the invalid cue data fit. The results of Experiment 3 show that even with masked stimuli, using these cue parameters resulted an absence of any cueing effect. This is further evidence that the absence of cueing effects reported in Kerzel, Gauch, and Buetti (2010) is not in fact due to an absence of a post mask, but instead because of a confound in the cue stimulus that impairs perception of both masked an unmasked low contrast target letters. They argued that cueing effects are observed with masked stimuli at full contrast, but didn't test low contrast, masked targets. They concluded that masked targets produce perceptual enhancement from involuntary attention and that unmasked targets do not, except at small eccentricities where crowding is less influential. Our results indicate that perception of masked low contrast targets is disrupted with a high contrast cue, and that the cue stimulus parameters are the reason for the absence of cueing effects previously reported.

5.1 Experiment 4: Low contrast letter discrimination with a short SOA

A significant amount of previously published research has suggested that involuntary attention is maximally captured around 110ms post-cue and that it decays rapidly thereafter (Montagna, Pestilli, & Carrasco, 2009; Muller & Rabbitt, 1989; Nakayama & Mackaben, 1989; Turatto, Vescovi, & Valsecchi, 2007). Since many studies reporting cueing effects with transient involuntary attention used shorter stimulus intervals than those presently tested, a fourth experiment was conducted to determine if cueing effects were still prominent with very brief stimuli.

5.2 Methods

The stimuli and task is similar to Experiment 2 except that the low contrast target is only presented for 10ms instead of 100ms, and different contrast levels are examined. As evident from Bloch's Law, there is a tradeoff between the contrast and the duration of stimuli in terms of visibility. Lowering the duration of the stimulus necessitates increasing the contrast of the stimulus to maintain a consistent level of performance. The cue was presented for 60ms, followed by 40ms of blank screen (making a 100ms stimulus onset asynchrony) and then a 10ms target stimulus. Seven contrast levels were tested in this experiment: 28.1%, 31.7%, 35.3%, 37.8%, 41.2%, 43.4%, and 46.8%. Pilot studies indicated that this range of contrast levels covered task performance from chance guessing to near 100% correct letter identification.

5.3 Results

In Figure 6 accuracy is plotted as a function of stimulus contrast. The Weibull function was fit to the valid cue and invalid cue data. Analysis of the proportion correct indicates performance was higher with a valid cue than an invalid cue with the exception of stimuli presented at 46.8% contrast where performance is near 100% correct. As indicated in Table 1, the group averaged threshold ratio was 1.207, indicating that the threshold of the cued target was significantly decreased t(5) = 7.745, p<0.001. The group averaged exponent ratio was significant at 1.358, indicating a shallowing of the slope for the valid cue trials t(5) = 8.1, p<0.001. The goodness of fit (χ^2) of the Weibull function was 5.6.

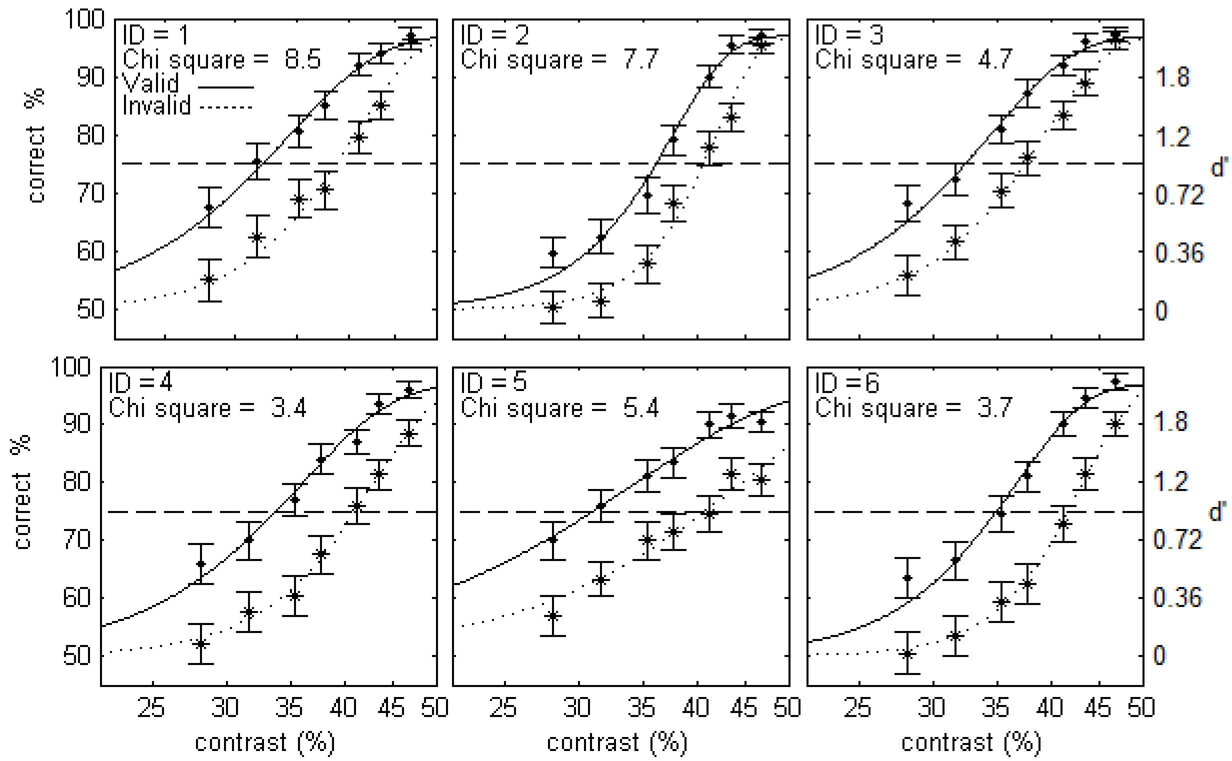

Figure 6: Accuracy as a function of target contrast for unmasked, low contrast, 10ms targets with an isoluminant cue. Valid cue data is illustrated by the solid line fit, while invalid cue data is shown by the dotted line. d' values are plotted on the right vertical axis. The threshold value is plotted as the horizontal dashed line.

5.4 Discussion

Across all 6 subjects, contrast thresholds ranged from 30 to 36 percent for the valid cue condition, and threshold ratios were consistently greater than 1. Averaging of the data across all subjects as shown in Table 1 indicated that threshold ratios were significantly increased, meaning that valid cue trials had a lower threshold than invalid cue trials. Exponents ranged from 2.8 to 7, and while all of the exponent ratios were larger than 1, none had a statistically significant difference from 1, indicating there there was no significant shallowing of the slope of the valid cue trials, compared in invalid trials. When averaged together however, exponent ratios were significantly higher than unity (1.0), indicating a shallowing of the slope for the validly cued data. The threshold values from Experiment 4 are larger given the higher contrast levels, so they are not shown in the first plot of Figure 3 but the values for subjects 1:6 are (respectively) 31.5, 35.7, 31.8, 33.1, 30.0, and 34.4 percent. The results show a large increase in response accuracy from involuntary attention with valid cues over invalid cues, for stimuli with a shorter duration (10ms) and therefore a shorter length of total processing time in this task (110ms vs 170ms). The positive cueing effect further confirms our hypothesis that that the previously reported absence of cueing effects with unmasked low contrast target letters was due to disruption from the high contrast cue positioned in close proximity to the target, thereby challenging the mask-dependent cueing hypothesis.

6. General Discussion

In these experiments, we sought to demonstrate that the reason Kerzel, Gauch, & Buetti (2010) did not find cueing effects for unmasked low contrast letter stimuli in the periphery is because of a confound in their cue stimulus. In their experiments with peripheral stimuli, observers performed worse with valid cues than invalid cues suggesting that the cue is interfering with perception of the low contrast target letters. They found that cueing effects re-emerged when stimuli were presented parafoveally, but only at small eccentricities. While they did not observe cueing effects in the peripheral visual field for unmasked low contrast letters, our results show a large cueing effect that is present in the peripheral visual field. By increasing the distance between the cue and the target, and by lowering the contrast of the cue to match the background luminance, we observed a large increase in accuracy judgment performance with valid cues compared to invalid cues.

Experiment	Masked	Cue Contrast	Cueing effect	Average Threshold	Average Slope
1	No	High	Negative	Cued Increased	Cued Increased
2	No	Low	Positive	Cued Decreased	Non-significant
3	Yes	High	Negative	Cued Increased	Cued Increased
4	No	Low	Positive	Cued Decreased	Cued Decreased

Table 2. Summary of results. Experiments 1 and 3 had a reversed cueing effect, a group average increase in threshold for the valid cue trials, and an increase in group average slope, while experiments 2 and 4 had positive cueing effects, a group average decrease in threshold for the valid cue trials, and experiment 4 had a group averaged shallowing of slope for valid cue trials, while experiment 2 had not significant change in slope.

In Experiment 1 using a full contrast cue and unmasked target stimuli, target identification accuracy was not higher with a valid cue compared to an invalid cue. It was hypothesized that the high contrast of the cue relative to the low contrast of the target was impairing perceptual sensitivity at the cued location and that by lowering the contrast of the cue, positive cueing effects would emerge. Additionally, as hypothesized in Kerzel, Gauch, & Buetti (2010), we hypothesized that the cue may be crowding the target stimulus, and we therefore doubled the distance between the two stimuli. The results of Experiment 2 show that target identification accuracy is higher with a valid cue than an invalid cue when the cue contrast is lowered and moved further away from the target. In Experiment 3, we used the full contrast cue stimulus with masked stimuli and observed that cueing effects disappeared, providing evidence that the high contrast cue confound acts on both masked and unmasked stimuli. These results challenge the mask dependent cueing hypothesis since no cueing effect was present with masked stimuli. In Experiment 4, stimulus duration was reduced from 100ms to 10ms, and correspondingly, contrast levels were increased. We found larger cueing effects in this short stimulus condition than in Experiment 2, providing evidence that involuntary attention may be more influential at shorter SOAs than those tested in Kerzel, Gauch, & Buetti (2010). Together, the results indicate that there is an improvement in target identification accuracy for low contrast letters and that these cueing effects are not dependent on the presence of a masking stimulus, as has previously been proposed in the mask-dependent cueing hypothesis.

Mechanisms of Involuntary Attention and Spatial Uncertainty Reduction

While many researchers have reported perceptual signal enhancement with involuntary attention using non-predictive cues, other researchers have provided evidence that observer uncertainty over the location of the target stimulus can produce cueing effects (Pelli, 1985; Tanner, 1961) and can bias response decisions leading to what appears to be improved target detection at cued locations, but in reality is just a result of decisional selection processes contributing to improved accuracy with a valid cue over an invalid cue (Prinzmetal, Long, & Leonhardt, 2008; Prinzmetal, McCool, & Park, 2005). In our experiments and those of others, accuracy judgments are not susceptible to response bias to the cue brought on by spatial uncertainty since the observer reports the stimulus identity and not its location. One question that remains from the presently conducted experiments is whether or not the observed cueing effects are a result of a perceptual process such as signal enhancement or a decisional process such as spatial uncertainty reduction.

In order to investigate signal enhancement, any effects of spatial uncertainty reduction must be controlled for (Shaw, 1984). Researchers have argued that spatial uncertainty alone does not always account for cueing effects (Baldassi & Verghese, 2005; Cameron, Tai, & Carrasco, 2002; Luck et al.,1996), though it may inflate the magnitude of the observed cueing effects when the set size is large since spatial uncertainty is higher with a larger set size (Kerzel, Gauch, & Buetti, 2010). Kerzel, Gauch, & Buetti (2010) argued that since some of their experiments did not result in cueing effects under conditions of spatial uncertainty, the uncertainty reduction from a cue is not sufficient to produce cueing effects.

One common argument against spatial uncertainty reduction accounting for reported cueing effects is that if localization accuracy is high, then spatial uncertainty must be low and uncertainty reduction would not account for any observed cueing effects (Cameron, Tai, Carrasco, 2002). When task performance is low such as when stimuli are difficult to identify or localize, there is more spatial uncertainty (Pelli, 1985), and it would be expected that the magnitude of improvement would be highest at low performance levels. Similar results would be expected from a signal enhancement mechanism however since attention would increase the signal strength of attended stimuli, producing a larger signal to noise ratio for low contrast stimuli (Cameron, Tai, Carrasco, 2002; Carrasco, Penpeci-Talgar, Eckstein, 2000; Lu & Dosher, 1998).

In Cameron, Tai, & Carrasco (2002), two tasks with different levels of contrast and spatial uncertainty led to cueing effects of the same magnitude and the researchers adopted a contrast enhancement hypothesis, arguing that the spatial uncertainty reduction hypothesis would have led to differences in the magnitude of the cueing effect between each task. Further, the entire contrast response function shifted into lower contrasts for both suprathreshold stimuli (for which it is argued there would be little spatial uncertainty since the targets are highly visible) and subthreshold stimuli (where spatial uncertainty reduction could account for some of the performance improvement), suggesting that spatial uncertainty alone wouldn't account for the cueing effect observed across all the levels of task difficulty. However, spatial uncertainty would increase with lower contrast stimuli, in which case the magnitude of task improvement from spatial uncertainty reduction would be much higher at these low contrasts and could potentially account for a larger proportion, if not all, of the cueing effect.

In their experiments, the slope of the psychometric curve was shallower for peripheral cued trials than for neutral cued trials (see figure 9b in Cameron, Tai, & Carrasco, 2002). According to signal detection theory, uncertainty reduction makes the slope of the psychometric function shallower (Green & Swets, 1966; Pelli, 1985). This could be taken as further evidence that their reported cueing effects were at least partially due to spatial uncertainty reduction. The slope of a Weibull function can vary however depending largely on parameter settings, such as whether the upper asymptote parameter is allowed to float. Adopting the conclusions from Wichmann & Hill (2001), the present data was fit using a floating slope parameter, but a fixed upper asymptote of 0.97. In Experiment 1, there is no statistically significant shallowing of the slope between valid and invalid conditions, which is not surprising since there is no consistent cueing effect present. In Experiment 2, subjects 1 and 6 show a shallowing of the slope of the valid cued trials indicated by exponential ratios greater than 1.0, but the slope changes are not statistically significant. Group averaging across all subjects also indicated no statistically significant change in slope. Three of the subjects actually show a reversed slope change, with the invalid cue trial fit having a shallower slope than the valid cue fit. These results indicate that there is not a statisically significant reduction of slope for the valid cued data, as predicted in signal detection theory if spatial uncertainty reduction is present. As such, spatial uncertainty reduction cannot fully account for the cueing effect results of Experiment 2. In Experiment 3, there is no statistically significant slope shallowing of the valid cue data, most likely because of the disruptive effect of the high contrast cue as also manifest in Experiment 1. In Experiment 4, all six subjects have an exponent ratio greater than 1.0 indicating a shallowing of slope as predicted by signal detection theory as an indicator of spatial uncertainty reduction, but none of the slope changes are statistically significant on individual subjects. Only when taken as an average across all 6 subjects, does the slope become significantly shallowed. As in Experiment 2, spatial uncertainty reduction is not a sufficient explanation for the observed cueing effects (unless averaged across all subjects in experiment 4). This does not mean that uncertainty reduction in any form (such as temporal uncertainty) doesn't account for some of our results, but it does indicate that our data do not produce one of the common indicators of spatial uncertainty reduction.

It could be argued that our results are not attributed to spatial uncertainty because there is spatial uncertainty in all of our experiments, yet in two of our experiments with a high contrast cue, there were no significant cueing effects. This argument was presented in Kerzel, Gauch, & Buetti (2010). If spatial uncertainty reduction were in fact the mechanism responsible for the cueing effect, we would have expected a cueing effect for these experiments since spatial uncertainty is present, but since we didn't see any positive cueing effect in Experiments 1 and 3, spatial uncertainty is likely not producing cueing effects and our cueing effects in Experiments 2 and 4 could instead be due to signal enhancement mechanisms. While our results are not readily attributable to spatial uncertainty reduction, the results could be attributed to other forms of uncertainty reduction such as temporal uncertainty reduction (Correa, et al., 2010; Coull & Nobre, 1998; Rolke & Hofmann, 2007). Considering all of these possible mechanisms of improved accuracy judgment performance, it is difficult to ascertain which mechanism(s) best account for our results or even to determine whether the improvement in accuracy judgment performance is due to perceptual or decisional processes.

Mask Dependent Cueing Hypothesis

The present four experiments demonstrate that cueing effects are not dependent on the presence of a backward mask, necessitating an alternative hypothesis. Researchers have argued that only stimuli temporally constrained with a mask result in improved accuracy judgments when spatial uncertainty reduction is controlled (Gould, Wolfgang, & Smith, 2007). Using a mask eliminates the iconic image in visual short term memory, limiting the available time to search for the target within memory (Phillips, 1974; Sperling, 1960). The valid cue is effective since it directs attention to the correct location before the signal is lost. Without a mask, more time may potentially be available to search more potential target locations, so a valid cue does not offer a performance advantage since processing time is less constrained. However, the precise duration of the image in iconic memory is unknown, and brief, low contrast stimuli may have such a rapid decay that available search time is not significantly extended. In this way, very brief or low visibility stimuli could act as a similar type of mask since search time is highly constrained.

Within our results, the mechanism proposed by the mask-dependent cueing hypothesis cannot account for the cueing effect since there is no post mask by which iconic memory would be constrained. The brief stimuli explanation of rapid iconic decay could thereby explain our results. Our results do not dismiss the mechanism of more efficient transfer of information to

VSTM as hypothesized in the integrated system model (Smith, et al., 2009), but rather challenge the claim that perceptual enhancements from involuntary attention only exist for masked stimuli.

Further Contributions of this investigation

Only a few studies have investigated the influence of attention on letter identification across the full psychometric function when targets are presented in isolation (Cameron, Tai, Carrasco, 2002; Carrasco, Penpeci-Talgar, & Eckstein, 2000). In all of the presently conducted experiments, multiple target contrast levels were tested in order to produce a psychometric function and demonstrate that cueing effects are not isolated to near-threshold levels or specific performance difficulty levels. Some studies have claimed that cueing effects only occur near detection threshold (Kerzel, Zarian, Gauch, Buetti, 2010), and conclude that a sensory luminance interaction accounts for the results rather than an attention induced perceptual enhancement, and that attention does not alter perception of readily perceived stimuli (Schneider, 2006). Similarly, it has been suggested that involuntary attention cueing effects are absent when the task is very difficult and performance is low (Kerzel, Zarian, Souto, 2009). The present experiments measure perceptual enhancement across a large range of contrast levels, encompassing stimulus intensities that are both well above and well below threshold detection levels. In agreement with Ling & Carrasco (2006), the results indicated that the cueing effect is not due to sensory interactions because the cueing effect is present well above and below threshold detection levels.

In some of the previous reported literature arguing against perceptual enhancement from involuntary attention and non-predictive cues, data was collected only at single contrasts (though sometimes using staircase procedures to obtain a specific level of performance such as 71% correct) or at a specified level of difficulty and performance(Kerzel, Gauch & Buetti, 2010; Kerzel, Zarian, Souto, 2009). In the present experiments, the same amount of data was collected at each contrast level (on average 220 valid and 220 invalid trials), but 5 or 7 contrast levels were tested, producing significantly more data per subject. Whether or not experienced subjects such as in our experiments produce significantly different results than less trained subjects as in Kerzel, Gauch, & Buetti (2010) is a topic in need of investigation. Perhaps subjects who have longer exposure to cueing tasks assign different weights to the cue, potentially leading to differences in observed cueing effects. This topic requires further investigation.

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Bias free double judgment performance accuracy during spatial attention cueing.

Abstract

Previously it has been demonstrated that involuntary attention improves target identification accuracy using non-predictive peripheral cues. While various cueing studies have demonstrated that reported cueing effects are not due to response bias, very few investigations have quantified the extent of any response bias or developed methods of removing bias from observed results. Using a multinomial model, selection bias can be quantified and removed from the results, eliminating location response bias and revealing the true, unbiased performance enhancement resulting from involuntary attention. In a 7AFC cueing task with backward masked stimuli, observers performed significantly better with a valid cue than an invalid cue even after response bias had been accounted for. Across a range of temporal parameters spanning the time course of involuntary and voluntary attention, non-predictive cueing increased target detectability at cued locations and decreased detectability at uncued locations. The multinomial modeling of joint location and identity judgments allows for detailed analysis of how involuntary spatial attention influences the perception of features and locations independently.

1. Introduction

Many cueing paradigms have demonstrated that covert attention can enhance target discriminability across a wide temporal range spanning the time course of activation of involuntary and voluntary attention. In these tasks, a cue captures attention to a feature or spatial region of the visual field, leading to improved target identification when the cue precedes a target stimulus within the same spatial region and/or has the same target feature (Lin et al., 2011). While a few studies have examined cueing effects across a temporal range spanning the activation of both involuntary and voluntary attention (Cheal & Lyon, 1991; Hein, Rolke, Ulrich, 2006; Koenig-Robert & VanRullen, 2011; Muller & Rabbitt, 1989; Nakayama & Mackaben, 1989) none of these studies have quantified response biases or implemented multiple accuracy judgments, though some have argued that response biases do not confound their results. Response bias has in some cases been shown to increase accuracy judgment performance with valid cues and decrease performance with invalid cues, thereby producing misleading cueing effects (Prinzmetal, McCool, & Park, 2005; Prinzmetal, Long, & Leonhardt, 2008). While there is agreement that voluntary attention leads to faster reaction times and improved accuracy judgment performance, there is considerable controversy in the topic of involuntary attention on whether or not a non-predictive cue improves response accuracy, and whether previous reports of improved accuracy performance were in fact due to response bias brought on by spatial uncertainty reduction.

To address the concerns over response bias from location uncertainty contributing to cueing effects with a large set size, we have developed a bias removal process using a multinomial model by which the extent of a response bias can not only be measured, but subtracted from the observed results. In addition, two measures of accuracy judgment are examined, a location judgment (susceptible to location response bias), and an identification judgment (not susceptible to bias). In this investigation, multinomial modeling has been implemented as a statistical technique for estimating theoretical parameters reflecting the probability of unobservable cognitive decisional/selection processes. Multinomial modeling is similar to computational theories of cognitive processes as a model can be used for collecting data, estimating parameters of cognitive events, and testing hypothesis. In developing a multinomial model of cognitive processes, theoretical assumptions about these processes are formulated to explain how the observed experimental data is generated by the processes. A multinomial model is useful for measuring multiple cognitive processes simultaneously, and in determining how each of these cognitive processes individually contributes to the observed results (Riefer, & Batchelder, 1988). Multinomial modeling is therefore highly useful in the 7AFC divided attention experiments reported here as a model can be created to obtain insight into unobservable cognitive processes relevant to these tasks, such as response bias, location uncertainty, and the differences that exist between subjects for these variables. The main incentive for implementing a multinomial model of the current experiment is to assess the magnitude of response bias from individual subjects, and then remove that bias from the results to reveal the extent of performance enhancement that cannot be attributed to response biases.

There is considerable evidence that perceptual enhancements result from attending to a localized region of the visual field using voluntary attention as manifested as a faster response time (Jonides, 1976; Jonides, 1980; Jonides, 1981; Joseph & Optican, 1996; Pashler, 1988; Prinzmetal, McCool, & Park, 2005; Theeuwes, 1991, 1992), location uncertainty reduction (Bonnel, Stein, & Bertucci, 1992; Davis, Kramer, & Graham, 1983; Foley & Schwarz, 1998; Graham, Kramer, & Haber, 1985; Lee, Itti, Koch, & Braun, 1997; Muller & Findlay, 1987; Palmer, 1994; Palmer, Ames, & Lindsey, 1993; Shaw, 1984), enhanced detection sensitivity (Bashinski & Bacharach, 1980; Brawn & Snowden, 2000; Downing, 1988; Hawkins, Hillyard, Luck, Mouloua, Downing, & Woodward, 1990; Luck, Hillyard, Mouloua, Woldorff, Clark, & Hawkins, 1994; Muller & Humphreys, 1991; Smith, 1998), or an improved performance in accuracy judgments (Carrasco, Ling, & Read, 2004; Carrasco & Yeshuran, 2009; Giordano, McElree, & Carraso, 2009; Lu & Dosher, 1998; Liu, Stevens, & Carrasco, 2007). However there is controversy as to whether or not perceptual enhancement occurs via involuntary attention mechanisms. There is a fair amount of evidence showing improved response accuracy with involuntary attention (Carrasco, Fuller, & Ling, 2008; Carrasco, Ling, & Read, 2004; Fuller, Park, & Carrasco, 2009; Fuller, Rodriguez, & Carrasco, 2008; Giordano, McElree, & Carrasco, 2009; Liu, Pestilli, & Carrasco, 2005; Montagna, Pestilli, & Carrasco, 2009; Pestilli & Carrasco, 2005; Pestilli, Viera, & Carrasco, 2007; Scolari, Kohnen, Barton, & Awh, 2007), yet there is contradicting evidence that non-predictive cueing does not improve response accuracy (Kerzel, Zarian, Souto, 2009; Prinzmetal, Ha, & Khani, 2010; Prinzmetal, McCool, & Park, 2005; Prinzmetal, Park, & Garrett, 2005) and that many reported cueing effects are due to decision bias from location uncertainty (Kerzel, Zarian, Gauch & Buetti, 2010; Prinzmetal, Long, & Leonardt, 2008; Schneider & Komlos, 2008; Valsecchi, Vescovi, & Turatto, 2010), or sampling error (Kerzel, Zarian, & Souto, 2009; Kerzel, Gauch, & Buetti, 2010). One of the aims of the present investigation is to determine if involuntary attention captured by non-predictive cues results in improved accuracy performance, and to assess the time course of such enhancement effects of involuntary and voluntary attention.

The effect of cue predictability on attention capture and response performance has been debated for both reaction time and accuracy judgment experiments, but remains more controversial for accuracy judgment experiments. Perceptual enhancement measured as faster reaction times has been demonstrated to occur when cues are predictive, non-predictive, and even anti-predictive (Esterman, Prinzmetal, DeGutis, Landau, Hazeltine, Verstynen, & Robertson, 2008; Posner, Cohen, & Rafal, 1982; Rafal & Henik, 1994; Sereno & Holzman, 1996; Warner, Joula, & Koshino, 1990). It's interesting to note that in some of these studies, even with a cue that is antipredictive, an involuntary cueing effect only occurs when the stimulus onset asynchrony (SOA) is very short suggesting that involuntary attention has a short, transient time window of activation.

It has been stated that non-predictive cues do not always improve perception, whereas predictive cues do (Kerzel, Zarian, Souto, 2009; Kerzel, Gauch, Buetti, 2010; Prinzmetal, McCool, Park, 2005; Prinzmetal, Park, Garrett, 2005). These researchers stated however that this generalization may not always hold true and that there are some experiment conditions that may produce cueing effects with involuntary attention such as when set size is large or when a mask is used. Some disagreement in the literature about the existence of improved task performance with involuntary attention and non-predictive cues is likely to be the result of differences in defining involuntary and voluntary attention.

There are three main ways of differentiating involuntary from voluntary attention using cueing stimuli. Some researchers have asserted that voluntary and involuntary attention can be operationally differentiated on the basis of cue predictability under the assumption that a subject will not voluntarily attend to the cue when the cue is non-predictive (Jonides, 1980, 1983; Kerzel, Gauch, & Buetti, 2010; Prinzmetal, Ha, & Khani, 2010; Prinzmetal, Long, & Leonhardt, 2008; Prinzmetal, McCool, & Park, 2005, Prinzmetal, Park, & Garrett, 2005; Wright & Richard, 2000). Others have argued that the systems are differentiated by the length of time available to attend to a stimulus or task. If enough time is available to complete the perceptual task using voluntary search with or without eye movements (covertly or overtly), then voluntary attention is utilized (Carrasco, Fuller, & Ling, 2008; Cheal & Lyon, 1991; Ling & Carrasco, 2007; Nakayama & Mackaben, 1989). In this view, voluntary attention is characterized as a voluntary, goal-directed orienting of attention, while involuntary attention is an involuntary, reflexive, and automatic orienting of attention. A third differentiation is on the nature of the cue stimulus. A cue can appear at central fixation and instruct the observer to voluntarily attend to other locations, which involves some degree of interpretation of the cue, or a cue could saliently appear at some location in the periphery which reflexively draws attention to the spatial region. While central symbolic cues generally activate voluntary attention and peripheral cues activate involuntary attention, cues don't necessarily have to be peripheral to engage involuntary attention (Driver, Davis, Ricciardelli, Kidd, Maxwell, & Baron-Cohen, 1999; Friesen & Kingstone, 1998; Kingstone, Smilek, Ristic, Friesen, & Eastwood, 2003; Lambert & Duddy, 2002; Langton, Watt, & Bruce, 2000; Ristic, Friesen, & Kingstone, 2002; Tipples, 2002). The location of the cue doesn't appear to be a consistent or reliable differentiating variable for voluntary and involuntary attention, and in fact can be combined in either of the first two differentiation variables (predictability and temporal stimulus parameters). If the differentiation of the two attention systems on the basis of cue predictability is adopted, it's possible to conduct an experiment with either a semantic central cue, or a salient peripheral cue which is non-predictive and interpret the results as a measure of involuntary attention. If instead the differentiation variable is the temporal parameters of the stimuli, either a central or peripheral cue could engage involuntary attention as long as the total processing time available is still short enough that the observer cannot voluntarily direct attention (Herrmann, Montaser-Kouhsari, 2010). Since the cue location differentiation is applicable to both the first two differentiation variables (and because it doesn't always hold true on its own as shown in these experiments), it will be considered in combination with each, and not considered as a differentiating variable in and of itself.

2. Experiment

3. Methods

The present investigation assesses the magnitude of improved accuracy judgment performance with non-predictive cues. While most research on this topic has been conducted using 2AFC tasks, we sought to maximize attentional capture by increasing the set size to seven, to improve the novelty of presented stimuli, but also to determine if cueing effects are as strong as those reported in 2AFC tasks.

3.1 Participants

Ten subjects (5 male and 5 female) were recruited from the community, consisting of students and non-students alike. Recruitment and experimental procedures were approved by the University of California affiliated Institutional Review Board ethics committee. Nine of the subjects were naïve observers, and one was the primary author. Subject ages ranged from 20 to 32. All participants signed an informed consent and were financially compensated for their time. All subjects had normal or corrected to normal vision.

3.2 Apparatus

In all experiments, stimuli are generated, presented, and responses recorded using the WinVis Psychophysical Testing platform, a toolbox for Matlab. Stimuli were presented on a 17 inch Sony Trinitron CRT monitor at a refresh rate of 100hz. The display resolution was 1024x768 pixels. The background was grey with an approximate luminance of 13 cd/m^2. Subjects were positioned in an Eyelink II eye tracker with a chin and forehead rest. Subject's eyes were positioned 50cm from the display resulting in 2.1 x 2.1 min square pixels. Subjects were told that eye movements were being recorded during each trial (though no eye movements were recorded) and to avoid making eye movements during a trial. The experiment was conducted in moderate brightness indoor lighting conditions.

3.3 Stimuli

Monitor luminance linearity was achieved using an 8 bit gamma correcting look up table. A 25% contrast fixation circle 0.2° in size was presented at the center of the screen at the beginning of each trial (Figure 1) over a grey background. The duration of the fixation circle was randomly selected from 0.5-2.0 sec for each trial to prevent the subject from being able to predict the cue onset. The fixation target was removed before the cue onset.

The target stimulus was a number ranging from two to eight in Arial font presented at one of seven locations (Figure 1). Letter distractors were presented at all non-target locations. There were six peripheral stimulus locations and one central stimulus location. The cue was a full contrast, 120° segment of a circle. The peripheral cue had a uniform diameter of ½°, whereas the central cue was smaller with a uniform diameter of ¼°. Stimuli presented at the center location were smaller than those presented in the periphery, so the cue was scaled accordingly. Targets and distractors presented in the periphery were 1° x 1° in size, but when presented at the central location, they were ¼° in size. The cue was presented for 60ms. The peripheral cue was positioned 1° beyond the edge of the forthcoming target/distractor (edge to edge) and the central cue was positioned 1/2° outside the central stimulus so there was never any spatial overlap between the cue and the target.

3.4 Procedure

Subjects were instructed to complete the task at their own preferred pace, and to take breaks between each run as often as desired to maintain a consistent attentive state. Each run consisted of 49 trials (lasting 3-4minutes) with 1/7 of the trials having valid cues and 6/7 with invalid cues. Each data collection session lasted 1 hour, and each subject participated in an approximate total of 10 hours. Since data collection is self-paced, there is some slight variation in the amount of data collected per subject, but the average number of trials completed by each subject is 6076 trials, or 124 runs encompassing each of the SOAs tested. The subjects were initially familiarized with the task by completing 147 trials, or 3 runs with large stimulus durations and having low task difficulty. The data from these training runs are not included in the final analysis.

Subjects were informed that a cue would precede the target stimulus, but not given any information about the reliability of the cue. In some previous published research, subjects were specifically instructed to ignore the cue since it was nonpredictive of the forthcoming target location (Jonides, 1981; Kerzel, Zarian, Souto, 2009). Some research has shown that observers cannot completely ignore a salient peripheral cue (Jonides, 1981; Muller & Rabbitt, 1989; Warner, Juola, Koshino, 1990). Providng subjects with explicit instructions to ignore the cue could activate top-down control systems that may decrease the saliency of reflexive attention capture and weaken any cueing effects. To avoid any confounds related to the subjects' intentions regarding attending to the cue, we refrained from giving the subjects any specific instructions about the cue other than informing them that it would be presented before the target. Beginning with the onset of the cue, there was a stimulus-onset-asynchrony (SOA) interval consisting of a blank screen, after which the target and distractors were presented at all seven stimulus locations. Full contrast peripheral targets and distractors were simultaneously presented at 7.5° eccentricity from the center of the screen for 30-60ms (variable between subjects, but consistent within subjects). Variable stimulus durations were tested during the training period to determine the performance capabilities of individual subjects since there was subject variability in performance capabilities in this task. The target number stimulus was simultaneously presented with distractor letters. After the target offset, there was a variable inter-stimulus-interval (ISI) consisting of a blank screen (10-40ms, variable between subjects, but consistent within subjects), followed by a 50ms mask stimulus consisting of random letters presented at each of the seven stimulus locations. After the mask offset, there was 400ms of blank screen, after which the question "Where was the target letter?" was presented at the center of the screen until the subject responded by pressing a number on the keypad between one and seven. After responding, "What was the target letter?" was presented until the subjects responded by pressing a number between two and eight to indicate the target identity. After reporting the location and identity of the target letter there is one second of visual feedback provided in the form of the previously presented target display containing the distractors. After each stimulus presentation, the subject used a keypad to indicate the observed target number (2-8), and the target location (1-7). A response initiated the next trial.

Distractor letters were randomly selected in each trial. Each target number appeared an equal number of times at each of the seven locations. The order of the target numbers was randomly selected, but followed an organized structure. There were 7 trials with valid cues at each of the target locations, and 42 trials with invalid cues at each of the target locations, totaling 49 trials. Of those 49 trials, 36 consisted of a target and cue appearing in the periphery, with 30 of those trials invalidly cued and 6 validly cued. The central cue and target condition was utilized to require the subjects to maintain fixation at the center of the screen throughout the trial. The cue was non-predictive of the forthcoming target location. Multiple SOAs spanning the time course of involuntary and voluntary attention were tested for each subject. In half of the runs, four SOAs were interleaved in each run (196 trials), while the other half consisted of single SOA runs (49 trials).

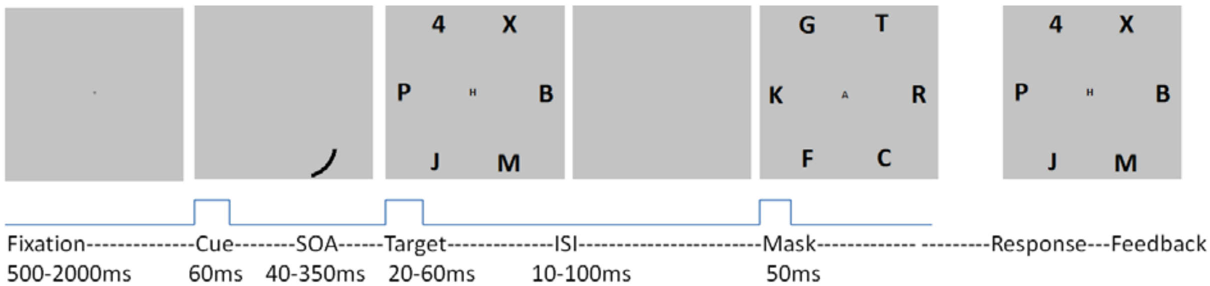

Figure 1. The sequence of stimuli in a single trial. An invalid cue trial is shown. After a fixation period, the cue is presented for 60ms, followed by a variable SOA before the target stimulus appears. The target stimulus is simultaneously presented with distractor letters. After the target offset, there is an interstimulus interval followed by a 50ms mask stimulus consisting of random letters. The observer's task is to report the identity of the target number. After reporting the location and identity of the target letter, visual feedback is provided in the form of the previously presented target display containing the distractors. The peripheral cue is non-predictive of the forthcoming target location. Observers report their response by pressing any number 1 through 7 to indicate target location, and any number 2 through 8 to indicate the target identity.

3.5 Multinomial Modelling

The methods of designing and testing the accuracy of the multinomial model are briefly discussed here as an introduction. For a more detailed discussion, see Dodson, Prinzmetal, Shimamura, 1998 and Riefer, Batchelder, 1988. In the present experiments, subjects can produce a wide variety of response combinations using two main response categories inherent in the experiment task. These responses may be conducted simultaneously, but can be investigated independently as location and identity judgments. The model is constructed to measure decision processes independently for valid and invalid cued trials. The invalid cue model is used to quantify and remove response bias and is presented in Figure 2 . The valid cue model is nearly identical except that when the observer does not know the target location and makes a biased decision to the cued location, the result is a correct location judgment, whereas in the invalid model, a biased response will always result in an incorrect location response. Since the primary purpose of the multinomial model is to determine response bias for location judgments, the identification judgment parameter is fixed, meaning that the model begins by creating separate decision tree pathways depending on whether the subject got the target identity correct or not. The model is essentially a decision tree, whereby possible response outcomes are predicted based on the probabilities of each of the parameters. The 5 probability parameters include:

L = Location is known, T = Identity is known, LT = Location and Identity are known, b_t = response to cued location, but target identity known, b_n = response to cued location, but target identity unknown

Probabilities present in the model not set as parameters simply represent the probability of non-occurance. For example, 1-LT is the probability of knowing the location but not the identity of the target stimulus.

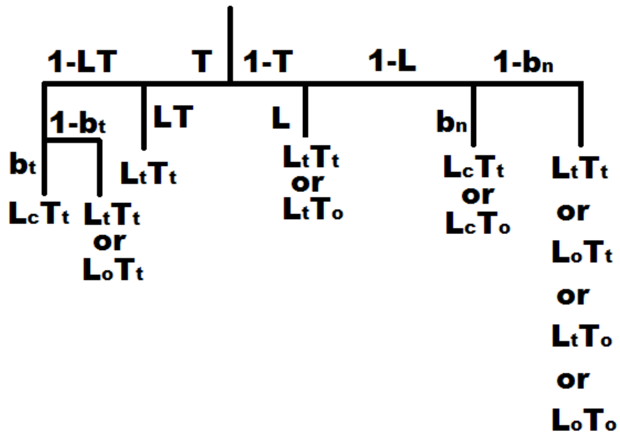

Figure 2: The target-based multinomial model for invalid cue trials. The model begins with an identity judgment followed by a location judgment since location judgments are where the response bias is located.

Theoretical probabilities were assigned to each response process based on the observed data from the experiment. A model fitting procedure using nonlinear least squares comparisons was utilized to determine the optimal probability assignments at each step of the model. The data from each experiment was categorized into ten contingencies, four for valid cue trials and five for invalid cue trials. These categories are as follows where "V" indicates a valid cue trial, "L" indicates a location judgment, "T" indicates an identification judgment, "t" indicates a correct response, "o" indicates an incorrect response, and "c" indicates a biased response to the cued location:

VLtTt VLtTo VLoTt VLoTo

ILtTt ILcTt ILoTt ILtTo ILcTo ILoTo

Figure 3 depicts the response contingencies in a simple Venn Diagram, illustrating the overlap between each judgment type and where the contingencies lie for valid and invalid cues. With the response contingencies categorized, it is possible to ascertain the number of trials in which an observer made a biased decision to the cued location. This is compared with the number of trials in which the observer should have picked the cued location (only with valid cues), and the magnitude of cueing effect due to response bias is quantified and removed from the data using the multinomial model. The biased contingencies terms are the ILcTt and ILcTo values. If there were no response bias to the cued location, the ILcTt value would be 1/5 of the ILoTt, and the ILcTo value would be 1/5 of the ILoTo since there are 5 uncued peripheral positions that should all have been responded to equally. If one position is responded to more often (the cued location), then response bias is present. The bias removal process works by quantifying how much the ILcTt and ILcTo values are relative to the ILoTt and ILoTo values and if the ILcTt and/or ILcTo values are larger than they should be (1/5 of ILoTt and ILoTo), then the response bias magnitude can be quantified. The number of trials in excess of 1/5 are re-inserted into the

ILtTt, ILoTt, ILtTo, and ILoTo contingencies and the multinomial modeling is conducted a second time, but with the bias parameters removed since the bias has been corrected for. The model uses nonlinear least squares comparisons of multiple data fits and picks the fit with the lowest chi square. The bias corrected values (% accuracy) are then generated.

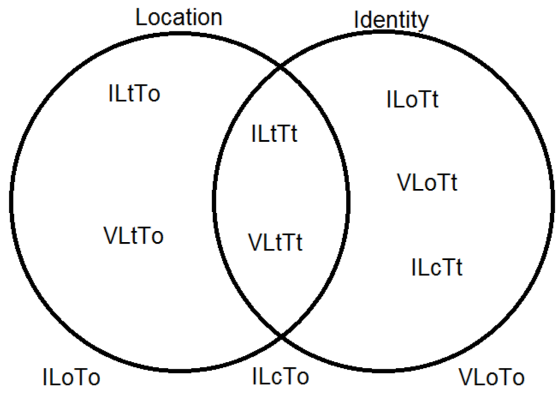

Figure 3: A Venn diagram is a convenient, simple way to visualize the ten response contingencies. The contingencies correspond with a correct response identifying either or both the location and identification of the target stimulus. Both valid and invalid contingencies are shown.

4. Results

Accuracy was measured as the percentage of trials that the observer correctly identified the target number or location. Since the central cue and target stimuli are presented so rarely and the main interest of this investigation was to examine involuntary attention in the peripheral visual field, data analysis was only examined on trials in which both a peripheral cue and a peripheral target were presented. In Figure 4 accuracy is plotted as a function of the amount of time available to allocate attention (60ms cue + SOA + target +ISI) for each of the 10 subjects. Each subject's data is plotted in two plots with the first plot indicating the accuracy for identification judgments and the second plot for location judgments, showing the original biased performance levels with "x" data points and the bias corrected accuracy with solid dots. The valid cue data is presented on the solid line and invalid cue data is on the dashed line. Subjects with large response bias will have a larger reduction of the difference between the valid and invalid cue data points, whereas those with little bias will show only slight changes between the lines. For subjects with considerable response bias, bias correction increased the invalid cue accuracy and decreased the valid cue accuracy. Standard error is calculated using Binomial Statisics where p is the probability of a correct response, and n is the total number of trials: $\sqrt{(p * \frac{1-p}{n})}$.

Analysis from a two-tail t-test indicated that all valid cue data points were significantly higher than invalid cue data points ($p<.01$) except at 120ms for subject 4 for location and identity judgments ($p>.05$), 80ms and for subject 8 for each location and identity judgments ($p>.05$), and at 100ms for the location judgment, data was significant at $p<.05$. Overall there is a highly significant increase in target identification and localization accuracy across all subjects across a range of intervals from 100-400ms. The majority of the valid cue data points were above detection threshold (d’=1) while many invalid cue data points were below detection threshold, particularly at shorter time intervals when the SOAs are brief.

Figure 5 plots each subject’s data on two plots, with identification judgment accuracy in the left plot and location judgment accuracy after bias removal in the right plot. Valid cue trial data points are illustrated by solid dots, while invalid cue trial data points are illustrated by “x”. Figure 6 displays the variation of multinomial model parameters (left plot), total accuracy (center plot), and independent and combined accuracies (right plot) of identification and localization judgments. All of the localization judgment data in Figure 6 has been bias corrected. The results from the left plot indicate that in most trials where the subject responds correctly with either or both the localization and identification judgments, there is a tendency to get both location and identification responses correct. The multinomial model parameters for response accuracy for correctly identifying both judgments (shown as “x”) is higher than trials in which only the identification judgment is correct (“o”), and vastly smaller is the accuracy of trials where the subject identifies the location correctly (“+”), but does not report the target identity correctly. The center plot indicates that response accuracy is higher for identification judgments (“o”) than localization judgments (“+”), though cueing effects are consistent for both response types as indicated by the vast majority of the data points being above the diagonal line. The right plot indicates that in trials where responses to either judgment are correct, subjects most often respond correctly to both the identification and localization judgments (“x”), with fewer trials resulting in a correct identification judgment with an incorrect localization judgment (“o”), and in far fewer trials do the subjects correctly identify the location, but not the identification (“+”).

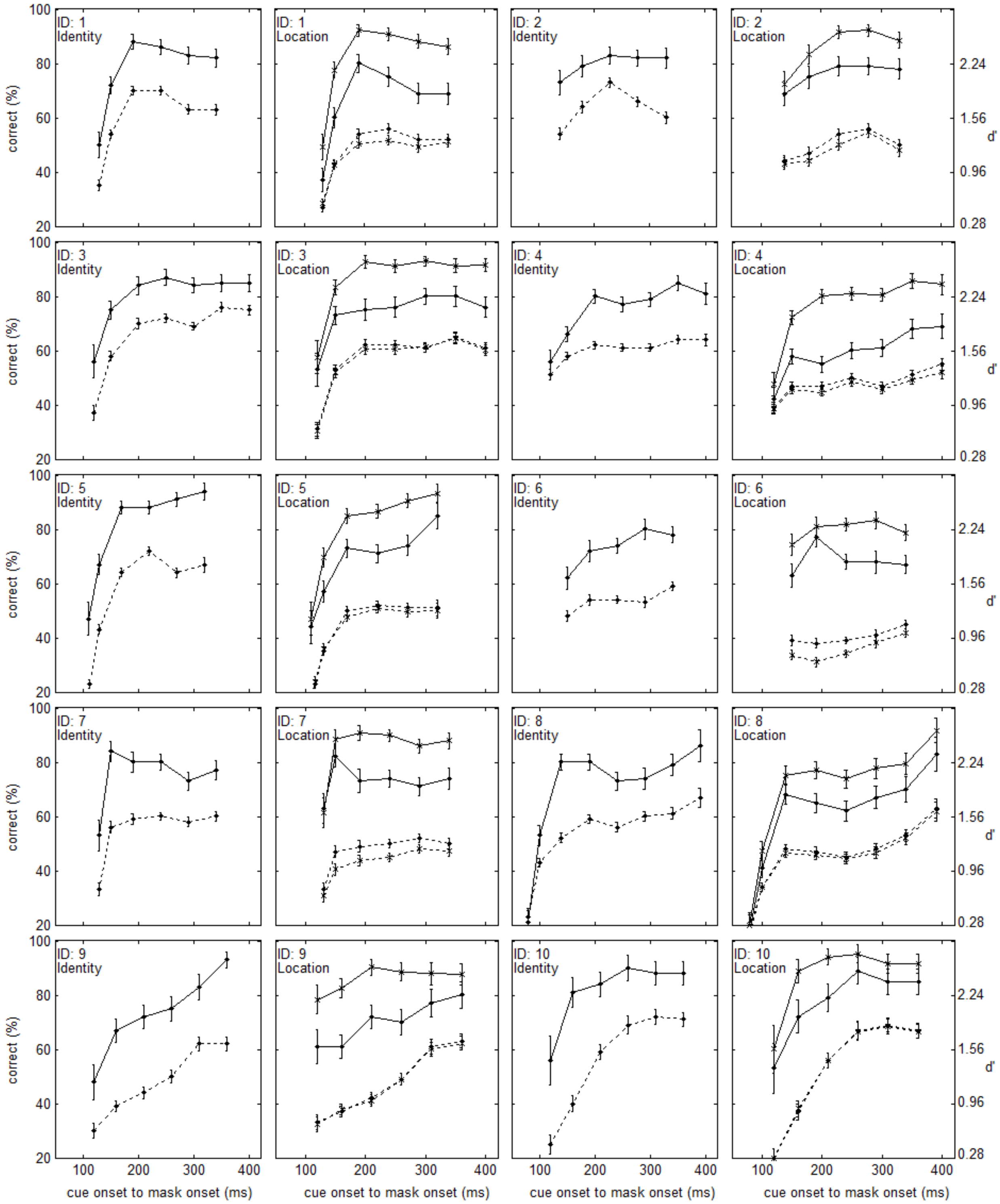

Figure 4: Response accuracy for valid and invalid cue data for all subjects. Valid cue data is shown on the solid line, while invalid cue data is shown by the dashed line. The first plot for each subject shows identification accuracy, while the second plot shows location accuracy before

and after bias removal. Data not yet bias corrected is shown for the valid and invalid cue with “x” data points. The error bars are +/- one binomial standard error.

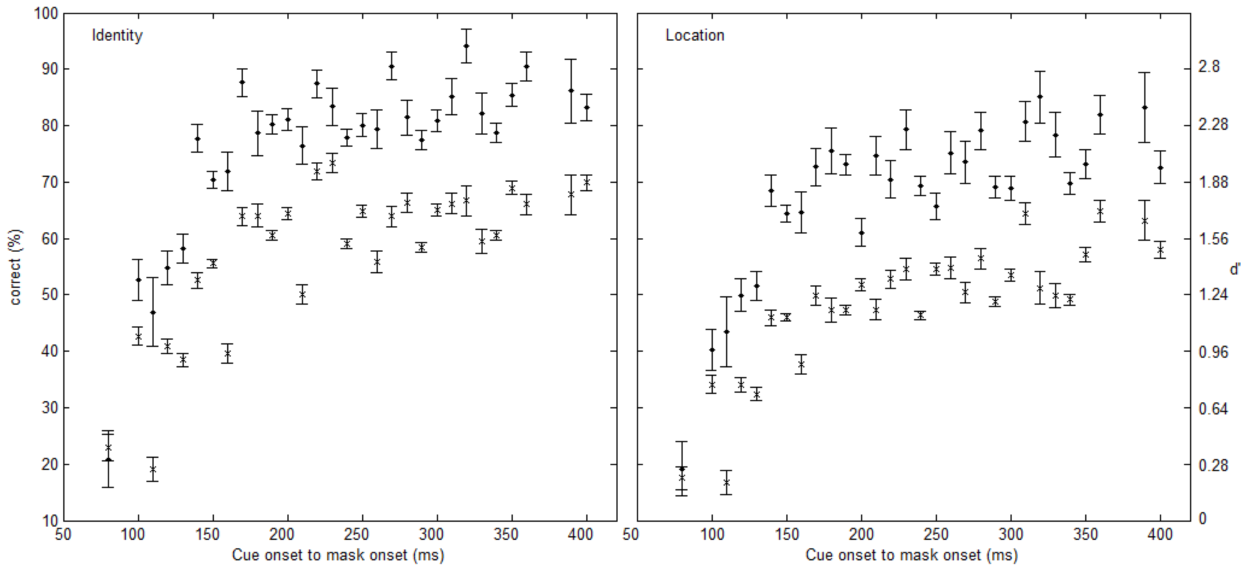

Figure 5: Accuracy performance plotted for all 10 subjects shown for identity judgments (left) and location judgments (right). Valid cue data is indicated by solid dots, while invalid cue data is indicated by “x”. The error bars are +/- one binomial standard error. The majority of the valid and invalid cue data points are above the detection threshold (d’=1).

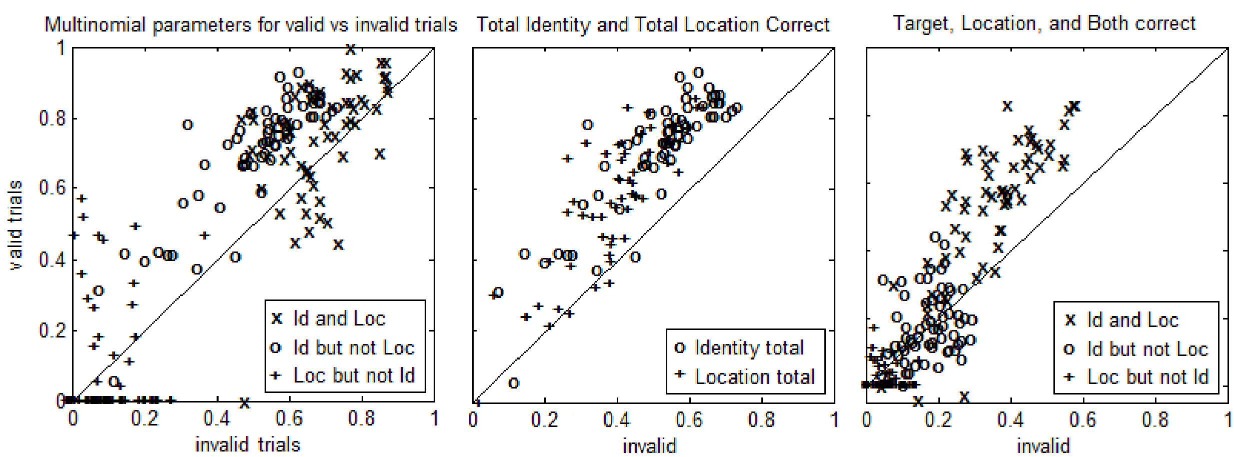

Figure 6. Comparisons of multinomial model parameters (left plot), total response accuracy (center plot), and separate response accuracy (right plot), of the localization and identification responses. When answering at least one of the judgments correctly, subjects are most likely to identify both the target location and identity correctly (“x” in the left and right plots), with fewer trials in which the identity response is correct, but the localization response is not (“o”), and very few trials in which subjects identify the location correctly, but not the identity (“+”). As shown in the center plot, subjects tend to have higher response accuracy for identification judgments (“o”)

than localization judgments (“+”). The diagonal line indicates an equal response accuracy between valid and invalid cue conditions.

5. General Discussion

These experiments were conducted to assess whether or not involuntary attention improves response accuracy for two independent responses, localization and identification. This is a unique contribution to the current literature in that there are two independent accuracy judgments measured, and while one is free of bias (identification), the other (localization) can be bias corrected using a new application of multinomial modeling. The multinomial modeling allowed for an assessment of the relationship between accuracy of reporting the target identity and location, providing insight into whether involuntary attention leads to improved performance on both tasks, or just one independent of the other.

Across all 10 subjects, response accuracy was higher with a valid cue than an invalid cue, with the exception of a few data points at very low SOAs in which response accuracy is near chance performance. Of the response contingencies, subjects most often correctly identified the location and identity of the target stimulus together, reporting the identity correctly without a correct localization judgment fewer times, and very infrequently reporting the location correctly while incorrectly reporting the target identity. While it may seem intuitive that an observer who correctly identifies the location of the target stimulus would also correctly identify the target number or vice versa, the results indicate that of the trials in which subjects correctly identified either the target identity or the location but not both, observers were more likely to correctly identify the target identity in isolation rather than the location in isolation (after bias removal). Prior to the bias removal, location accuracy is higher than identification accuracy though this is partially due to inflation of accuracy performance from response bias to the cued location.

Before bias correction, when pooling all of the subject’s data together including valid and invalid cue trials, in 42.4% of the data subjects correctly identified the target location along with the target identity, in 18.9% of the data subjects correctly identified the target identity but not the location, and in 9.5% of the data subjects correctly identify the target location but not the identity. After the bias correction, these results change to 42.8% of the data where data subjects correctly identified the target location along with the target identity, 18.2% of the data where subjects correctly identified the target identity but not the location, and 9.8% where subjects correctly identify the target location but not the identity. This indicates that while the bias removal substantially reduces the magnitude of the cueing effect of the location judgment data (depending on the observer and his/her response bias), it produces very little change in the contingencies results. The observers still have greater precision reporting the identity of the target than the location of the target.

5.1 Characterizing Involuntary and Voluntary Attention

While the results of the present investigation do not indicate a change in performance indicative of a shift from involuntary attention into voluntary attention, most of the subject's results indicate a characteristic rapid increase in response accuracy beginning around 100ms, and remaining sustained or slowly increasing across the longer SOAs assumed to include the transition from involuntary to voluntary attention allocation. A large number of studies have reported a rapid rise and decay of involuntary attention around 110ms, which is replaced by the gradual rise of voluntary attention.

In Cheal & Lyon (1991), using a peripheral cue to initiate involuntary attention resulted in a rapid increase in correct responses from 0-100ms SOA, tapering off at a steady maximal performance level around 100ms. An attention gating model has been proposed, predicting that only about 100ms are needed to engage the fast involuntary attention process, while about 300ms are necessary for the slow voluntary attention process (Weichselgartner & Sperling, 1987). A similar cueing effect was found with peripheral cues, revealing a rapid rise in response accuracy with a short SOA, followed by an asymptote around 100ms, and then a continuous decrease in response accuracy from 200ms onward (Nakayama & Mackeben, 1989). While the cueing was entirely predictive in this study, these results still give interesting insight into the time course of involuntary and voluntary attention. Their research indicates that the reflexive, involuntary attention system is activated quickly and then decays, and that the maximal perceptual enhancement occurs around 100ms, though our experiments don't show any transition between involuntary and voluntary attention. The researchers concluded that there are two types of attention and that each is characterized by the length of time between the cue and target (Nakayama & Mackeben, 1989). The sustained attention system is voluntarily directed to a region of the visual field, while the transient attention system is reflexive, involuntary, and time locked to the cue.

While these experiments (Cheal & Lyon 1991; Nakayama & Mackeben 1989) didn't investigate any performance differences with cue predictability, nor compare performance of valid, invalid, or non-cue conditions, the findings are of great interest to the current investigation as added insight is gained into the time course of the activation of involuntary attention. It may seem that this experiment is of little interest in the current discussion since it only investigates the effect of valid cues on involuntary attention, and there is already widespread agreement that a valid cue will enhance perceptual performance, but because the experiment reveals the time course of involuntary attention, it is highly relevant to the discussion of the potential for involuntary attention to enhance perceptual sensitivity with non-predictive cueing as it shows that involuntary attention is quickly engaged, and rather short lived. This has shaped the experimental prediction that as involuntary attention passes its time of maximum effect, voluntary attention engages and maintains perceptual performance at a high level of accuracy. The involuntary attention system occurs reflexively to a salient stimulus and is devoid of voluntary control. The voluntary attention system begins to be activated at times long enough to give rise to voluntary orienting (covertly or overtly), and is sustained for a long time (potentially activating as early as 200-300ms). The processing time differentiation as described has been tested many times and continues to show that involuntary attention is transient, having a quick activation, peaking around 110ms, and then rapidly decaying (Carrasco & McElree, 2001, Carrasco, Ling, & Read, 2004, Carrasco, Fuller, & Ling, 2008; Giordano, McElree, & Carrasco, 2009; Liu, Pestilli, & Carrasco, 2005; Montagna, Pestilli, & Carrasco, 2009).

Some research has claimed that voluntary attention can be engaged as early as 50ms, but these studies use cue-predictability as a differentiator of attention rather than temporal parameters (Prinzmetal, McCool, Park, 2005; Warner, Joula, & Koshino, 1990). Additionally, Warner and colleagues used reaction time as a measure of performance whereas the current experiment involved accuracy judgments. Also in their experiment, no mask was used so recurrent processing may be a significant confound if observers can still process the visual information. In our experiment, we used a backward mask to constrain the amount of time available to attend to a visual stimulus. Using a mask eliminates recurrent iconic image processing, for which an observer can continue to access visual information from memory, thereby having extra time to cognitively search for the target stimulus even after the image is no longer present on the display or the retina (Sperling, 1960).

In one recent publication, spatiotemporal maps of involuntary and voluntary attention were obtained with results suggesting that involuntary attention leads to improved target detection during 150-430ms (increasing as early as 50ms and maximizing from 200-350ms), and voluntary attention activating around 400ms and being sustained for at least another 300ms (Koenig-Robert, VanRullen, 2011). Their task involved identifying the presence of a low contrast cross presented in a noisy background. While the present experiment didn't measure beyond 380ms, our results confirm that involuntary attention leads to a rapid increase in target identification and localization accuracy and since the cueing effect and performance levels are fairly consistent up to 380ms, we are confident that voluntary attention accounts for the sustained performance levels.

Summary:

The present experiment tested attentional cueing for two types of accuracy judgments in a demanding divided attention task: location detection, and feature identification. Across all subjects, and over a wide range of temporal separation of the pre-cue and target (SOA), the results show that an involuntary capture of attention via a non-predictive peripheral cue improves response accuracy for identifying both where and what the target stimulus was. The use of multinomial modeling enabled the removal of response bias associated with the cue location which can otherwise contaminate the results. The experiment demonstrated that multinomial modeling can be used to gain insight into unknown underlying psychological processes such as those inherent in cueing tasks.

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Involuntary attention improves double judgment accuracy for unmasked targets: Insight from multinomial modeling.

Abstract

This is the first attentional cueing study to use multinomial modeling of double judgment accuracy responses to unmasked stimuli to remove response bias. We have previously shown that multinomial modeling in a 7-AFC double judgment accuracy task can remove response bias to cued locations in attentional cueing tasks, revealing unbiased improvements in response accuracy with a valid cue over an invalid cue, but for backward masked stimuli. The presence of a backward mask constrains the amount of time available to allocate attention to the iconic memory of information presented, and some researchers have proposed a mask-dependent cueing hypothesis which states that only backward masked stimuli lead to cueing effects. This investigation utilizes unmasked target letters presented at various low contrast levels to assess accuracy judgment performance across the psychometric function and to determine whether the mask-dependent cueing hypothesis is valid. Contrary to the mask-dependent cueing hypothesis, the results of the present experiments indicate improved accuracy at identifying both the location and the identity of low contrast target letters without any dependency on backward masking. The results indicate a leftward shift of the psychometric function without a reduction of slope with valid cued data, providing evidence that the cueing effects observed are not due to spatial uncertainty reduction. Both non-predictive (1/6 valid) and semi-predictive (3/6 valid) cueing conditions indicate cueing effects, demonstrating that cue predictability is not a valid differentiating variable of voluntary and involuntary attention as has been previously argued.

Introduction

Spatial precues have been extensively studied providing evidence that covert attention can enhance target discriminability and/or reaction time across the time courses of involuntary and voluntary attention. The differentiation and mechanisms of these systems is controversial. Some researchers differentiate these two attention systems on the basis of whether a pre-cue is strategically advantageous for enhancing perceptual sensitivity at the cued location, while others differentiate these systems by temporal characteristics. Many studies have shown that involuntary attention improves accuracy of target identification at the attended location, while other research refutes this claim and argues that accuracy performance enhancement from involuntary attention is actually a result of spatial uncertainty and/or response bias (Eckstein, 1998; Foley & Schwartz, 1998; , 2010; Kerzel, Zarian, Souto, 2009; Palmer, 1994; Prinzmetal, Ha, & Khani, 2010; Prinzmetal, Long, & Leonhardt, 2008; Prinzmetal, McCool, & Park, 2005; Prinzmetal, Park, & Garrett, 2005; Schneider & Komlos, 2008; Solomon, Lavie, & Morgan, 1997; Valsecchi, Vescovi, & Turatto, 2010). The present experiments were conducted to determine both the relevance of cue predictability to the engagement of these two attention systems as well as determine if spatial uncertainty reduction is the underlying mechanism of involuntary attention.

To address the question of whether the attention systems are differentiated based on cue predictability, this study examines cueing effects for involuntary attention in a 7AFC cueing task for both non-predictive cues (14.3% valid cue trials), and 50% predictive cues. The intent of this endeavor is to determine if involuntary and voluntary attention can be differentiated on the basis of cue predictability, as some researchers have proposed (Jonides, 1980; Jonides, 1983; Kerzel, Gauch & Buetti, 2010; Prinzmetal, Ha, & Khani, 2010; Prinzmetal, Long, Leonhardt, 2008; Prinzmetal, McCool & Park, 2005; Prinzmetal, Park & Garrett, 2005; Wright & Richard, 2000). If involuntary attention is specifically activated by non-predictive cueing, and voluntary attention with predictive cueing, then we would expect there to be performance differences in this task since voluntary and involuntary attention systems have different characteristics. If enough time is available to complete the perceptual task using voluntary search with or without eye movements (covertly or overtly), then voluntary attention is utilized (Carrasco, Fuller, & Ling, 2008; Cheal & Lyon, 1991; Ling & Carrasco, 2007; Nakayama & Mackaben, 1989). If there is insufficient time to voluntary shift attention during the task, then involuntary attention is utilized (Fuller, Rodriguez, Carrasco, 2008; Giordano, McElree, Carrasco, 2009; Herrmann, Montaser-Kouhsari, Carrasco, Heeger, 2010). In this view, voluntary attention is characterized as a voluntary, goal-directed orienting of attention, while involuntary attention is an involuntary, reflexive, and automatic orienting of attention. If involuntary attention is active regardless of cue predictability, then we would expect a similar psychometric curves for the non-predictive (14.3% valid) and the slightly predictive (50% valid) conditions. The hypothesis we adopt is that the attention systems are differentiated on the basis of temporal characteristics with involuntary attention characterized as having a rapid onset and decay, while voluntary attention is activated more gradually and is sustained.

This study also investigates the mask-dependent cueing hypothesis to assess whether a backward mask is required for performance enhancement to occur with validly cued stimuli. Based on previous experiments we have conducted, it was hypothesized that cueing effects would be present with unmasked targets, even though spatial uncertainty is high with 7 stimulus locations and non-predictive cues. This previous investigation indicated that spatial uncertainty reduction was not responsible for the increased response accuracy from involuntary and voluntary attention, so we hypothesized that spatial uncertainty would also not be responsible for any cueing effects with unmasked stimuli.

This is the first experiment to implement multinomial modeling of independent location and identification judgments with unmasked stimuli, which makes it possible to account for spatial uncertainty response bias in the data and within the model. This eliminates response bias to a cue as a factor contributing to cueing effects, a previously demonstrated confound in spatial cueing experiments. As will be discussed, the results indicate that neither response bias nor spatial uncertainty reduction are responsible for the cueing effect with unmasked stimuli for both levels of cue predictability tested.

Experiment 1

The first experiment was conducted to determine if cueing effects were present for brief unmasked stimuli with highly non-predictive cues, a large set size, and across the entire psychometric function. It was hypothesized that response accuracy would be higher for valid cues than invalid cues for both location and identification judgments, thereby challenging the mask-dependent cueing hypothesis. We further hypothesized that cueing effects would be present across the psychometric function above and below the detection threshold, challenging previous arguments that cueing effects only occur near threshold (Kerzel et al., 2010; Kerzel, Zarian, Souto, 2009; Schneider, 2006).

Methods

Participants

Five subjects (3 male and 2 female) were recruited from the local public community, consisting of students and non-students alike. Recruitment and experimental procedures were approved by the University of California affiliated Institutional Review Board ethics committee. Four of the subjects were naïve observers, and one was the primary author. Subject ages ranged from 19 to 32. All participants signed an informed consent and were financially compensated for their time. All subjects had normal or corrected to normal vision.

Apparatus

In all experiments, stimuli are generated, presented, and responses recorded using the WinVis Psychophysical Testing platform, a toolbox for Matlab. Stimuli were presented on a 17 inch Sony Trinitron CRT monitor at a refresh rate of 100hz. The display resolution was 1024x768 pixels. The background was grey with an approximate luminance of 13 cd/m^2. Subjects were positioned in an Eyelink II eye tracker with a chin and forehead rest. Subject's eyes were positioned 50cm from the display resulting in 2.1 x 2.1 min square pixels. Subjects were told that eye movements were being recorded during each trial and to avoid making eye movements during a trial. The experiment was conducted in moderate brightness indoor lighting conditions.

Stimuli

Monitor luminance linearity was achieved using an 8 bit gamma correcting look up table. A 25% contrast fixation circle 0.2° in size was presented at the center of the screen at the beginning of each trial (Figure 1) over a grey background. The duration of the fixation circle was randomly selected from 0.5-2.0 sec for each trial to prevent the subject from being able to predict the cue onset. The fixation target was removed before the cue onset. The cue was a full contrast, 120° segment of a circle with an orientation focused on the forthcoming target location. The peripheral cue had a uniform diameter of ½°, whereas the central cue was proportionally scaled and smaller with a uniform diameter of ¼°. Stimuli presented at the center location were smaller than those presented in the periphery, so the cue was scaled accordingly. The target stimulus was a number ranging from two to eight in Arial font presented at one of seven locations (Figure 1). Letter distractors were presented at all non-target locations. There were six peripheral stimulus locations and one central stimulus location. Targets and distractors presented simultaneously in the periphery were 1° x 1° in size, but when presented at the central location, they were ¼° in size. The cue was presented for 60ms. The peripheral cue was positioned 1° outside of the edge of the forthcoming target/distractor (edge to edge) and the central cue was positioned 1/2° outside the central stimulus so there was never any spatial overlap between the cue and the target.

Beginning with the 60ms cue, there was a stimulus-onset-asynchrony (SOA) interval of 40ms consisting of a blank screen, after which the target and distractors were presented at all seven stimulus locations for 20ms at 7.5° eccentricity from the center of the screen. After the target offset, there was 500ms of blank screen after which the question "Where was the target letter?" was presented at the center of the screen in full contrast black letters until indicated a response by pressing any number on the keypad between one and seven. After responding, a second question, "What was the target letter?" was presented until subjects responded by pressing any number between two and eight to indicate the target identity. After reporting the location and identity of the target letter there is a one second display of visual feedback provided in the form of the previously presented target display containing the distractors. To begin the next trial, subjects pressed any button on the keyboard.

Distractor letters were randomly selected in each trial from the 26 letters of the alphabet, and were all capitalized. Each target number appeared an equal number of times at each of the seven locations. The order of the target numbers was randomly selected, but followed an organized structure. There were 7 trials with valid cues at each of the target locations, and 42 trials with invalid cues at each of the target locations, totaling 49 trials. Of those 49 trials, 36 consist of a target and cue appearing in the periphery, with 30 of those trials invalidly cued and 6 validly cued. The central cue and target condition was utilized to require the subjects to maintain fixation at the center of the screen throughout the trial. Stimulus contrasts were

Multiple contrasts spanning performance levels of chance guessing up to 100% correct were tested for each subject. The cue was non-predictive of the forthcoming target location.

Procedure

Subjects were instructed to complete the task at their own preferred pace, and to take brief breaks between each run to maintain a consistent attentive state. After each stimulus presentation, the subject used a keypad to indicate the observed target number (2-8), and the target location (1-7). A response initiated the next trial. Each run consisted of 49 trials (lasting 3-4 minutes) with 1/7 of the trials having valid cues and 6/7 with invalid cues. Each data collection session lasted on average 1 hour, and each subject participated in an approximate total of 12 hours. Since data collection is self-paced, there is some slight variation in the amount of data collected per subject, but the average number of trials completed by each subject is 6664 trials, or 136 runs encompassing all 6 contrasts. This consisted of 4080 trials with invalid peripheral cues and peripheral targets, 816 trials valid peripheral cues, and 1768 central cues or targets. In the trials with either central targets or central cues, 272 were valid central cues, and 1496 were a combination of invalid peripheral cues with a central target and invalid central cues with a peripheral target. The subjects are initially familiarized with the task by completing 147 trials, or 3 runs with large stimulus durations and high contrasts, having low task difficulty. The data from these training runs are not included in the final analysis.

Subjects were informed that a cue would precede the target stimulus, but not given any information about the reliability of the cue. In some previous published research, subjects were specifically instructed to ignore the cue since it was nonpredictive of the forthcoming target location (Jonides, 1981; Kerzel, Zarian, Souto, 2009). Some research has shown that observers cannot completely ignore a salient peripheral cue (Jonides, 1981; Muller & Rabbitt, 1989; Warner, Juola, Koshino, 1990). Providng subjects with explicit instructions to ignore the cue could activate top-down control systems that may decrease the saliency of reflexive attention capture and weaken any cueing effects. To avoid any confounds related to the subjects' intentions regarding attending to the cue, we refrained from giving the subjects any specific instructions about the cue other than informing them that it would be presented before the target.

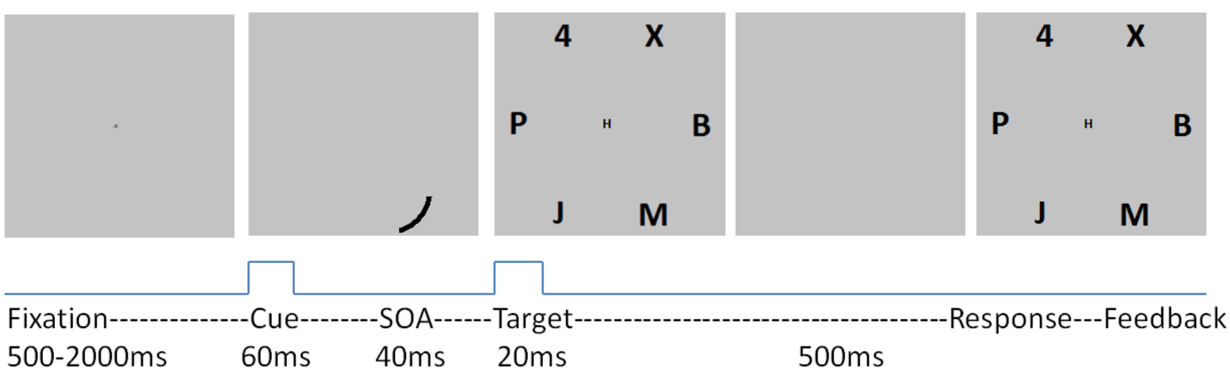

Figure 1. The sequence of stimuli in a single trial. An invalid cue trial is shown. After a fixation period, the cue is presented for 60ms, followed by a 40ms SOA before the target stimulus appears for 20ms. The target stimulus is simultaneously presented with distractor letters. After the target offset, there is a 500ms display of blank screen before the subject is prompted for a response. The observer's task is to report the identity of the target number. After reporting the location and identity of the target letter, visual feedback is provided in the form of the previously presented target display containing the distractors. Observers report their response by pressing any number 1 through 7 to indicate target location, and any number 2 through 8 to indicate the target identity.

Multinomial modeling procedures and theory were previously explained in detail in a previous article (Pack, Carney, Klein, *in submission*). As a brief summary, multinomial modeling was used in the present experiments to determine response bias for location judgments. The same modeling procedure was used in the present experiments as was in the masked experiments.

Results

Accuracy was measured as the percentage of trials that the observer correctly identified the target letter. In figures 2 and 3 accuracy is plotted as a function of stimulus contrast for each subject. Psychometric functions were fitted to each subject's valid and invalid cue data using the Weibull function. The parameters of this function are the upper asymptote (a) fixed at 97%, the floating exponent or slope (β), and the threshold definition (k) of 55.65%, where $p(c)$ is the percent correct at a given contrast level (c) for the psychometric function from 14.3% chance guessing up to 100% correct: $p(c) = a - (a - .143) * .5\hat{}(-(\frac{c}{k})^{\beta})$

Standard error was calculated using Binomial statistics where p is the probability of a correct response, and n is the total number of trials: $\sqrt{p(1-p)/n}$

The upper asymptote parameter was fixed at 97% accuracy, while the exponent parameter (slope) was allowed to float. Analysis of the proportion correct indicates that in general valid cue trials produced lower accuracy performance than invalid cue trials, though not all data points are statistically significant. The goodness of fit (chi square, χ^2) is shown in the figure for each subject. Parameter values for the Weibull function fit are shown in Figure 4 for location and identification judgments. The χ^2 values representing the goodness-of-fit are shown in the plots.

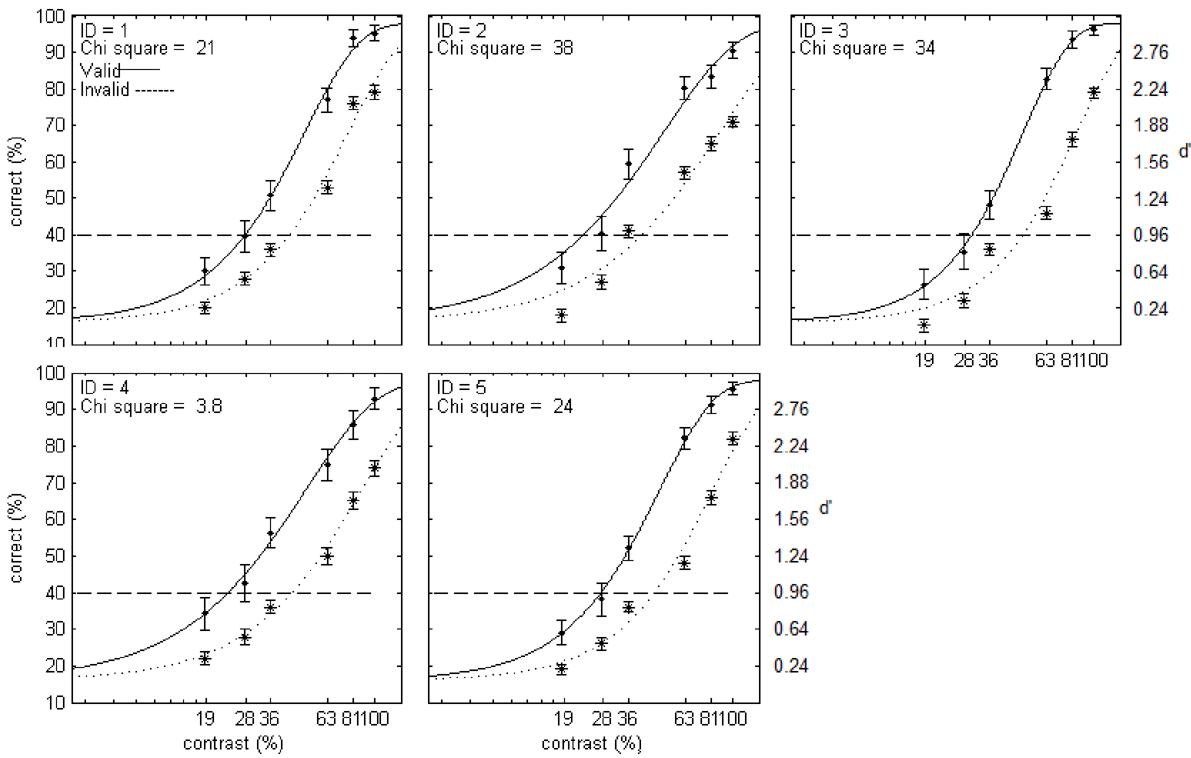

Figure 2. Accuracy (percent correct) as a function of target contrast for identification judgments. A Weibull function was fit to each individual subject's accuracy performance from Experiment 1. The error bars are +/- one binomial standard. The Weibull fit of performance with a valid cue is shown as the solid line, while performance with an invalid cue is shown by the dotted line. d' values are plotted on the right vertical axis. The threshold contrast of 55.65% correct is plotted as the horizontal dashed line. The IDs are subject identification codes, which are the same across both experiments. All valid to invalid cue data points are statistically different at or below $p<.01$.

In figure 4, the fit parameter values for each individual subject are plotted with each subject ID on the horizontal axis against the specified parameter on the vertical axis. The first subplot shows the contrast thresholds for valid cue trials. The second subplot shows the ratio of the contrast thresholds for invalid and valid cue conditions. A threshold value above 1 indicates a higher threshold with invalid cue trials than valid cue trials, while a value less than 1 shows the opposite. In the third subplot, the exponent (slope) for the valid cue trials is shown. In the fourth subplot, the invalid to valid ratios of the exponent (slope) is shown. A ratio larger than 1 indicates that the valid cue condition has a shallower slope than the invalid cue condition, while a ratio smaller than 1 indicates the opposite.

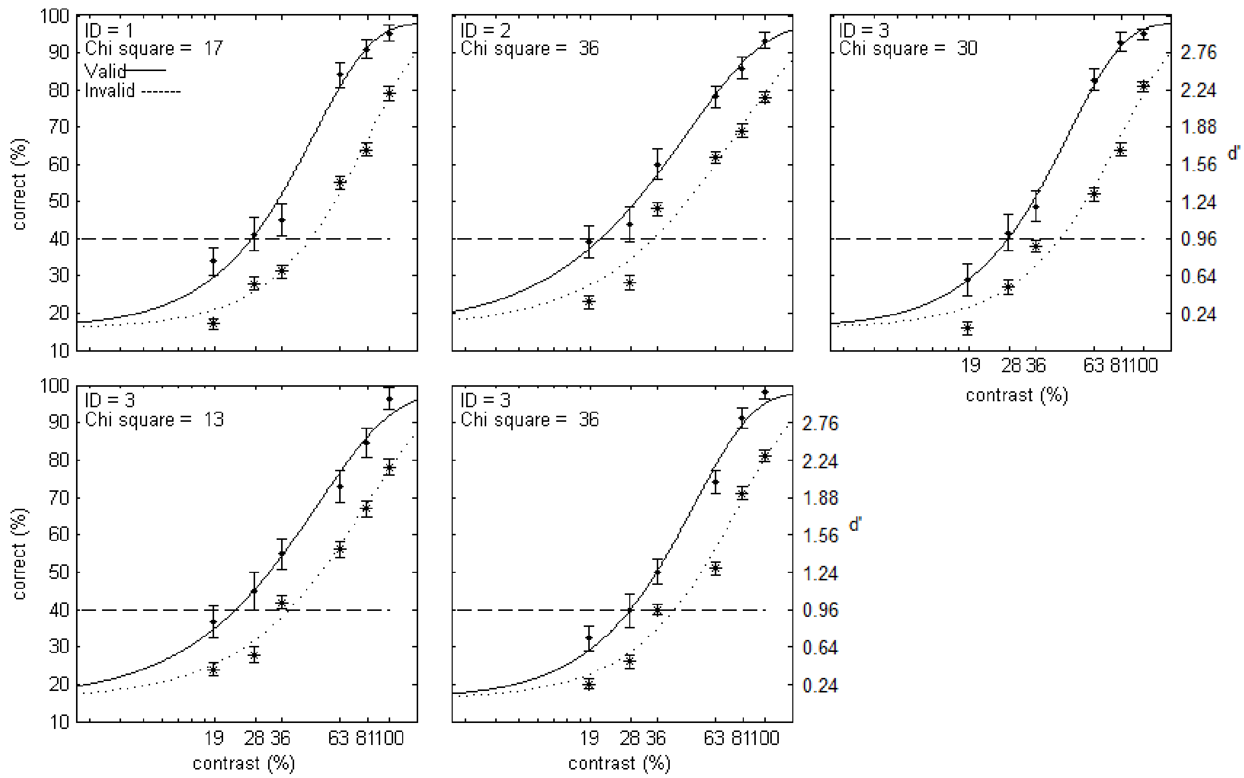

Figure 3. Accuracy (percent correct) as a function of target contrast for location judgments. Data is shown after the bias removal. A Weibull function was fit to each individual subject's accuracy performance from Experiment 1. The error bars are +/- one binomial standard. The Weibull fit of performance with a valid cue is shown as the solid line, while performance with an invalid cue is shown by the dotted line. d' values are plotted on the right vertical axis. The threshold contrast of 55.65% correct is plotted as the horizontal dashed line. All valid to invalid cue data points are statistically different at or below $p<.01$.

As shown in Table 1, the group averaged threshold ratio was 1.692 for identity judgments and 1.632 for location judgments, indicating that the threshold of the cued target was significantly decreased $t(4) = 17.981$, $p<0.001$ for identity judgments and $t(4) = 23.238$, $p<0.001$ for location judgments. The group averaged exponent ratio was 1.026 for identity judgments $t(4) = 1.102$, $p>0.05$ and 1.025 for location judgments $t(4) = 1.502$, $p>0.05$ indicating that the psychometric function for the cued stimulus was not significantly different from unity (1.0).

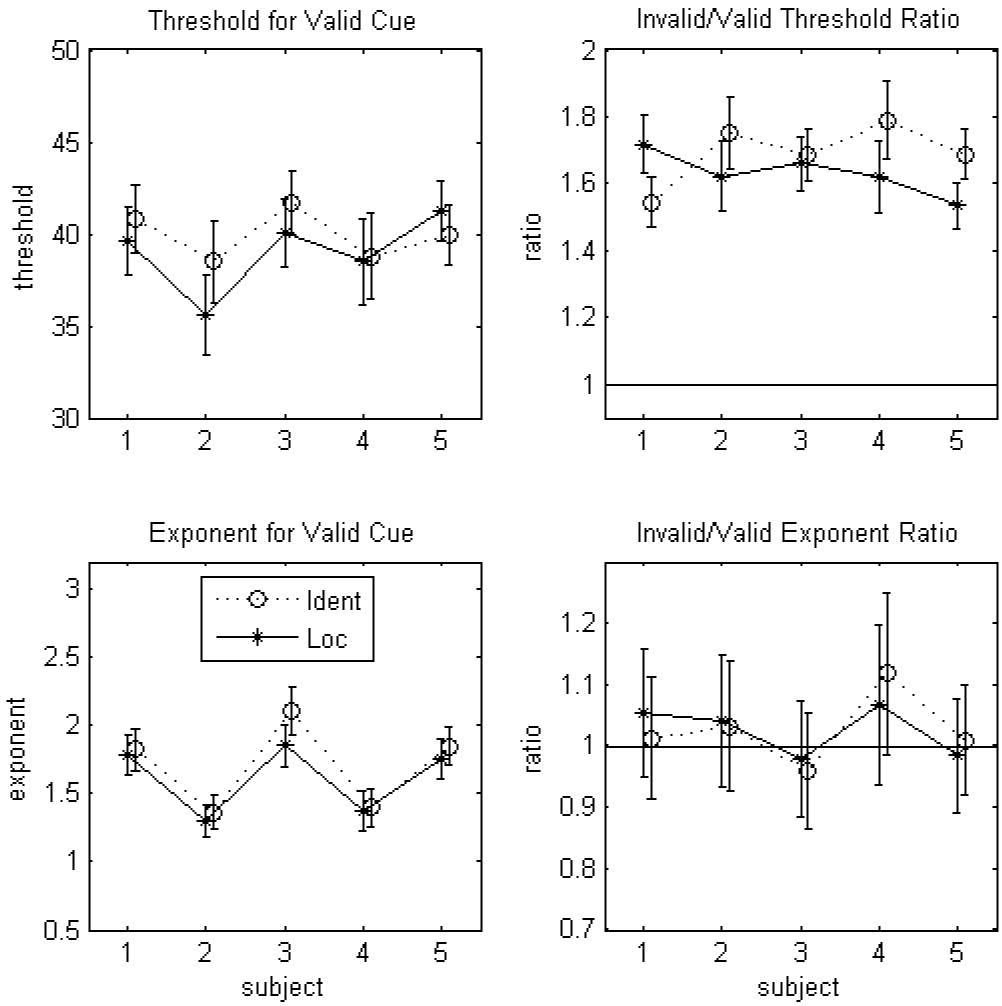

Figure 4: Plots of the parameter values of the Weibull function fit. The first subplot is of threshold parameter values for each judgment type across each individual subject. The second subplot indicates the ratio of the thresholds of invalid and valid cue trials. The third subplot indicates the exponent (slope) of valid cue data. The fourth subplot indicates the exponent ratio between invalid and valid cue trials.

	Exp 1 Identity	Exp 1 Location	Exp 2 Identity	Exp 2 Location
Exponent Ratio	1.026 +/- 0.024	1.025 +/- 0.017	1.038 +/- .021	0.989 +/- 0.026
t	1.102	1.5024	1.857	-0.415
p-value	0.321	0.193	0.123	0.695
Threshold Ratio	1.692 +/- 0.039	1.632 +/- 0.027	1.559 +/- 0.026	1.543 +/- 0.04
t	17.981	23.238	21.694	13.583
p-value	p<.001	p<.001	p<.001	p<.001

Table 1: Analysis of group averages of exponent and threshold ratios for each judgment and each experiment. All of the threshold ratios were significant while none of the exponent ratios were significant.

Discussion

As shown in figure 4, across all 5 subjects there was a consistent contrast threshold between 35 and 45 percent contrast, indicating fairly equal performance and task difficulty across all subjects and for each individual judgment type. The threshold ratio was consistently above 1.4 for each subject and judgment, and the mean threshold ratio (Table 1) indicated a significant increase in performance with the valid cue compared to the invalid cue. The Weibull function exponents, corresponding to the slopes of the psychometric function for valid cue trials varied between 1 and 2.5, and the exponent ratios of invalid to valid cue data were not significantly different from unity (1.0), indicating that any spatial uncertainty reduction was not large enough to produce a shallowing of the valid cue trial slope. Across the entire psychometric function, performance was higher with a valid cue than with an invalid cue as all data points were significant below $p<.01$.

Experiment 2

The purpose of experiment 2 was to determine if increasing the cue predictability by a substantial amount resulted in any change in performance relative to when the cue is highly non-predictive. If the psychometric function is similar to the results of Experiment 1, then this would suggest that the same attention mechanisms were utilized regardless of the increase in cue predictability and that cue predictability is not a valid differentiator of involuntary and voluntary attention.

Methods

All experimental methods and procedures were the same as in experiment 1 except that the cue predictability was changed to 50% predictive, resulting in 77 trials per run consisting of 60 peripheral cue trials (30 valid and 30 invalid) and 17 central cues (5 valid and12 invalid). The average number of trials completed by each subject is 5929 trials, or 77 runs encompassing all 6 contrasts. This consisted of 2310 trials with invalid peripheral cues and peripheral targets, 2310 trials valid peripheral cues, and 1309 central cues or targets. In the trials with either central targets or central cues, 385 were valid central cues, and 924 were a combination of invalid peripheral cues with a central target and invalid central cues with a peripheral target.

Results

As in experiment 1, there were too few central cue trials to obtain any meaningful information from the data, so only the peripheral cue data is analyzed. In Figure 5, accuracy for target identification is plotted as a function of stimulus contrast for all 5 subjects. Figure 6 plots accuracy for location identification and the data shown has been bias removed with multinomial modeling. As shown in Table 1, the group averaged threshold ratio was 1.559 for identity judgments and 1.543 for location judgments, indicating that the threshold of the cued target was significantly decreased $t(4) = 21.694$, $p<0.001$ for identity judgments and $t(4) = 13.583$, $p<0.001$ for location judgments. The group averaged exponent ratio was 1.038 for identity judgments t(4)= 1.857, p>0.05 and 0.989 for location judgments t(4) = -0.415, p>0.05 indicating that the psychometric function for the cued stimulus was not significantly different from unity (1.0).

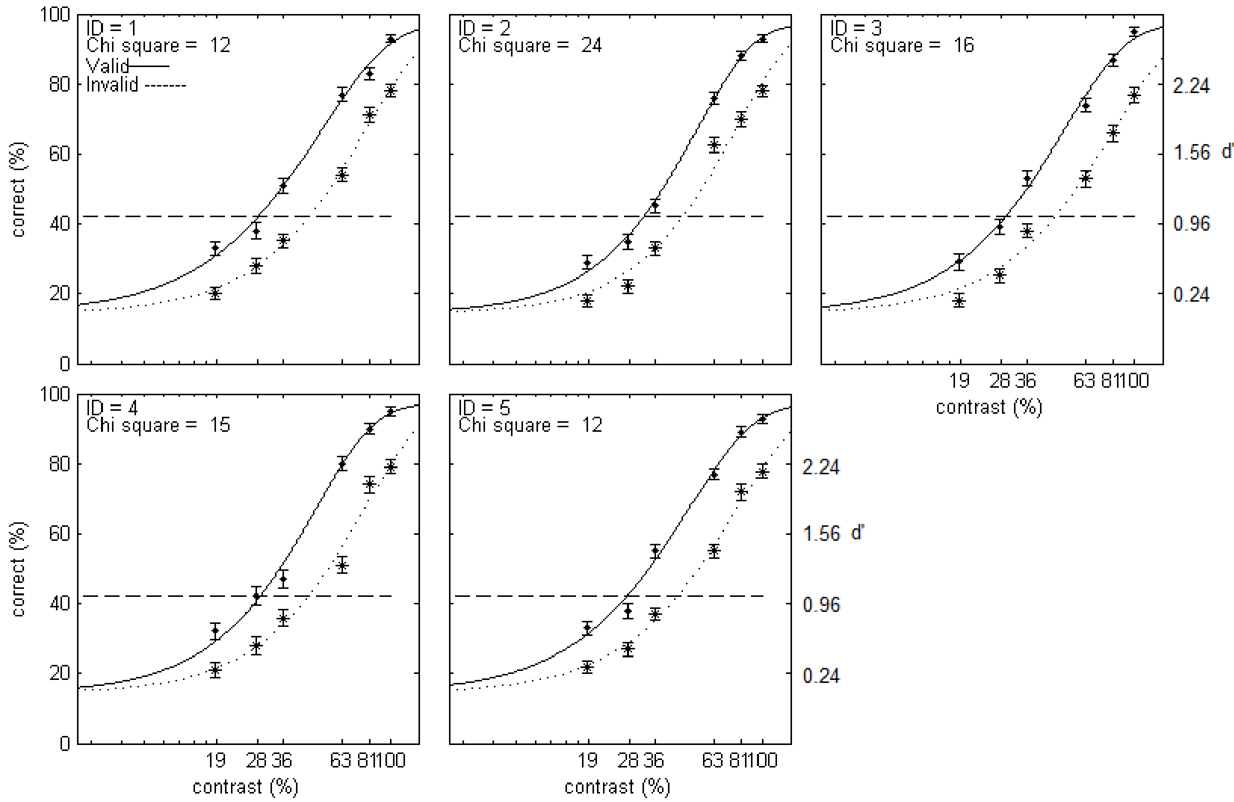

Figure 5. Accuracy (percent correct) as a function of target contrast for identification judgments. The Weibull fit of performance with a valid cue is shown as the solid line, while performance with an invalid cue is shown by the dotted line. d' values are plotted on the right vertical axis. The threshold contrast of 55.65% correct is plotted as the horizontal dashed line. All valid to invalid cue data points are statistically different at or below p<.01.

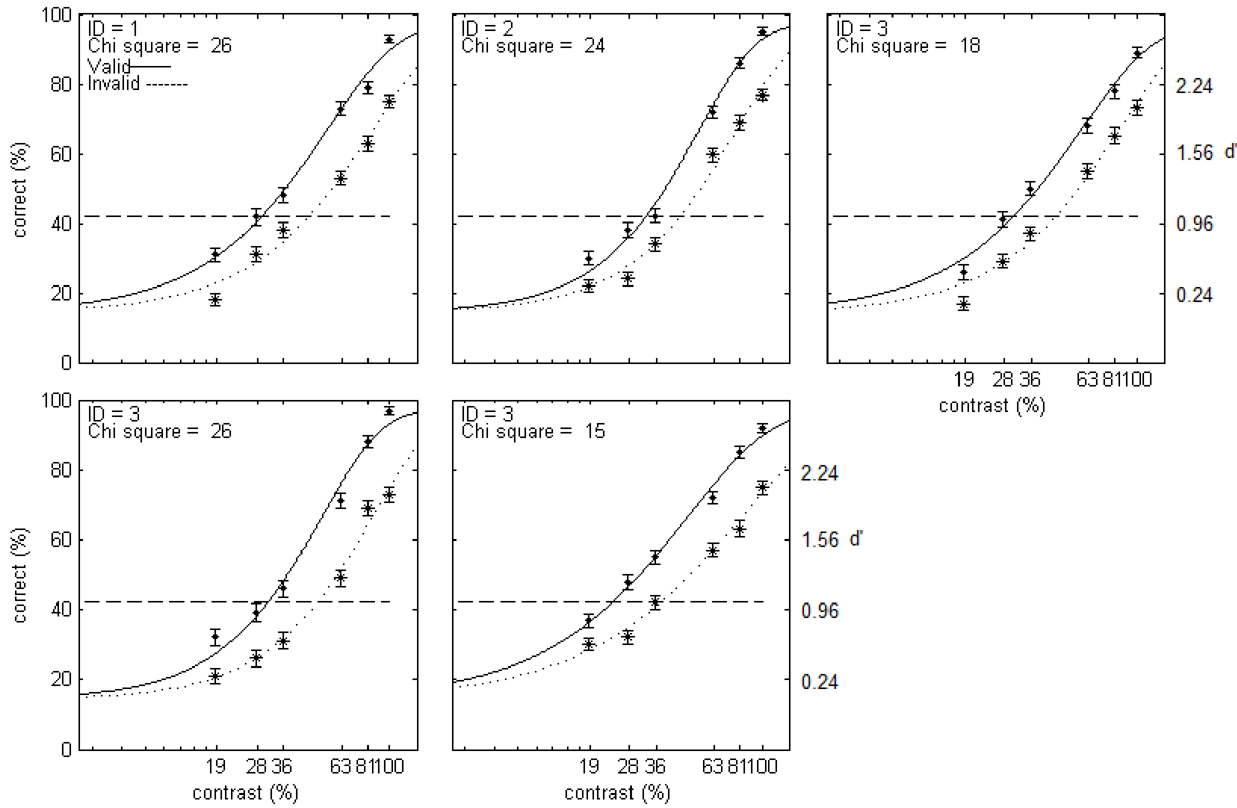

Figure 6. Accuracy (percent correct) as a function of target contrast for location judgments. The Weibull fit of performance with a valid cue is shown as the solid line, while performance with an invalid cue is shown by the dotted line. d' values are plotted on the right vertical axis. The threshold contrast of 55.65% correct is plotted as the horizontal dashed line. All valid to invalid cue data points are statistically different at or below p<.01.

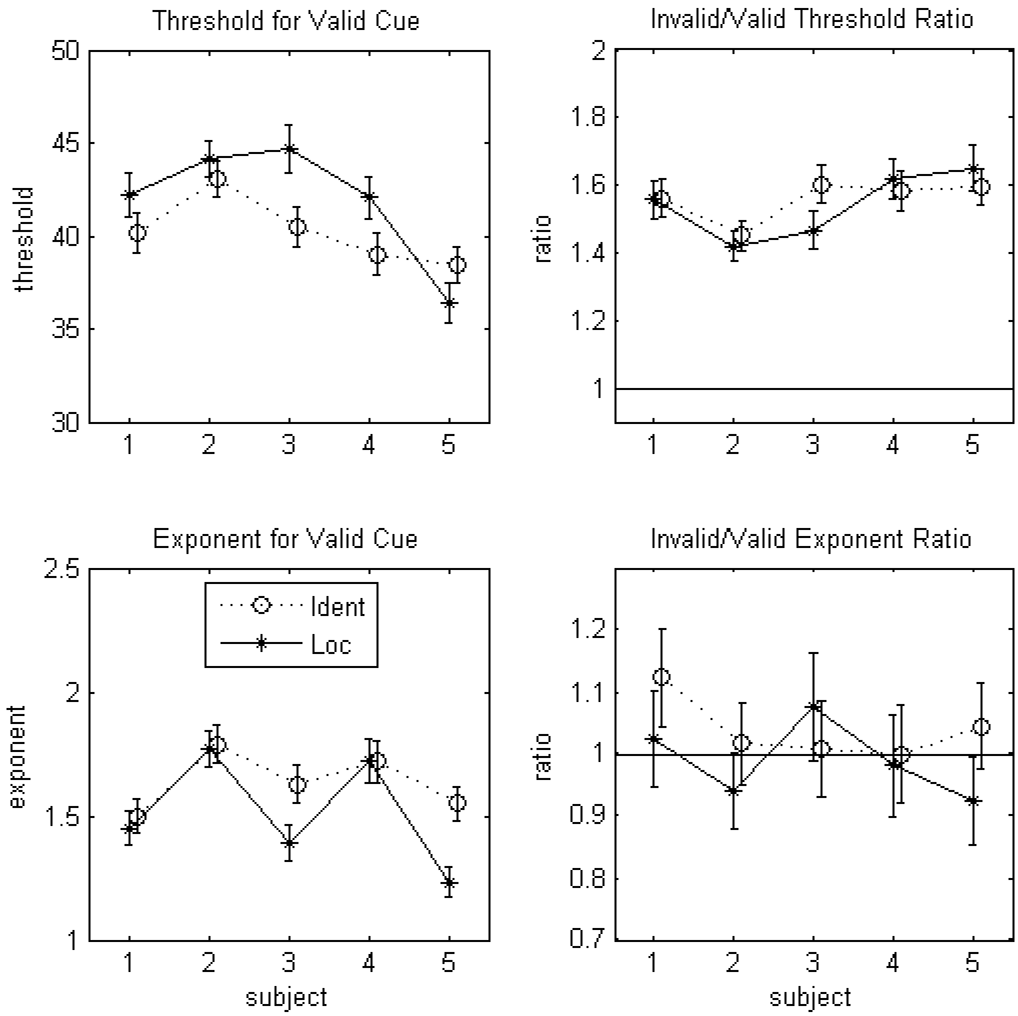

Figure 7: Plots of the parameter values of the Weibull function fit. The first subplot is of threshold parameter values for each judgment type across each individual subject. The second subplot indicates the ratio of the thresholds of invalid and valid cue trials. The third subplot indicates the exponent (slope) of valid cue data. The fourth subplot indicates the exponent ratio between invalid and valid cue trials.

Discussion

As shown in figure 7, across all 5 subjects there was a consistent contrast threshold between 35 and 45 percent contrast, indicating fairly equal performance and task difficulty across all subjects and for each individual judgment type though subject 5 had lower threshold values. The threshold ratio was consistently above 1.4 for each subject and judgment type, and the mean threshold ratio (Table 1) indicated a significant increase in performance with the valid cue compared to the invalid cue. The Weibull function exponents, corresponding to the slopes of the psychometric function for valid cue trials varied between 1 and 2, and the exponent ratios of invalid to valid cue data were not significantly different from unity (1.0), indicating that any spatial uncertainty reduction was not large enough to produce a shallowing of the valid cue trial slope. Subject ID 1 had the highest identity judgment exponent ratio, but it was just short of significance of difference from unity. Across the entire psychometric function, performance was higher with a valid cue than with an invalid cue as all data points were significant below $p<.01$.

General Discussion

These experiments demonstrate that involuntary attention can improve target identification and localization accuracy judgments with non-predictive cues and that these cueing effects are not due to response bias. Further, these cueing effects are present with unmasked stimuli, contrary to the predictions of the mask-dependent cueing hypothesis (Smith & Wolfgang, 2004, 2007). Additionally, no change in slope for the valued cue data was observed, indicating that spatial uncertainty reduction was not sufficient to explain the observed cueing effects. These cueing effects were similar both with non-predictive cues (14.3%) and 50% predictive cues, providing evidence that the same mechanism of involuntary attention was involved in each of these experiments. The results indicate that cue predictability is not a reliable differentiator of voluntary and involuntary attention.

Some researchers have proposed that involuntary attention does not influence the perceptual representation and only shows cueing effects for reaction time judgments (Prinzmetal, Ha, & Khani, 2010; Prinzmetal, Long, Leonhardt, 2008; Prinzmetal, McCool & Park, 2005; Prinzmetal, Park & Garrett, 2005; Schneider, 2006; Schneider & Komlos, 2008). It has been proposed that reported accuracy response improvements with involuntary attention are actually due to response bias and location uncertainty reflecting a decisional selection process rather than an actual enhancement of spatial vision (Gould, Wolfgang, Smith, 2007; Kerzel, Zarian, Gauch, Buetti, 2010; Prinzmetal, Long, Leonardt, 2008; Schneider & Komlos, 2008; Valsecchi, Vescovi, Turatto, 2010). Many studies have been published showing a performance enhancement from involuntary attention, but in recent publications, it has been argued that these cueing effects are non-existent for accuracy judgments and that cueing effects are dependent on the presence of a post-mask (Kerzel, Zarian, Souto, 2009; Kerzel, Gauch, Buetti, 2010; Smith, Lee, Wolfgang, & Ratcliff, 2009; Smith, Ratcliff, & Wolfgang, 2004; Smith & Wolfgang, 2004; Smith & Wolfgang, 2007; Smith, Wolfgang, & Sinclair, 2004). This has been presented as the mask-dependent cueing hypothesis.

In a recent investigation, we demonstrated that involuntary attention cueing effects were present with unmasked, non-predictive cues for accuracy judgments and that the effects were neither attributable to response bias or spatial uncertainty reduction, thereby challenging the mask-dependent cueing hypothesis. The present investigation involved 7 stimulus locations rather than 2, which not only increased spatial uncertainty, but also made the cues highly non-predictable (14.3% valid and 50% valid). The addition of the double judgment responses allowed for investigation into the magnitude of response biases across the full psychometric curve covering chance performance up to 100% accuracy. Multiple contrasts were examined, producing a psychometric function and demonstrating that cueing effects are not isolated to near-threshold levels or specific performance difficulty levels. Some studies have claimed that cueing effects only occur near detection threshold (Kerzel, Zarian, Gauch, Buetti, 2010), and conclude that a sensory luminance interaction accounts for the results rather than an attention induced performance enhancement (Schneider, 2006). Similarly, it has been suggested that involuntary attention cueing effects are absent when the task is very difficult and performance is low (Kerzel, Zarian, Souto, 2009). The present experiments measure perceptual enhancement across a large range of contrast levels, encompassing stimulus intensities that are both well above and well below threshold detection levels. In agreement with Ling & Carrasco (2006), the results indicate that the cueing effect is not due to sensory interactions because the cueing effect is present well above and below threshold detection levels.

In some of the previous reported literature arguing against response accuracy improvement from involuntary attention and non-predictive cues (Kerzel, Gauch & Buetti, 2010; Kerzel, Zarian, Souto, 2009), data was collected only at single contrasts (though sometimes using staircase procedures to obtain a specific level of performance such as 71% correct) or at a specified level of difficulty and performance. The present experiments make a much stronger argument in favor of involuntary attention resulting in response accuracy improvement than previous investigations that are limited to a single contrast or performance level.

Spatial Uncertainty Reduction

Signal detection theory predicts that observer uncertainty over the location of the target stimulus can produce cueing effects (Pelli, 1985; Tanner, 1961) and can bias response decisions leading to what appears to be improved target detection at cued locations. This is manifested as a shallowing of the slope of the cued trial data since the cue is proposed to reduce spatial uncertainty. The results of this experiment and our previous 2AFC experiments with unmasked stimuli did not show the characteristic shallowing of slope of the Weibull psychometric function for the cued trials for individual subjects, indicating that spatial uncertainty reduction was not the mechanism of performance enhancement from involuntary attention. Additionally, the results of the present experiments indicated cueing effects when accuracy was near 100%, where spatial uncertainty is very low, so cueing effects must be due to another mechanism.

Some researchers have argued that attention works by either noise reduction or the late component affecting the efficiency of sensory information relayed to perceptual decision making processes (Smith, Ellis, Sewell, Wolfgang, 2010). The present experiments did not use noise reduction and since the “late component model of attention” is the mask-dependent cueing hypothesis, the fact that cueing effects were observed with unmasked stimuli supports a mechanism other than these two, though we cannot ascertain what it is exactly based on these experiments.

Mechanisms of Involuntary Attention

The specific mechanism of enhancement for involuntary attention is controversial and exists in two main categories: signal enhancement mechanisms and decision-making mechanisms. The signal enhancement mechanism is generally improved signal processing of the stimuli within the spatial region of the cue as manifested as faster reaction times and improved discrimination accuracy (Kerzel, Gauch, Buetti, 2010; Herrmann, Heeger, Carrasco, 2012; Herrmann, et al., 2010). The decision-level mechanism occurs through spatial uncertainty reduction of the target and can also be manifested as faster reaction times (Prinzmetal, Ha, & Khani, 2010; Prinzmetal, McCool, & Park, 2005) and improved discrimination accuracy (Gould, Wolfgang, & Smith, 2007; Prinzmetal, Long, & Leonhardt, 2008; Prinzmetal, at al., 1997). The decision-level mechanism works by regulating the transfer of visual information into a system with fixed capacity that makes the decision whether the target is present (Duncan, 1980; Mueller & Humphreys, 1991; Sperling, 1984). An invalid cue degrades information transfer leading to lower target identification accuracy or a slower reaction time, whereas a valid cue affects the activation of memory and decision processes to more efficiently transfer visual information into short term working memory (Luck, et al., 1994, Smith, Lee, Wolfgang, & Ratcliff, 2009). Since the results with our unmasked stimuli experiments show improved discrimination performance for both localizing and identifying the features of the targets, we believe a signal enhancement mechanism is accounting for the improved accuracy.

Cue Predictability

Some researchers have asserted that voluntary and involuntary attention can be operationally differentiated on the basis of cue predictability under the assumption that a subject will not voluntarily attend to the cue when the cue is non-predictive (Jonides, 1980; Jonides, 1983; Kerzel, Gauch & Buetti, 2010; Prinzmetal, Ha, & Khani, 2010; Prinzmetal, Long, Leonhardt, 2008; Prinzmetal, McCool & Park, 2005; Prinzmetal, Park & Garrett, 2005; Wright & Richard, 2000). Others have argued that the systems are differentiated by the length of time available to attend to a stimulus or task. If enough time is available to complete the perceptual task using voluntary search with or without eye movements (covertly or overtly), then voluntary attention is utilized (Carrasco, Fuller, & Ling, 2008; Cheal & Lyon, 1991; Ling & Carrasco, 2007; Nakayama & Mackaben, 1989). If there is insufficient time to voluntary shift attention during the task, then involuntary attention is utilized (Fuller, Rodriguez, Carrasco, 2008; Giordano, McElree, Carrasco, 2009; Herrmann, Montaser-Kouhsari, Carrasco, Heeger, 2010).

Some researchers have stated that with non-predictive cueing, subjects will ignore a cue regardless of its saliency if they believe the cue is not helpful for predicting the forthcoming target location. By conducting a much longer investigation across a range of task difficulty levels that produce a psychometric function, and by using a cue that has very low predictability (14.3%), the present experiments demonstrate that subjects do not ignore the cue since the cue improves accuracy judgments at both 14.3% and 50% predictability levels. This suggests that the same mechanism of involuntary attention was involved in each of these experiments and we conclude that cue predictability is not a reliable differentiator of voluntary and involuntary attention and instead that these attention systems should be differentiated on the basis of temporal characteristics as has been discussed.

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Involuntary feature/shape attention improves double judgment accuracy with non-predictive central feature cues

Abstract

In a series of recent experiments, we have demonstrated that visuospatial attention improves target identification and localization accuracy to non-predictive peripheral cues in a seven alternative force choice cueing task. Using multinomial modeling, response bias to the cued location was quantified and removed from the data, yielding bias free cueing effects present for both masked and unmasked stimuli. The present experiment was conducted to determine if the same attention enhancements occur with feature-based attention. It was recently shown that involuntary feature-based attention can accelerate visual search, leading to faster reaction times in conjunction with a peripheral feature cue (Lin et al., 2011). Improvements in accuracy judgments were not investigated and improved reaction time was only observed with peripheral cues, not with central cues. We conducted a double judgment 7AFC task with multinomial modeling to eliminate response bias in order to determine if cueing effects were present for two independent types of accuracy judgments using central cues. The results confirm our hypothesis that involuntary feature/shape-based attention improves response accuracy for both voluntary and involuntary attention. This is the first investigation into involuntary feature-based attention implementing a bias removal process and showing cueing effects with central cues.

1. Introduction

Visual attention can be directed voluntarily or involuntarily and covertly or overtly depending on the properties of presented stimuli and the amount of time available to attend to the stimuli. Attention can be directed to spatial locations or to objects with specific visual features.

It has recently been demonstrated that a non-predictive peripheral cue can improve reaction time with involuntary feature-based attention (Lin et al., 2011) but that central cues produce no benefit. In their first experiment, the results indicated that subjects had the fastest reaction time when both the feature and spatial properties of the cue were valid. This is to be expected since attention is guided to the location of the target stimulus immediately following the cue onset and requires less time in search for the target. More interesting however is the observation that the performance benefit of a valid cue is greater for the spatial characteristic of a cue compared to the feature characteristic. Not only was the magnitude of the cueing effect larger, but reaction time was faster for valid spatial cues than valid feature cues. This was the first published research to demonstrate that feature attention can be captured exogenously with irrelevant non-predictive peripheral cues. There are a number of factors that may have been overlooked in this study however, the first of which is that the time available to conduct visual search from the cue onset to the target onset in this task was 266ms, which is long enough for voluntary search processes. In addition to this time, subjects were allotted a maximum of 2000ms to search the target display, though the average response times to valid cues in their three experiments ranged from 650ms to 876ms. Since observers have all this time available to direct attention to the presented stimuli in search of the target, we argue that their experiments were measuring voluntary attention and not involuntary attention since there is sufficient time available to engage voluntary search processes. Additionally, since no backward masking was utilized there was no temporal constraint of search time, though search time would certainly be shorter than the reported reaction times.

While these experiments demonstrate that spatial and feature-based attention quickens reaction times with a valid cue, these experiments did not investigate improved performance for accuracy judgments. Response accuracy was designed to be stationary near 100%, being suprathreshold, and no additional accuracy levels were tested. In recent experiments, we demonstrated that voluntary and involuntary spatial attention improve target identification and localization accuracy at cued spatial locations in the peripheral visual field for masked, unmasked, low-contrast, and full contrast brief alphanumeric stimuli with cues that were either non-predictive (14.3%) or 50% predictive. The cues had no task relevance, were non-predictive, and did not share any of the features of the target stimuli (targets were numbers, distractors were letters), so the results cannot be explained by any sort of search strategies implemented by the observer. The results demonstrate that the allocation of involuntary and voluntary spatial attention to a specific location results in perceptual enhancement at the cued location, a topic significantly debated in the literature. Using a multinomial model and novel analysis methods, we demonstrated that our obtained results were not due to location uncertainty or any response bias and that the reported cueing effects were not isolated to near-detection threshold levels of performance; concerns previously raised in regards to perceptual enhancement from involuntary attention in the literature (Kerzel, Zarian, Gauch, Buetti, 2010; Kerzel, Zarian, Souto, 2009; Prinzmetal, Long, & Leonhardt, 2008; Prinzmetal, McCool, & Park, 2005; Schneider, 2006). While our experiments provide compelling confirmation that involuntary attention allocation to a spatial region of the visual field leads to perceptual enhancement at that location, the question remains as to whether or not this perceptual enhancement effect is specific to spatial attention, or if it also exists with feature based attention.

While spatial attention produces a perceptual enhancement to a specific spatial region of the visual field, feature-based attention produces a global perceptual enhancement for a specific visual feature such as color, motion direction, or orientation (Baldassi & Verghese, 2005; Ling, Lu, & Carrasco, 2008; Lu, & Itti, 2005; Maunsell, & Treue, 2006; Melcher, Papathomas, & Vidnyanszky, 2005; Saenz, Buracas, & Boynton, 2002, 2003; Sally, Vidnyanszky, & Papathomas, 2009; Scolari & Serences, 2009; Shulman & Wilson, 1987; Zhang & Luck, 2008). With feature-based attention, visual search benefits from information about the features of a target stimulus even when the location of the target is unknown (Bichot, Rossi, & Desimone, 2005; Buracas & Albright, 2009; Wolfe & Horowitz, 2004). There is evidence that spatial and feature-based attention are independent and can interact, leading to further perceptual enhancement than obtainable by only one system alone (Hayden & Gallant, 2005, 2009; Lin et al., 2011; Patzwahl & Treue, 2009). The present investigation seeks to answer the question of whether or not involuntary feature-based attention results in perceptual enhancement to cued features similar to our previous experimental results showing that spatial attention leads to perceptual enhancement via a pre-cue.

2. Experiment

The aims of this experiment were to determine if central feature cues can improve peripheral accuracy judgment performance for both target location and identification, and to quantify and remove any response bias to the central cue. The double judgment accuracy measure allows for analysis of two independent judgments, one susceptible to response bias to the cue, and one not susceptible to response bias to the cue identity.

3. Methods

3.1 Observers

Eight subjects (1 male and 7 female) were recruited from the community, consisting of students and non-students alike. Recruitment and experimental procedures were approved by the University of California affiliated Institutional Review Board ethics committee. Seven of the subjects were naïve observers, and one was the primary author. Subject ages ranged from 20 to 28. All participants signed an informed consent and were financially compensated for their time. All subjects had normal or corrected to normal vision.

3.2 Apparatus

In all experiments, stimuli are generated, presented, and responses recorded using the WinVis Psychophysical Testing platform, a toolbox for Matlab. Stimuli were presented on a 17 inch Sony Trinitron CRT monitor at a refresh rate of 100hz. The display resolution was 1024x768 pixels. The background was grey with an approximate luminance of 13 cd/m^2. Subjects were positioned in an Eyelink II eye tracker with a chin and forehead rest. Subject's eyes were positioned 50cm from the display resulting in 2.1 x 2.1 min square pixels. Subjects were told that eye movements were being recorded during each trial (though no eye movements were recorded) and to avoid making eye movements during a trial. The experiment was conducted in moderate brightness indoor lighting conditions.

3.3 Stimuli and design

Monitor luminance linearity was achieved using an 8 bit gamma correcting look up table. A 25% contrast fixation circle 0.2° in size was presented at the center of the screen at the beginning of each trial (Figure 1) over a grey background. The duration of the fixation circle was randomly selected from 0.5-2.0 sec for each trial to prevent the subject from being able to predict the cue onset. The fixation target was removed before the cue onset.

The target stimulus was a number ranging from two to seven in Arial font presented at one of six peripheral locations (Figure 1). Letter distractors were presented at all 5 non-target locations. Targets, distractors, and cues were 1° x 1° in size. The cue was a full contrast alphanumeric character presented at fixation. The cue was presented for 60ms. In ¾ of the trials the cue was a number, while in ¼ of the trials, the cue was a random letter.

Beginning with the onset of the cue, there was a stimulus-onset-asynchrony (SOA) interval consisting of a blank screen, after which the target and distractors were presented at all six stimulus locations. Full contrast peripheral targets and distractors were simultaneously presented at 7.5° eccentricity from the center of the screen for 20ms. The target number stimulus was simultaneously presented with distractor letters. After the target offset, there was a variable inter-stimulus-interval (ISI) consisting of a 30ms blank screen followed by a 40ms mask stimulus consisting of random letters presented at each of the seven stimulus locations. After the mask offset, there was 400ms of blank screen, after which the question "Where was the target letter?" was presented at the center of the screen until the subject responded by pressing a number on the keypad between one and seven. After responding, "What was the target letter?" was presented until the subjects responded by pressing a number between two and eight to indicate the target identity. After reporting the location and identity of the target letter there is one second of visual feedback provided in the form of the previously presented target display containing the distractors. To begin the next trial, subjects pressed any button on the keyboard.

Distractor letters were randomly selected in each trial. Each target number appeared an equal number of times at each of the six locations. The order of the target numbers was randomly selected, but followed an organized structure. There were 6 trials with valid number cues at each of the target locations, and 30 trials with invalid number cues at each of the target locations, totaling 36 trials. In addition, there were 12 neutral trials with a letter cue (targets are always numbers) totaling 48 trials per run. The cue was non-predictive of the forthcoming target location.

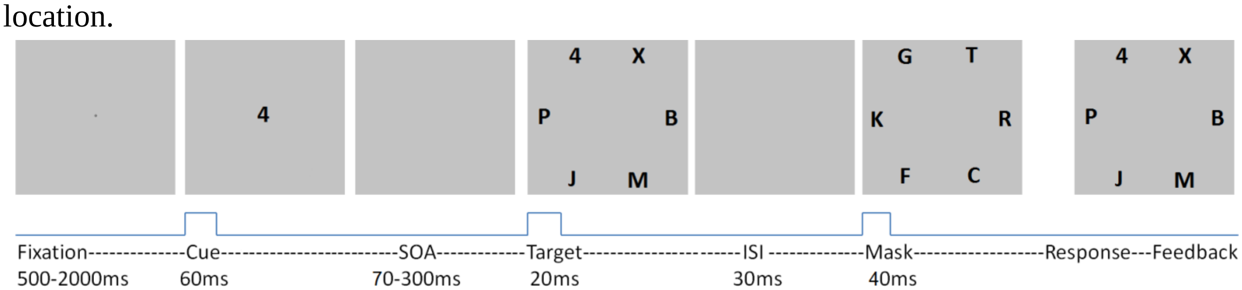

Figure 1. The sequence of stimuli in a valid cue trial. After a fixation period, the cue is presented for 60ms, followed by a variable SOA before the target stimulus appears. The target stimulus is simultaneously presented with distractor letters for 20ms. After the target offset, there is a 30ms inter-stimulus interval followed by a 40ms mask stimulus consisting of random letters. The observer's task is to report the identity of the target number. After reporting the location and identity of the target letter, visual feedback is provided in the form of the previously presented

target display containing the distractors. The cue is non-predictive of the forthcoming target location and identity.

3.4 Procedure

Subjects were instructed to complete the task at their own preferred pace, and to take breaks between each run as often as desired to maintain a consistent attentive state. After each stimulus presentation, the subject used a keypad to indicate the observed target number (2-7), and the target location (1-6). A response initiated the next trial. Each data collection session lasted 1 or 2 hours, and each subject participated in an approximate total of 10 hours. Since data collection is self-paced, there is some slight variation in the amount of data collected per subject, but the average number of trials completed by each subject is 4800 trials, or 100 runs encompassing all of the SOAs tested. The total number of trials consisted of 600 valid cue trials, 3000 invalid cue trials, and 1200 neutral letter cue trials. One subject, the primary author, collected data across six SOAs instead of three, requiring about 20 hours of data collection.

The subjects were initially familiarized with the task by completing 144 trials (3 runs) with large stimulus durations and having low task difficulty. The data from these training runs are not included in the final analysis. Subjects were informed that a cue would precede the target stimulus, but not given any information about the reliability of the cue. In some previous published research, subjects were specifically instructed to ignore the cue since it was nonpredictive of the forthcoming target location (Jonides, 1981; Kerzel, Zarian, Souto, 2009). Some research has shown that observers cannot completely ignore a salient peripheral cue (Jonides, 1981; Muller & Rabbitt, 1989; Warner, Juola, Koshino, 1990). Providng subjects with explicit instructions to ignore the cue could activate top-down control systems that may decrease the saliency of reflexive attention capture and weaken any cueing effects. To avoid any confounds related to the subjects' intentions regarding attending to the cue, we refrained from giving the subjects any specific instructions about the cue other than informing them that it would be presented before the target.

3.5 Bias removal with Multinomial Modelling

The process of quantifying and removing response bias using multinomial modeling has been previously explained in a recently submitted article. To briefly summarize, response bias occurs as a result of subjects reporting the cue as a response to the unknown target. In previous experiments we have conducted, the response bias was to a location since cueing was implemented to study visuospatial attention. In the present experiment, a feature (number identity) is cued, so response bias occurs to the cued identity and the location response is unbiased by any responses to the cue. The response bias results in a large decrease in the accuracy of invalid cue trials and a small inflation of the valid cue accuracy. Multinomial modeling is used to quantify the extent to which the subject responds with the cue identity relative to the number of times the subject responds with non-cued identities, and then to remove this bias by refitting the model without bias parameters. The model is then used to calculate new accuracy values that reflect the removal of response bias to the cue.

4. Results

Accuracy was measured as the percentage of trials that the observer correctly identified the target identity or location. In Figure 2 accuracy is plotted as a function of the amount of time available to allocate attention (60ms cue + SOA + target (20ms)) to the target stimulus for each of the 8 subjects. Each subject's data is plotted in two plots with the first plot indicating the accuracy for identification judgments, showing the original biased performance levels with "x" data points and the bias corrected accuracy with solid dots, and the second plot for location judgments which are unbiased. The valid cue data is presented on the solid line and invalid cue data is on the dashed line. Accuracy with neutral letter cues is presented on the dashed line with circle data points. Subjects with large response bias will have a larger reduction of the difference between the valid and invalid cue data points, whereas those with little bias will show only slight changes between the lines. For subjects with considerable response bias the correction largely increases the invalid cue accuracy. Standard error is calculated using Binomial Statisics where p is the probability of a correct response, and n is the total number of trials: $\sqrt{(p * \frac{1-p}{n})}$.

Analysis from a two-tail t-test indicated that all valid cue data points were significantly higher than invalid cue data points and neutral cue data points ($p<.01$) except for the neutral letter cue at 320ms for subject 3 for location judgments ($p>.05$). Overall there is a highly significant increase in target identification and localization accuracy across all subjects across a range of intervals from 90-320ms spanning the time course of involuntary and voluntary attention. All of the valid cue data points were above detection threshold (d'=1) while many invalid cue data points were below detection threshold, particularly at shorter time intervals when the SOAs are brief.

Each of the subject's results indicate a general trend of increasing response accuracy with increasing SOA. This trend is observed for valid, invalid, and neutral cues and present with both localization and identification judgments. Response accuracy with a neutral cue was in close proximity to performance with an invalid cue, though sometimes higher and sometimes lower. Both invalid and neutral cues produced lower performance levels than valid cues, though one data point was not significantly lower for subject 3.

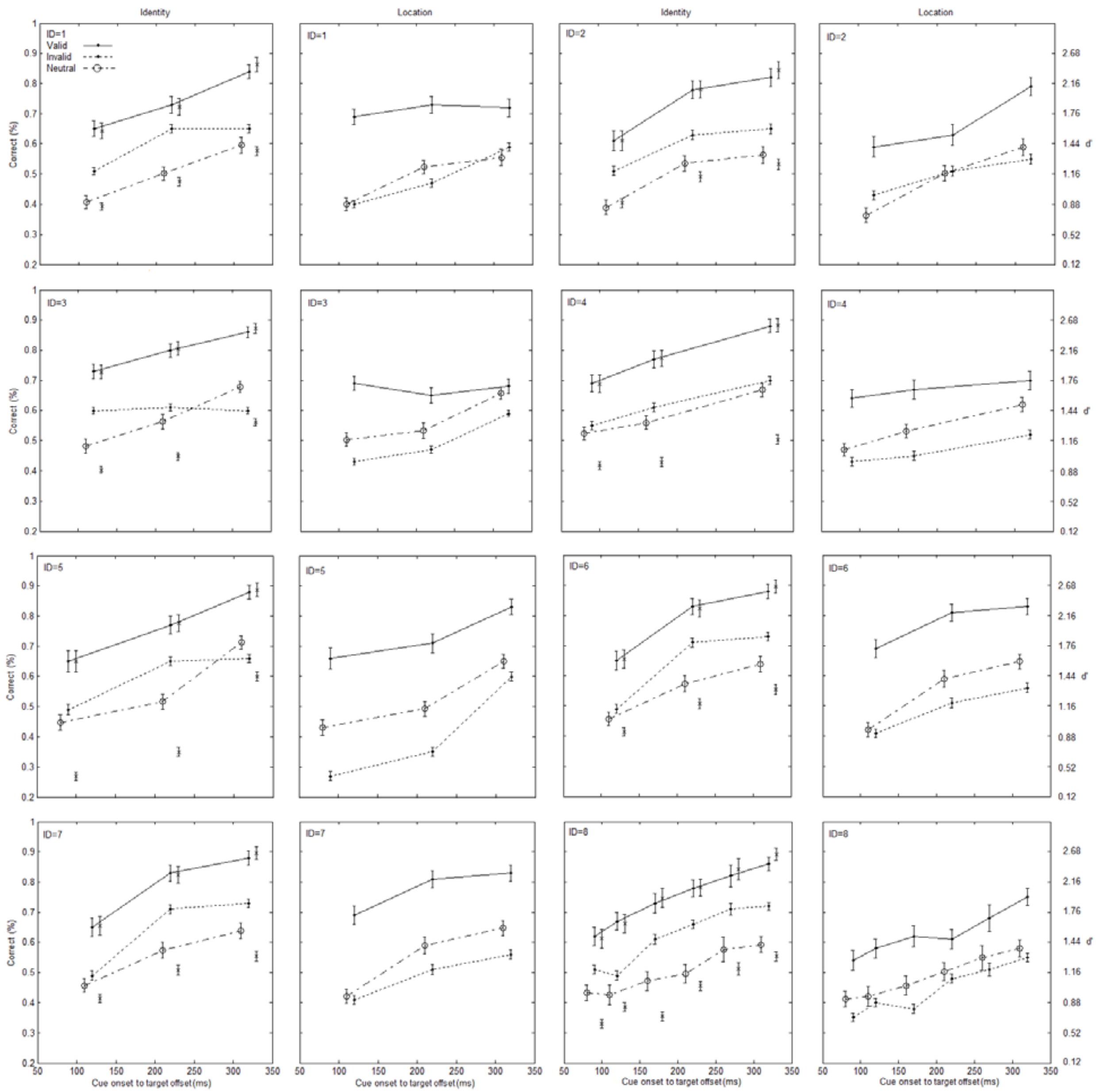

Figure 2. Accuracy for valid, invalid, and neutral cue data for 8 subjects. Valid cue data is shown as the solid line, invalid cue data as the dotted line, neutral cue data as the dashed line with circle data points, and biased identity judgment data as "x" points (for valid and invalid data). Two plots are shown per subject, the first indicating target identification accuracy before and after bias removal, and the second plot indicating location accuracy. The error bars are +/- one binomial standard error.

5. Discussion

The main goal of this experiment was to determine if involuntary attention to centrally presented feature cues in the form of numbers and letters improves response accuracy for two independent judgments, location and identity. Additionally, we wanted to determine if multinomial modeling could be used to quantify and remove response bias as we have previously conducted with spatial attention. The results indicate that involuntary feature-based attention does improve both target localization and identification using a central cue and peripheral targets. Response accuracy for bother identification and localization judgments was higher with valid cues than either neutral or invalid cues. Using multinomial modeling, we quantified and removed any response bias from the data, uncontaminated results. To our knowledge, this is the first experiment to use multinomial modeling for this purpose with feature cueing and also the first experiment to show that involuntary attention using central cues can improve accuracy judgment performance.

In a recent involuntary feature-based attention cueing study, Lin et al., 2011 measured reaction time and found no cueing effects with central cues. They attributed the absence of a cueing effect with a central cue to a lack of reflexive attention capture to the cue since voluntary attention is already allocated to the central location as part of trial fixation. Since our results indicate a positive cueing effect with central cues, we conclude that a central cue can reflexively capture involuntary attention as well as voluntary attention and produce improved task performance, at least in the form of increased response accuracy. There are a number of hypotheses as to why they did not obtain cueing effects with central cueing.

On possible explanation for their reported absence of cueing effects was because of their temporal parameters. If involuntary attention does have a peak effect at a specific temporal stage (about 110ms), followed by a rapid decay as previous researchers have demonstrated (Carrasco & McElree, 2001, Carrasco, Ling, & Read, 2004, Carrasco, Fuller, & Ling, 2008; Cheal & Lyon, 1991; Fuller, Rodriguez, & Carrasco, 2008; Giordano, McElree, & Carrasco, 2009; Hanes & Schall, 1996; Hermann, Kouhsari, Carrasco, & Heeger, 2010; Liu, Pestilli, & Carrasco, 2005; Liu, Stevens, & Carrasco, 2007; Montagna, Pestilli, & Carrasco, 2009; Muller & Rabbitt, 1989; Nakayama & Mackaben, 1989; Thompson, Biscoe, & Sato, 2005; Turatto, 2007; Weichselgartner & Sperling, 1987), an experiment on involuntary attention should be optimally designed to have stimuli presented for the ideal durations which maximally activate involuntary attention capture. In the experiment by Lin et al., (2011) a cue was presented for 66ms followed by a 200ms blank interval before the target stimulus and distractors were presented. The search array containing the target stimulus with the distractors remained on the display until the subject generated a response or 2000ms had elapsed. This gives the subjects a total of 2266ms to search for the target stimulus, which is far more than enough time to engage voluntary attention in search of the target stimulus. Granted, reported reaction times ranged from 650-950ms, demonstrating that subjects rarely, if ever, utilized the full 2000ms duration of the search array. The temporal onset, activation, and duration of involuntary attention is not directly obtainable from reaction time data, so there is no practical way of knowing the average time required to identify the target visually in this task. Therefore, it is difficult to conclude that involuntary attention is the attention system utilized in this task, since there is more than sufficient time to engage voluntary search, and therefore utilize voluntary attention. However, in our experiment we did observe cueing effects at longer SOAs encompassing voluntary attention using the central reflexive cue, so perhaps this is not the best explanation.

One possibility is that reaction time doesn't benefit from central cueing with involuntary feature-based attention, while accuracy judgment does. Some researchers have proposed that involuntary and voluntary attention have different mechanisms of reaction time and accuracy (Prinzmetal, Ha, Khani, 2010; Prinzmetal, McCool, Park, 2005; Prinzmetal, Park, Garrett, 2005; Prinzmetal, et al., 2011) and this could account for the difference in cueing effects between our results and those of Lin et al., 2011. The mechanism by which involuntary and voluntary feature-based attention can improve response accuracy as we have reported remains uncertain however.

In recent experiments, we have demonstrated that with visuospatial attention improves response accuracy for two independent judgments, target identification and localization. Analysis of the results of those experiments demonstrated that spatial uncertainty reduction was not the mechanism responsible for our observed cueing effects. The precise mechanism remains uncertain, however other researchers have proposed various mechanisms by which spatial attention can enhance task performance such as external noise reduction (Dosher & Lu, 2000a, 2000b; Lee et al., 1999; Lu & Dosher, 1998, 2000; Lu, Jeon, & Dosher, 2004; Lu, Lesmes, & Dosher, 2002), accelerated information accrual and processing (Carrasco, Fuller, & Ling, 2008; Carrasco & McElree, 2001; Hein, 2006; Herrmann et al., 2010; Liu, Abrams, & Carrasco, 2009; Liu, Wolfgang, & Smith, 2009; Smith, Ellis, Sewell, Wolfgang, 2010; Smith, Lee, Wolfgang, & Ratcliff, 2009; Smith, Ratcliff, & Wolfgang, 2004; Smith & Wolfgang, 2004, 2007; Smith, Wolfgang, & Sinclair, 2004), reduction of decisional noise (Kinchla, Chen, & Evert, 1995; Palmer, 1994; Shiu & Pashler, 1995), and various forms of signal enhancement such as improved visuospatial sensitivity (Cameron et al., 2004; Carrasco & Yeshuran, 2009; Giordano, McElree, & Carrasco, 2009), enhanced spatial resolution (Carrasco, Williams, & Yeshuran, 2002; Carrasco, Loula, & Ho, 2006; Talgar & Carrasco, 2002; Yeshuran & Carrasco, 1998; Yeshuran & Carrasco, 1999; Yeshuran & Carrasco, 2000; Yeshuran & Carrasco, 2008), and increased contrast sensitivity (Carrasco, Penpeci-Talgar, & Eckstein, 2000; Carrasco, Ling, & Read, 2004; Pestilli & Carrasco, 2005).

The mechanism of involuntary and voluntary attention responsible for our observed cueing effects would not likely be external noise reduction since there is no external noise in the background display, and it wouldn't be increased contrast sensitivity since stimuli were presented at full contrast. It could be accelerated information accrual, improved visuospatial sensitivity, or enhanced spatial resolution, and since there is no spatial uncertainty reduction with a central feature cue, as is the case in our recently reported experiments, spatial uncertainty reduction does not account for the observed cueing effects.

Some research suggests that feature based attention has a slower activation than spatial attention (Huang, 2010; Lin et al., 2011; Liu, Stevens, & Carrasco, 2007). Consistent with our previous experiments on spatial cueing, we report robust cueing effects with non-predictive cues throughout the time courses of both involuntary and voluntary attention. In both the feature cueing experiment and the spatial cueing experiments, we find cueing effects before 100ms that are maintained beyond 300ms, indicating no difference in the time course of feature-based attention and spatial attention.

To our knowledge the results of the present experiment are the first to show positive cueing effects with non-predictive, central feature cues for both involuntary and voluntary attention. In Lin et al., (2011), reaction time was improved with cues having both spatial and feature validity, and presented in the periphery. The authors concluded that involuntary attention improved reaction time with feature-based attention. We question this conclusion however for a number of reasons, the first of which has to do with the amount of time available to attend to the stimuli in their task. Our experiment has a number of advantages over their's in terms of being able to claim involuntary feature-based attention cueing effects. As was briefly mentioned in the introduction, they reported cueing effects for reaction time judgments as early as 260ms. Subjects however had more than 2260ms to search for the stimuli, which would engage voluntary attention search rather than involuntary attention. This being the case, their experiment was likely measuring voluntary search rather than a reflexive capture of involuntary attention. Unlike in our experiment, they did not use a backward mask, so the unconstrained iconic memory access could mean that they were actually measuring voluntary attention. Considering these issues, we believe that our investigation is the first to indicate cueing effects with involuntary feature-based attention. In addition, most of the debate over involuntary attention and performance enhancement is not for reaction time performance but rather on whether or not performance enhancement occurs with involuntary attention for accuracy judgments. A major part of this ongoing debate is on the topic of what the mechanism of involuntary attention perceptual enhancement is for accuracy judgments. Our experiments were conducted to elucidate these mechanisms for feature-based involuntary attention and to obtain further insight as to whether or not feature based attention leads to improved accuracy judgment performance as a manifestation of some form of signal enhancement. Since we measured response bias and Lin et al., (2011) did not, our study also has the advantage of being free of counfounds related to decisional selection processes. Additionally, their reported cueing effects were only present at a single level of performance, which was well above threshold. Our experiment demonstrates that cueing effects are present across a range of performance levels spanning the time course of voluntary and involuntary attention.

One final issue to discuss is whether contingent capture of attention could account for the cueing effects we obtained since the cue has features that match a task-relevant feature in the visual search (Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994; Theeuwes, 1994; Theeuwes & Burger, 1998). As concluded in Lin et al., 2011, we are able to rule out the possibility that subjects could implement a search strategy based on the cue's feature since the cue identity and location were non-predictive, therefore there was no strategic advantage to using the cue to guide visual search. Our results are not attributable to spatial uncertainty reduction, response bias, nor a contingent capture of attention.

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Summary

Differentiating involuntary and voluntary attention

A lot of effort has been made to concisely define and differentiate voluntary and involuntary attention on the basis of the type of cue presented (features, spatial location, temporal placement), but substantial disagreement still exists as to what precisely constitutes involuntary attention, and further what specific mechanisms underlie the varied perceptual enhancements present in cueing attention tasks. Precise definitions of what is meant by involuntary and voluntary attention is crucial, otherwise interpretations of experimental results can be inconsistent as a result of not actually referring to the same attention systems or measures. The current discussion and investigations focuses on covert attention, in which no eye movements are made but attention is still allocated to a particular region of visual space.

There are three main ways of differentiating involuntary from voluntary attention using cueing stimuli. Some researchers have asserted that voluntary and involuntary attention can be operationally differentiated on the basis of cue predictability under the assumption that a subject will not voluntarily attend to the cue when the cue is non-predictive (Jonides, 1980, 1983; Kerzel, Gauch & Buetti, 2010; Prinzmetal, McCool & Park, 2005; Prinzmetal, Park & Garrett 2005; Prinzmetal, Long & Leonhardt, 2008; Prinzmetal, Ha & Khani, 2010; Wright & Richard, 2000). Others have argued that the systems are differentiated by the length of time available to attend to a stimulus. If enough time is available to complete the perceptual task using voluntary search with or without eye movements (covertly or overtly), then voluntary attention is utilized (Carrasco, Fuller & Ling, 2008; Cheal & Lyon, 1991; Ling & Carrasco, 2007; Nakayama & Mackaben, 1989). If there is insufficient time to voluntary shift attention during the task, then involuntary attention is utilized (Fuller, Rodriguez & Carrasco, 2008; Giordano, McElree & Carrasco, 2009; Herrmann et al., 2010). In this view, voluntary attention is characterized as a voluntary, goal-directed orienting of attention, while involuntary attention is an involuntary, reflexive, and automatic orienting of attention. A third differentiation is on the spatial location and nature of the cue stimulus. A cue can appear at central fixation and instruct the observer to voluntarily attend to other locations, which involves some degree of interpretation of the cue, or a cue could saliently appear at some location in the periphery which reflexively draws attention to the spatial region. While central symbolic cues generally activate voluntary attention and peripheral cues activate involuntary attention, cues don't necessarily have to be peripheral to engage involuntary attention (Driver et al., 1999; Friesen & Kingstone, 1998; Kingstone et al., 2003; Lambert & Duddy, 2002; Langton, Watt & Bruce, 2000; Ristic, Friesen & Kingstone, 2002; Tipples, 2002). The location of the cue doesn't appear to be a consistent or reliable differentiating variable for voluntary and involuntary attention, and in fact can be combined in either of the first two differentiation variables (predictability and temporal stimulus parameters).

Within the experiments conducted in this dissertation, cues can appear at fixation in the center of the visual field and still activate both involuntary and voluntary attention. Similarly, cues can appear in the periphery and activate either voluntary or involuntary attention. Therefore cue location is not a reliable differentiator of voluntary and involuntary attention and an alternative characteristic must account for the differences of these two systems.

Cue predictability

Many early experiments with cueing and attention made use of the cue-predictability differentiation (Jonides, 1980, 1983) to study voluntary and involuntary attention. The reasoning was that with predictive cues, subjects strategically use the cues to voluntarily guide visual attention to the cued region of visual space, even when not informed of the predictive nature of the cue. With a non-predictive cue, it was thought that observers would learn to ignore the cue since there is no incentive to attend to an unreliable cue, so involuntary attention was assumed to be utilized (Kerzel, Zarian & Souto, 2009; Prinzmetal, McCool & Park, 2005; Prinzmetal, Park, & Garrett, 2005). This is one of the main assumptions made under the cue-predictability differentiation, yet research has demonstrated that salient, peripheral cues cannot be ignored or suppressed (Jonides, 1981; Muller & Rabbitt, 1989; Warner, Juolo & Koshino, 1990). In the experiments within this dissertation, cueing effects were found with non-predictive cues for both feature-based and spatial attention systems, and with both involuntary and voluntary attention so cue predictability is not a valid differentiator of these attention systems. Additionally, cueing effects and task performance was very similar with unmasked peripheral targets for cues that were non-predictive, and cues that were 50% predictive. Published research has indicated that perceptual enhancement measured as faster reaction times has been demonstrated to occur when cues are predictive, non-predictive, and even anti-predictive (Esterman, et al., 2008; Posner, Cohen, & Rafal, 1982; Rafal & Henik, 1994; Sereno & Holzman, 1996; Warner, Juola & Koshino, 1990). It's interesting to note that in some of these studies, even with a cue that is antipredictive, an exogenous cueing effect only occurs when the stimulus onset asynchrony (SOA) is very short. This provides support for the processing time differentiation since exogenous cueing effects only occurred with processing time was very limited.

Temporal characteristics of voluntary and involuntary attention

The question of how much processing time is available to allocate attention to a psychophysical task is not straight forward. Research has shown that attention has two components spread across processing time. The first is a transient component which is time-locked to the cue stimulus and has a rapid activation (reaching peak around 110ms) followed by a rapid decay (Cheal & Lyon, 1991; Muller & Rabbitt, 1989; Nakayama & Mackaben, 1989). This is the involuntary attention system as it occurs reflexively to a salient stimulus and is devoid of voluntary control. The voluntary attention system begins to be activated at times long enough to give rise to voluntary orienting (covertly or overtly), and is sustained for a long time (potentially activating as early as 200-300ms). The processing time differentiation as described has been tested many times and continues to show that involuntary attention is transient, having a quick activation, peaking around 110ms, and then rapidly decaying (Carrasco & McElree, 2001; Carrasco, Ling & Read, 2004; Carrasco, Fuller & Ling, 2008; Giordano, McElree & Carrasco, 2009; Liu, Pestilli & Carrasco, 2005; Montagna, Pestilli & Carrasco, 2009).

Some research has claimed that voluntary attention can be engaged as early as 50ms, but these studies use cue-predictability as a differentiator of attention rather than the SOA (Prinzmetal, McCool, Park, 2005; Warner, Juola & Koshino, 1990). In Warner (1990), no mask was used so recurrent processing may be a significant confound if observers can still process the visual information within iconic memory storage. In the present experiment, no subjects could perform and experimental task at 50ms. One confound with using cue predictability as a differentiator is that it contradicts an extensive amount of electrophysiological evidence that voluntary shifts of attention aren't made faster than ~200ms. Recording the speed at which an observer conducts a voluntary eye movement reveals the length of time required to plan an eye movement, plus the length of time required to execute the saccade, but the question that is of interest is how long it takes to voluntarily shift attention before saccades are made. Single cell electrophysiology research has been conducted to determine the time course of attention shifts during covert attention. In Thompson, Biscoe & Sato 2005, covert attention neural activity was shown to be independent of motor-saccade activity in Frontal Eye Fields (FEF) of the Macaque prefrontal cortex. In the FEF, there are motor neurons with functions specific to saccade planning and execution and there are visual neurons that are involved in searching the visual field for stimuli of interest for which saccades may be executed to. The FEFs have a well-documented role in both covert and overt attention shifts for both voluntary and involuntary attention (Hanes & Schall, 1996; Kinkade et al., 2005; Thompson, Biscoe & Sato, 2005; Schall et al., 1995).

Electrophysiology studies on the Macaque FEF show that covert voluntary attention neural spiking begins accelerating at 250ms after target onset and gradually builds up a maximum peak over the following 100-150ms (Hanes & Schall, 1996) This neural activity is separate and independent from saccade execution activity (Juan, Shorter-Jacobi & Schall, 2004; Thompson & Bichot, 2005). Electrophysiological recordings also show that involuntary attention to a salient, peripheral stimulus is coupled with an accelerating rate of action potentials starting around 50-70ms, and maximizing at 100ms (Thompson, Biscoe & Sato, 2005). A rapid deceleration of action potentials from FEF visual neurons is observed immediately following this peak at 100ms. While the electrophysiological recordings were conducted on non-human primates, it is reasonable to assert that these results support the psychophysical research on humans which shows involuntary attention having a transient activation and decay, peaking around 110ms; and that voluntary attention requires more than ~200ms. This evidence shows that the differentiation of involuntary and voluntary attention merely on the basis of cue-predictability is incorrect. A human observer cannot conduct voluntary attention shifts prior to ~200ms, so stimulus intervals shorter than this activate involuntary attention which has its own unique "pre-attentive" mechanisms. With invalid cues and non-predictive cueing at stimulus intervals long enough for voluntary attention shifts, voluntary attention is utilized because the subject uses visual search or decision mechanisms to reorient attention in search of the target.

Numerous psychophysical investigations have demonstrated that involuntary attention has a shorter duration and faster activation than voluntary attention with involuntary attention having maximal perceptual enhancement around 120ms and decaying rapidly thereafter (Cheal & Lyon, 1991; Nakayama & Mackaben, 1989; Muller & Rabbitt, 1989), and voluntary attention having maximal perceptual enhancement after 200ms with a very slow decay rate (Carrasco, Ling & Read, 2004; Liu, Fuller & Carrasco, 2006; Liu, Stevens & Carrasco, 2007; Turatto, Vescovi & Valsecchi, 2007). Voluntary attention can be sustained for long periods of time, whereas involuntary attention is brief. Kincade et al. (2005) showed that cueing effects from exogenous attention rapidly decrease as time available to attend increases beyond 150ms, and that cueing effects from endogenous attention increase with time. Their experiment measured reaction time, and not accuracy judgments, but the results are still of interest to the current discussion since it shows that exogenous attention is activated and then deactivated quickly, whereas endogenous attention is more sustained and requires longer processing time to be activated.

In Cheal & Lyon (1991), an experiment was conducted showing slightly better performance with a central cue than a peripheral cue when SOAs were greater than 300ms. This supports the observation that involuntary attention has a maximal perceptual enhancement effect around 100ms, which is briefly maintained (but quickly decreases) until around 300ms or so, at which point the SOA is long enough that voluntary attention is engaged. This further supports the view that involuntary attention is characterized by the length of time between a cue and target, being active at intervals shorter than those sufficient to make a voluntary shift of attention via a saccade (200-250ms). In another study, a cueing effect was found with peripheral cues, revealing a rapid rise in response accuracy with a short SOA, followed by an asymptote around 100ms, and then a continuous decrease in response accuracy from 200ms onward (Nakayama & Mackeben, 1989). While the cueing was entirely predictive in this study, these results still give interesting insight into the time course of involuntary and voluntary attention. This research provides further evidence that a reflexive, involuntary attention system is activated quickly and then decays, and that the maximal perceptual enhancement occurs around 100ms. The researchers concluded that there are two types of attention and that each is characterized by the length of time between the cue and target (Nakayama & Mackeben, 1989). The sustained attention system is voluntarily directed to a region of the visual field, while the transient attention system is reflexive, involuntary, and time locked to the cue. In this experiment, the observers knew that the cue was entirely predictive, and a transient attention cueing effect was observed (even in a condition where the target showed up at the same position every time). Having foreknowledge of the future target location, for which an observer could voluntarily attend to the location since it is already known, didn’t change the rise and fall of the transient cueing effect. The brief performance boost persisted as before, suggesting that it is entirely independent of voluntary control. Therefore the cueing effect observed is most certainly involuntary attention, and any cueing effects beyond the performance boost interval of involuntary attention must therefore be a result of voluntary attention since the cueing effect of involuntary attention decreases rapidly as involuntary attention fades.

In Carrasco & Yeshuran (2009), subjects performed a texture segmentation task using either involuntary or voluntary attention. The involuntary attention task consisted of a 47ms cue, a 47ms ISI, and a 30ms stimulus totaling 124ms before the mask appears. The voluntary attention task consisted of a 200ms cue, a 600ms ISI, and a 30ms stimulus, totaling 830ms before the mask appears. The type of attention utilized is determined by the duration of the stimuli, not on some other factor such as cue predictability. Goal-directed saccades require 200-250ms for execution (Mayfrank et al., 1987), so any duration shorter than this constitutes involuntary attention. In a second task investigating attention in a Landolt gap resolution task, involuntary attention was measured utilizing a 48ms cue, a 72ms ISI, and a 36ms stimulus, whereas voluntary attention was measured utilizing a 300ms cue, a 300ms ISI, and a 36ms stimulus. These two experiments are of particular relevance in that it demonstrates that both forms of attention can be utilized in the same task, and that what differentiates each type of attention is the temporal properties of the stimuli and task. This provides further evidence for the view that involuntary attention is utilized when processing time is limited to less than 200ms, and voluntary attention is utilized when processing time is larger than 200ms.

Voluntary attention is not synonymous with cue validity, nor is it always utilized when a cue is highly predictive. Neither is involuntary attention synonymous with non-predictive cueing. Voluntary attention is instead a volitional orienting, or even a reorienting (still volitional), of visual attention. With non-predictive cues, an experiment isn’t necessarily examining involuntary attention. A non-predictive cue with sufficient time to voluntarily orient attention (~200ms) will initially result in not detecting the target at the cued location (if it’s an invalid cue), but then voluntary shifts of attention are made as the observer voluntarily scans the visual field in search of the target stimulus. So with non-predictive cues where ~200ms or more is available to process the stimuli, what’s actually being investigated is the re-orienting of attention in a voluntary manner once the observer determines that the target is not at the cued location. As a result, an invalid cue will require a longer response time as the subject has to voluntarily re-orient attention in search of the target. If the time available to view the stimulus is too short such that voluntary shifts of attention cannot be made, then involuntary attention is utilized.

To summarize, a cue can be predictive and still involuntary as long as the cue reflexively draws involuntary attention, and does so sufficiently quickly that the observer cannot voluntarily direct attention. A predictive cue will engage voluntary attention if the subject has enough time to volitionally shift attention. Similarly, a non-predictive cue can engage involuntary attention if the time available to attend is shorter than what is required to voluntarily shift attention, and can also engage voluntary attention is enough time is available for the observer to volitionally shift attention. It is for these reasons that in the presently conducted experiments, results are interpreted by differentiating involuntary and voluntary attention based on the length of time available to process the stimuli.

Mechanisms of Involuntary Attention

In addition to the differentiations of voluntary and involuntary attention, there is debate as to what mechanisms specifically lead to task performance enhancement. Each attention system can have unique mechanisms by which performance enhancement occurs. The proposed mechanisms by which a spatial cue can cause perceptual enhancement such as external noise reduction (Dosher & Lu, 2000a, 2000b; Lee et al., 1999; Lu & Dosher, 1998, 2000; Lu, Jeon, & Dosher, 2004; Lu, Lesmes, & Dosher, 2002), accelerated information accrual and processing (Carrasco, Fuller, & Ling, 2008; Carrasco & McElree, 2001; Hein, Rolke & Ulrich, 2006; Herrmann et al., 2010; Liu, Abrams, & Carrasco, 2009; Liu, Wolfgang, & Smith, 2009; Smith et al., 2010; Smith, Lee, Wolfgang, & Ratcliff, 2009; Smith, Ratcliff, & Wolfgang, 2004; Smith & Wolfgang, 2004, 2007; Smith, Wolfgang, & Sinclair, 2004), reduction of decisional noise (Kinchla, Chen, & Evert, 1995; Palmer, 1994; Shiu & Pashler, 1995), and various forms of signal enhancement such as improved visuospatial sensitivity (Cameron et al., 2004; Carrasco & Yeshuran, 2009; Giordano, McElree, & Carrasco, 2009), enhanced spatial resolution (Carrasco, Williams, & Yeshuran, 2002; Carrasco, Loula, & Ho, 2006; Talgar & Carrasco, 2002; Yeshuran & Carrasco, 1998; Yeshuran & Carrasco, 1999; Yeshuran & Carrasco, 2000; Yeshuran & Carrasco, 2008), and increased contrast sensitivity (Carrasco, Penpeci-Talgar, & Eckstein, 2000; Carrasco, Ling, & Read, 2004; Pestilli & Carrasco, 2005) vary extensively depending on stimulus parameters such as the stimulus onset asynchrony, the use of a mask, and the number of target/distractor locations. There is currently a substantial debate as to whether involuntary attention cueing effects occur as a result of perceptual enhancement (via these mechanisms), or instead as a cognitive decision process. Some researchers have proposed that exogenous cueing perceptual enhancements are actually a result of more efficient transfer of visual information into visual short-term memory (Smith, Lee, Wolfgang, & Ratcliff, 2009; Smith, Ratcliff, & Wolfgang, 2004; Smith & Wolfgang, 2004, 2007; Smith, Wolfgang, & Sinclair, 2004). The various proposed mechanisms of perceptual enhancement from involuntary attention are highly debated, and the presently conducted experiments provide insight into this discussion.

Spatial uncertainty reduction

In the 2AFC and 7AFC unmasked cueing studies, analysis of the results indicated that cueing effects were not due to spatial uncertainty reduction as predicted by signal detection theory. Additionally, response bias as a decision mechanism did not account for the observed cueing effects since response bias was either controlled for and/or removed from the results using multinomial modeling. Some researchers have proposed that cueing effects with attention are exclusively a result of a reduction of spatial or location uncertainty (Eckstein, 1998; Foley & Schwartz, 1998; Palmer, 1994; Prinzmetal, McCool & Park, 2005; Solomon, Lavie & Morgan, 1997). When multiple target locations are possible, especially with the presence of distractors, having a cue precede the target could assist the observer by directing attention to a specific location or time, reducing the amount of information, locations, or time duration the observer needs to attend to. While uncertainty reduction does likely contribute to the cueing effect with attention, it doesn't account for all of the perceptual enhancement. It has been shown that decision biases from location uncertainty can modulate cueing effects, but do not produce cueing effects alone (Kerzel, Gauch & Buetti, 2010). In the presently conducted experiments, spatial uncertainty reduction was dismissed as the mechanism of perceptual enhancement for involuntary attention. With response bias decision processes and spatial uncertainty reduction dismissed, the mechanism of improved accuracy judgments is likely one of the signal enhancement mechanisms.

What is it about the features of a reflexive cue that engage involuntary attention and lead to perceptual enhancement? Many investigations into involuntary attention have demonstrated that a salient visual stimulus acts competitively against another target stimulus, even when the target stimulus presentation is part of an engaging cognitive task. Certain properties of this involuntary stimulus draw visual attention resources, usually pulling away attention resources from the less salient target stimulus, which results in lowered spatial resolution and/or sensitivity for the less salient stimulus. In conducting investigations of involuntary attention and cueing, a cue of significant salience is ideal to generate a truly reflexive transient capture of attention. If reflexive orienting of attention is desired, especially a quick involuntary capture of attention, then an optimal cue should be highly salient so as to demand additional resources of the visual system. The presently conducted experiments used highly salient cues to capture involuntary and voluntary attention, resulting in robust cueing effects significantly larger than those reported in the literature.

Mask Dependent Cueing Hypothesis

The most defining characteristic for differentiating voluntary and involuntary attention is the critical time between the cue onset and stimulus onset called the stimulus onset asynchrony (SOA), or between the cue onset and the mask onset if a mask is used. Using a mask eliminates recurrent iconic image processing, for which an observer can continue to access visual information from memory, thereby having extra time to search for the target stimulus even after the image is no longer present on the display or the retina (Sperling, 1960). In the presently conducted experiments with masks, the amount of time the subject has available to process the stimuli is the SOA plus the target duration and inter-stimulus interval (ISI) between the target offset and mask onset.

Some research has shown that a mask is not necessarily required to observe cueing enhancements with involuntary attention (Hendersen, 1996; Carrasco, Penpeci-Talgar & Eckstein, 2000; Carrasco, Williams & Yeshuran, 2002; Carrasco, Ling & Read, 2004; Fuller, Rodriguez & Carrasco, 2008), but others have replicated some of these studies showing that no cueing effect exists without a mask, and have proposed mask dependent mechanisms by which involuntary attention causes perceptual enhancement (Kerzel, Gauch & Buetti, 2010; Prinzmetal, McCool & Park, 2005; Smith, Lee, Wolfgang, & Ratcliff, 2009; Smith, Ratcliff, & Wolfgang, 2004; Smith & Wolfgang, 2004, 2007; Smith, Wolfgang, & Sinclair, 2004). Similar cueing effects are present in experiments where a mask is used (Yeshuran & Carrasco, 1998; Yeshuran & Carrasco, 2008). Some stimulus paradigms result in a substantial cueing effect with and without a mask (Carrasco, Penpeci-Talgar & Eckstein, 2000; Carrasco, Williams & Yeshuran, 2002; Hendersen, 1991; Yeshuran & Rashal, 2010). In the published experiments without a mask, recurrent processing of iconic memory following stimulus offset is rarely considered (or even mentioned) as a factor in potentially increasing the amount of time for which a subject can attend and process information presented. This is however a very important factor which needs to be accounted for since observers could be processing the stimuli beyond the stimulus offset time. For those experiments that do investigate this, cueing effects are claimed to be due to the presence of a masking stimulus (Kerzel, Gauch, Buetti, 2010; Smith, Ratcliff & Wolfgang, 2004). A mask-dependent cueing hypothesis has been proposed by Smith, Ratcliff & Wolfgang (2004). In their experiments, peripheral cues only manifest cueing effects with masked high-contrast gabors, while unmasked, low contrast gabors produced no cueing effects. The proposed mechanism is that attention continues to process presented stimuli in visual short term memory (as similarly proposed by Sperling, 1960), and that using a mask prevents access to iconic memory. The subject therefore adapts to the mask by accelerating information accrual, which gives rise to the cueing effects of having faster response times with valid cues compared to invalid cues.

The use of a mask is a major factor in cueing experiments because of the possibility of recurrent processing. In Fuller, Rodriguez, & Carrasco, (2008), there was no mask and a precue lasted 67ms, followed by a 53ms (varied per trial) SOA, and then a 50ms target and distractor stimulus. The authors assert that involuntary attention was utilized in this task as there was a maximum of 170ms from cue onset to stimulus offset. Since involuntary attention provides the greatest perceptual enhancement around 100-120ms from cue onset, the 50ms target stimulus is presented within the active time window of involuntary attention. While not addressed in the examined literature, these times could be potentially be longer considering that since no mask was used, the iconic image could still be further processed in memory, potentially extending the amount of time available to “search” for the target. This could extend into the length of time necessary for voluntary attention (assumed to be 200-250ms at earliest). This length of additional time however is not known, nor was it considered as a factor in most of the literature on exogenous cueing with non-predictive cues. To study voluntary attention in the same task, a 433ms SOA was implemented, acting as a control condition to compare any cueing effect of involuntary and voluntary attention and providing the subject with more than enough time to voluntarily direct attention to the cued location. The voluntary control condition was also implemented to rule out response bias in the involuntary attention condition, since a response bias would show up in both conditions if present. There was no cueing effect in the control condition, so the cueing effect observed with involuntary attention is not a result of response bias, and is specific to involuntary attention and not to voluntary attention. The authors concluded that involuntary attention does fade quickly (but only tested a 500ms SOA), and that cueing effects of involuntary attention enhance perceptual sensitivity in the absence of a mask.

The results of the present research indicate that cueing effects are not dependent on the presence of a backward mask since both involuntary and voluntary attention improve target detection and/or localization for accuracy judgments devoid of any masking. The results do not dismiss the mechanism of faster information accrual and processing as described in the mask-dependent cueing hypothesis, but rather indicate that cueing effects are not mask dependent. The mechanism of faster information accrual may still operate with low visibility stimuli since the very brief duration of the iconic image of these stimuli may mimic the presence of a mask which otherwise limits access to the iconic memory storage. This is actually a highly probable mechanism that could explain the observed results from these four research investigations.

These investigation show that a perceptual enhancement from non-predictive cueing occurs under conditions of transient, involuntary attention, as well as voluntary ttention and that the cueing effects are not a result of spatial uncertainty reduction. Response bias also cannot account for the results. This research provides valuable insight into the workings of involuntary and voluntary attention and resolves a number of controversies over mechanisms of improved accuracy judgment performance.

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