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Great Expectations: Advance Knowledge and Distractibility

Permalink
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Author
Das, Dipanjana

Publication Date
2021

Peer reviewed|Thesis/dissertation

UNIVERSITY OF CALIFORNIA

Santa Barbara

Great Expectations: Advance Knowledge and Distractibility

A dissertation submitted in partial satisfaction
of the requirements for the degree
Doctor of Philosophy
in Psychological and Brain Sciences
by
Dipanjana Das

Committee in charge:
Professor Barry Giesbrecht, Chair
Professor Emily Jacobs
Professor Scott Grafton
Professor Miguel Eckstein

December 2021

The dissertation of Dipanjana Das is approved.

Miguel Eckstein

Emily Jacobs

Scott Grafton

Barry Giesbrecht, Committee Chair

October 2021

ACKNOWLEDGEMENTS

This work would not have been possible without the support of people in my professional and personal life. I would first like to thank Professor Barry Giesbrecht for his patience, kindness, and encouragement throughout the PhD program. The other graduate students and I in the lab often remark that there are so many times when we are sitting with our research and things don't make sense. But then we go chat with Barry and things make sense again. I am going to miss that.

I would also like to thank the members of my committee, Professor Emily Jacobs, Professor Scott Grafton and Professor Miguel Eckstein for their helpful feedback and support throughout dissertation process.

I would like to express my gratitude and appreciation for Dr. Tom Bullock and Dr. Mary MacLean, who were both instrumental in getting each of my projects off the ground. Aside from being knowledgeable about just about everything research related, they are so fun to talk to and be around. I am also grateful to have gotten to know Cris Garduno, Jordan Garrett, Anne Milner, Dr. James Elliot, Carly Chak, Henri Skinner and Lindsey Purpura. I couldn't have asked for more inspiring, funny, and helpful lab mates. Outside the lab, I would like to thank my cohort mates, especially Youngki Hong, Evan Layher, Spencer Mermelstein and Puneeth Chakravarthula, for always being willing to help out with research and for the much-needed hangouts. I am also grateful for Stella von Meer, Madeleine Gross and Devi Klein for making time to do fun things together. I would like to thank all the research assistants in the lab who helped with data collection and helped me grow as a mentor and person. I would like to thank our collaborator Dr. Søren Kyllingsbæk for his help with data analysis. I would also like to thank Chris McFerron and Katherine Lowe for helping me stay on track with coursework.

I would like to thank my parents for their love and encouragement. I would like to thank my friend Anna Kazatskaya for inspiring me to pursue research. I would also like to thank my dance friends in Santa Barbara and my friends back in New York for keeping me grounded over the last several years. Most importantly, I wish to thank my partner, Robert Moore, for his love, care, and confidence in me which helped me finish this dissertation.

VITA OF DIPANJANA DAS
OCTOBER 2021

EDUCATION

Doctor of Philosophy in Psychological and Brain Sciences, Santa Barbara, December 2021(expected)
Master of Arts in Psychology, The City College of New York, June 2015.
Bachelor of Science in Psychology, The City College of New York, June 2012.

PROFESSIONAL EMPLOYMENT

2021: Summer user experience research intern, Upwork.
2015-2021: Teaching Assistant, Department of Psychological and Brain Sciences, University of California Santa Barbara
2013-2015: Adjunct Lecturer, Department of Psychology, The City College of New York

AWARDS

2017: Kavli Summer Institute Fellow for Cognitive Neuroscience, University of California Santa Barbara
2015: Joseph E. Barmack Award for Outstanding Master's Thesis, The City College of New York
2012: Dean's List-Spring, The City College of New York
2011: Dean's List-Fall, The City College of New York

CONFERENCE PRESENTATIONS

Das, D., & Giesbrecht, B. (2019). Both target and distractor cues elicit spatially selective responses. Abstract accepted at the 20th annual meeting of the Vision Sciences Society, St. Pete's Beach, Florida.

Das, D., & Giesbrecht, B. (2017). Modulation of inhibition as a function of distractor cue validity. Poster presented at the 17th annual meeting of the Vision Sciences Society, St. Pete's Beach, Florida.

Das, D., Kyllingsbæk, S., Bundesen, C., & Giesbrecht, B. (2016). Accurate location information modulates perceptual distraction during search. Poster presented at the 16th annual meeting of the Vision Sciences Society, St. Pete's Beach, Florida.

ABSTRACT

Great Expectations: Advance Knowledge and Distractibility

By

Dipanjana Das

Our visual environment is complex and contains both target and distractor objects. To navigate effectively, an ability to ignore visual distractors is as important as being able to focus on target information. While there has been a lot of research studying target processing, understanding of how distractors are processed is less clear. The goal of this research was to investigate how distractors are processed. In part I, distraction was examined as a function of spatial information available in the display. The motivation for this comparison was to assess predictions made by two theories of attention: Load theory (LT) and Theory of visual attention (TVA). LT posits that attention is allocated in a two-step process with an underlying assumption that spatial information is available pre-attentively. TVA, on the other hand, suggests a one-step attention allocation process, where spatial information needs to be computed or builds up over time. To test these predictions, distraction was compared across displays in which possible target and distractor locations were marked with placeholders, to displays in which no explicit spatial information was provided. If spatial information is available pre-attentively, providing spatial information should make no difference in distraction. Results from four experiments show reduced distraction when spatial information was provided compared to when it was not. This showed that spatial information is not available pre-attentively and in the absence of any expectation or bias, all objects are processed simultaneously. In part II, the extent to which advance knowledge of distractor location impacts distractor processing was examined. This study was motivated by 1) mixed evidence of reduced distraction when a cue indicates the location of an upcoming distractor, 2) mixed evidence for whether distractor cue leads to inhibition at the cued location and 3) lack of knowledge around how a distractor cue compares to target cue in impacting behavior. Results show some benefit of cueing the location of the distractor- reduced distraction as a function of distractor cue was seen in one out of three experiments. Cueing the target showed the most clear impact on behavior. Finally, there was no evidence that any benefit observed from distractor cueing was due to inhibition at the cued location.

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Chapter I

The daily visual environment for human beings contains both goal-relevant and goal-irrelevant objects. In traversing these complex environments, an ability to ignore visual distractors is as consequential as being able to focus on goal-relevant or target information. While there has been a lot of progress in studying how target information is processed (Buschman & Kastner, 2015; Desimone & Duncan, 1995; Reynolds & Heeger, 2009), understanding of how distractors are processed remains less clear (van Moorselaar & Slagter, 2020).

The purpose of this study was to understand how distractors are processed. Distractor processing was examined in two parts: 1) as a function of spatial information available in the search display and 2) as a function of expected distractor location.

In part I, distraction was compared across two kinds of displays, one in which all possible target and distractor locations were marked using placeholders and another display in which target and distractor locations were not marked. The motivation for this comparison was to test predictions made by Load theory of attention (Lavie, 1995) and Theory of Visual Attention (Bundesen, 1990) which have divergent assumptions about how distractors are processed. Assessing these assumptions using empirical data would facilitate understanding of when and how distractors are processed, relative to targets. There are four experiments in this part.

In part II, distractibility was measured as a function of advance knowledge of distractor location in a visual search task. There has been a lot of evidence showing that advance knowledge of target location facilitates target processing. However, there is mixed evidence as to whether advance spatial knowledge hinders or facilitates processing of distractors or what the underlying neural mechanism might be. The purpose of this study was to examine these questions as well as to compare how expectation of distractor and target location impact behavior. There are three experiments in this part.

Chapter II

Introduction

A long-standing debate in understanding how distractors are processed has been about *when* they are processed (for a recent review see Murphy et al., 2016). According to one view, due to limited perceptual processing capacity only attended objects are perceived and distractors are filtered out at an early stage. This early-selection view posits that incoming information is selected based on physical features or locations (Broadbent, 1958; Treisman, 1969). An alternative view is that selection occurs later in the processing timeline. This late-selection view posits that perception is of unlimited capacity and both relevant and irrelevant stimuli are automatically and indiscriminately processed to the post-perceptual stage. The selection mechanism then extracts the task relevant information from these more completely processed representations and excludes distracting representations from being further encoded and thus minimizing their impact on behavior (Deutsch & Deutsch, 1963; Duncan, 1980). There has been a lot of evidence in support of both early selection (Francolini & Egeth, 1980; Yantis & Johnson, 1990) and late selection (Eriksen & Eriksen, 1974; Tipper & Driver, 1988).

Load theory (LT; (Lavie, 1995) was a model that explained the discrepancy between early and late selection perspectives, by suggesting that selection was determined by the perceptual load of the task. LT provides a compelling perspective of how we process distractors in the environment. Similar to the early-selection perspective, LT states that perception is a limited capacity process. Like the late-selection perspective, perception proceeds automatically until perceptual capacity is full. Critically, according to LT, perceptual load is the determinant of how processing capacity is allocated to task-relevant objects instead of task-irrelevant objects. Furthermore, allocation of processing capacity occurs in two steps: 1. Resources are allocated to task-relevant stimuli first 2. Any left-over resources spill over to task-irrelevant stimuli. This mechanism leads to two main predictions. First, distraction is lower in high perceptual load conditions, since all processing capacity is engaged by task-relevant stimuli leaving no spare capacity for processing task irrelevant stimuli. Second, distraction is higher in low perceptual load conditions because processing capacity does not get fully used by task-relevant stimuli, which then spills over to task-irrelevant stimuli causing distraction. These predictions have been corroborated by evidence from behavioral studies showing reduced flanker effects under conditions of high perceptual load (Lavie, 1995; Lavie & Cox, 1997) as well as neuroimaging evidence showing reduced processing of distractors under high load (Rees et al., 1997).

Despite the intuitiveness of the predictions, there have been several criticisms of this theory. First, perceptual load has been hard to operationalize (Giesbrecht et al., 2014; Tsal & Benoni, 2010). Lavie & Tsal (1994) acknowledge that perceptual load includes two components that are not easily defined- the number of units in the display and the nature of processing required for each unit. Units are thought not to be basic perceptual units but rather items that serve as different alternatives for the relevant response in the task. The number of units are thought to provide the level of perceptual load, but perceptual load also correlates with the amount of information required to process each unit to produce the required response. It is not clear from this description what the precise units are. More recent definitions of perceptual have not been any more precise. Lavie (2005) suggests that increased perceptual load means that either the number of different-identity items that need to be perceived is increased or that for the same number of items perceptual identification is more demanding. However, it is suggested that high perceptual load is not equivalent to an increase in task difficulty or data limitation via manipulating contrast or size, but rather attention “resource limits.” Since a precise definition of resource limits is not provided, it is hard to know how to manipulate load in an independent way in experiments. The lack of a precise definition of perceptual load has led to experimental findings being misattributed in favor of load theory when they do not meet the criteria for perceptual load manipulation as outlined by LT. For example, Handy et al., (2001) used noise masking to show reduced neural responses to distractors under increased task difficulty conditions. This finding has been cited in favor of LT (Lavie, 2005) even though noise masking is generally considered to be a data-limited manipulation (Breitmeyer & Öğmen, 2006) and, according to LT, should not increase perceptual selectivity.

There has also been evidence contrary to the notion of automatic allocation of attention driven solely by perceptual load. For example, spatial cues predicting target location have been shown to reduce distraction in low load conditions (Johnson et al., 2002). Mixing high and low load displays have been shown to increase distraction in high load displays, which contrasts what load theory predicts (Theeuwes et al., 2004). Furthermore, a cue validly predicting task demand has been shown to reduce distraction, even under low load conditions (Sy et al., 2014). Similarly, the number and discriminability of flankers presented have also shown to impact distraction independently of load (Kyllingsbæk et al., 2011). Thus, the idea the perceptual load solely determines attention outcomes has been questioned, since the factors mentioned above also modulate distraction.

The current study aims to examine another assumption embedded within load theory. The idea that resources go sequentially from task-relevant to task irrelevant stimuli assumes that humans are aware of where task-relevant and task-irrelevant locations are at all times or at least at the start of the task. In other words, load theory assumes pre-attentive spatial knowledge in how attention is allocated. However, there is a class of theories that do not make the assumption that spatial information about task-relevant and task-irrelevant objects is available pre-attentively. For example, theory of visual attention (TVA; (Bundesen, 1990)) suggests that visual processing is a competitive race between different categorizations of stimuli in visual field. Processing capacity, which is fixed and limited, is allocated to objects based on initial computation of attentional weights. The categorizations that win the race first are encoded into a limited visual working memory store. After visual working memory capacity has filled up, no other information is encoded. Critically, allocation of processing capacity is based on attentional weights computed for both task-relevant and task-irrelevant stimuli. Unlike LT, there is no process of capacity going to task-relevant stimuli first followed by a spill over to task-irrelevant stimuli (Giesbrecht et al., 2014). Finally, the assumption underlying TVA is that spatial information is not available pre-attentively and builds up over time. TVA is part of a broad class of models that are based on such assumptions, including biased competition model (Desimone & Duncan, 1995), normalization model (Reynolds & Heeger, 2009), visual attention model (Schneider, 1995) and signal detection model ((Eckstein, 1998; Eckstein et al., 2000). Common through each of these models is the idea that target and distractor features are weighted differently, but simultaneously, in a one-step process.

The current study aims to examine the assumptions about the availability of spatial information made by LT and TVA. To reiterate, in LT, the amount of distraction experienced is explained solely by perceptual load. In low perceptual load, task-relevant stimuli do not use all processing capacity, which then spills over to task-irrelevant stimuli, causing distraction. In high perceptual load, capacity is used up by task-relevant stimuli, leaving no resources for task-irrelevant stimuli, thus preventing or reducing distraction. This mechanism assumes that humans know where the task-relevant and task-irrelevant locations are at all times. By contrast, in TVA, distraction is determined by a competitive race between all objects in visual, task-relevant and task-irrelevant. This mechanism assumes that spatial information is not available pre-attentively and immediately capable of biasing processing, but rather builds over time. To test these assumptions, the distinctiveness of the spatial information available about targets and distractors in a visual search task was manipulated to examine its impact on distraction. If spatial information is available pre-attentively, as LT suggests, there should be no difference in distraction between conditions in which spatial information is made salient versus when it is not. On the other hand, if spatial information builds up over time, as TVA suggests, distraction should be less in a condition where spatial information is made salient compared to when it is not. Over four experiments, performance was compared in a visual search task typically used in LT experiments, while manipulating the availability of spatial information of task-relevant and task-irrelevant stimuli with placeholder circles.

In LT experiments, typically the task used is a hybrid between a visual search task and a flanker task (Lavie, 1995; Lavie & Cox, 1997). There are two types of task-displays. In some studies, the task- relevant search locations are on the horizontal meridian with the task-irrelevant location above or below the task-relevant area (Lavie, 1995). In other studies, the task-relevant locations are on an imaginary circle around a central fixation cross. Task-irrelevant location is on the left or right side of the imaginary circle (Forster & Lavie, 2007, 2009; Lavie & Cox, 1997). As discussed earlier, LT does not precisely define perceptual load. Perceptual load is manipulated by varying the number of letters presented in the task-relevant search location or by manipulating the difficulty of discrimination between search items. The lack of a definition makes it hard for perceptual load manipulation to be independently verifiable, thus, making results hard to interpret (Benoni & Tsal, 2013). Participants' task in these experiments is to identity a target letter presented in the task-relevant search location, presented alone (low load) or with other letters (high load), while ignoring a letter appearing in the task-irrelevant location. Critically, like a classic flanker task, the identity of the irrelevant letter could either be congruent or incongruent to the target letter. Interference is measured as the difference between congruent and incongruent trials, which is the standard flanker effect.

The current experiment adopted a hybrid visual search task as is used in LT experiments. Perceptual load was manipulated by varying the number of letters presented, with more letters corresponding to higher perceptual load. Motivation for using this manipulation was to simplify comparison to previously published LT experiments. The task-relevant locations were positioned around an imaginary circle while the task-irrelevant locations were on either side of the imaginary circle on the horizontal meridian. There were two additional manipulations. First, the exposure duration of the items presented for search was varied and any further processing was terminated using masks. This was done to examine how processing time impacts distraction. Second, the irrelevant flanker could either be presented on the left or right of the task-relevant search location, or not at all. The flanker absent condition was included to examine how number of flankers impact distraction. This was motivated by previous research that had shown that the number of targets reported in a partial report task was modulated by the number of flankers presented (Giesbrecht et al., 2014; Kyllingsbæk et al., 2011). These additional variables were added to also allow computational modeling of the data, which will not be discussed in the current paper. The task as described above was called the no placeholder condition. In the placeholder condition, everything was the same as the no placeholder condition, except circular placeholders indicated the location of all task-relevant and task-irrelevant locations throughout a trial.

Outline of experiments

In experiment 1, performance on a hybrid visual search task (e.g. Lavie, 1995) was compared while manipulating availability of stimulus location information in the task. Six participants were tested on a version with placeholder circles, that provided location of task-relevant and task-irrelevant stimulus. Another six participants were tested on the task without placeholder circles, thus, without explicit stimulus location information. Each participant completed 3456 trials, so this experiment was similar to a psychophysical study. Experiment 2 replicated experiment 1 and also accounted for confounding some factors. In experiment 3, performance was measured in a colored placeholder condition, in which task-relevant and task-irrelevant stimulus locations were further differentiated by colored placeholder circles. Blue placeholder circles were used to indicate task-relevant locations, while red placeholder circles were used for task-irrelevant locations. Thirteen participants were tested in this experiment. Performance in the colored placeholder condition was compared to performance in both placeholder and no placeholder conditions from experiments 1 and 2. These conditions allowed us to measure how incremental changes in stimulus location information effects performance. Experiments 1-3 were between-subject experiments, with self-paced tasks in which participants were instructed to prioritize accuracy in completing the tasks. In experiment 4, performance on a speeded version of the placeholder and no placeholder tasks was assessed. This was a within-subjects design in which each participant was tested on both the placeholder and no placeholder tasks. Both response time and accuracy were measured. Sixty-two participants were tested for this experiment. Detailed information on the methods of each of these experiments can be found below.

Experiment 1

In experiment 1, performance in the no placeholder condition was compared to the placeholder condition.

Method

Participants. Six participants (mean 22.5 years old, 4 females) at the University of Copenhagen, Denmark volunteered to be tested in the no placeholder condition. Another six participants (mean 23 years old, gender breakdown not available) at the University of California, Santa Barbara were recruited to be in the placeholder condition. Participants were paid $20/hour (6 hours total) for their participation. All participants had normal or correct-to-normal visual acuity.

Stimuli. No Placeholder condition: Stimulus presentation was controlled using Psychtoolbox 3.0.12 (Kleiner, Brainard, Pelli, 2007) scripts written in MATLAB (Mathworks, Inc., Boston, MA). A monitor (36.5cm x 27.5cm) was used to present stimulus. The task consisted of four displays: fixation, search, mask and response. All displays (1024 x

768 pixels) were presented on a gray background (RGB:127 127 127). In the fixation display, a fixation cross (0.29° X 0.29° visual angle) was presented in the center of the screen. In the search display, task-relevant and task-irrelevant search letters were presented along the circumference of an imaginary circle. There were up to six task relevant search locations (60°, 90°, 120°, 210°, 240°, 270°) that were arranged in an imaginary circle approximately 3° visual angles away the fixation cross. There were also two possible task irrelevant locations (0°, 180°), 3.58° visual angle away from the fixation cross, horizontally to its right or left (Figure 1a). All search letters (XZVWNKM) were white and upper case and approximately 0.48° X 0.43° visual angle in size. Presentation of search letters was followed by pattern masks approximately 0.24° in size. The response display consisted of a prompt asking participants to respond by clicking the mouse. The viewing distance from the monitor to the participant was 120 cm.

Placeholder condition: Stimuli used in this condition were identical to the no placeholder condition. The only addition was the presence of placeholder circles (0.95° X 0.95° visual angle) that identified all possible task-relevant and task-irrelevant positions in the display. These placeholders were present throughout the duration of a trial, except for the response display (Figure 1b).

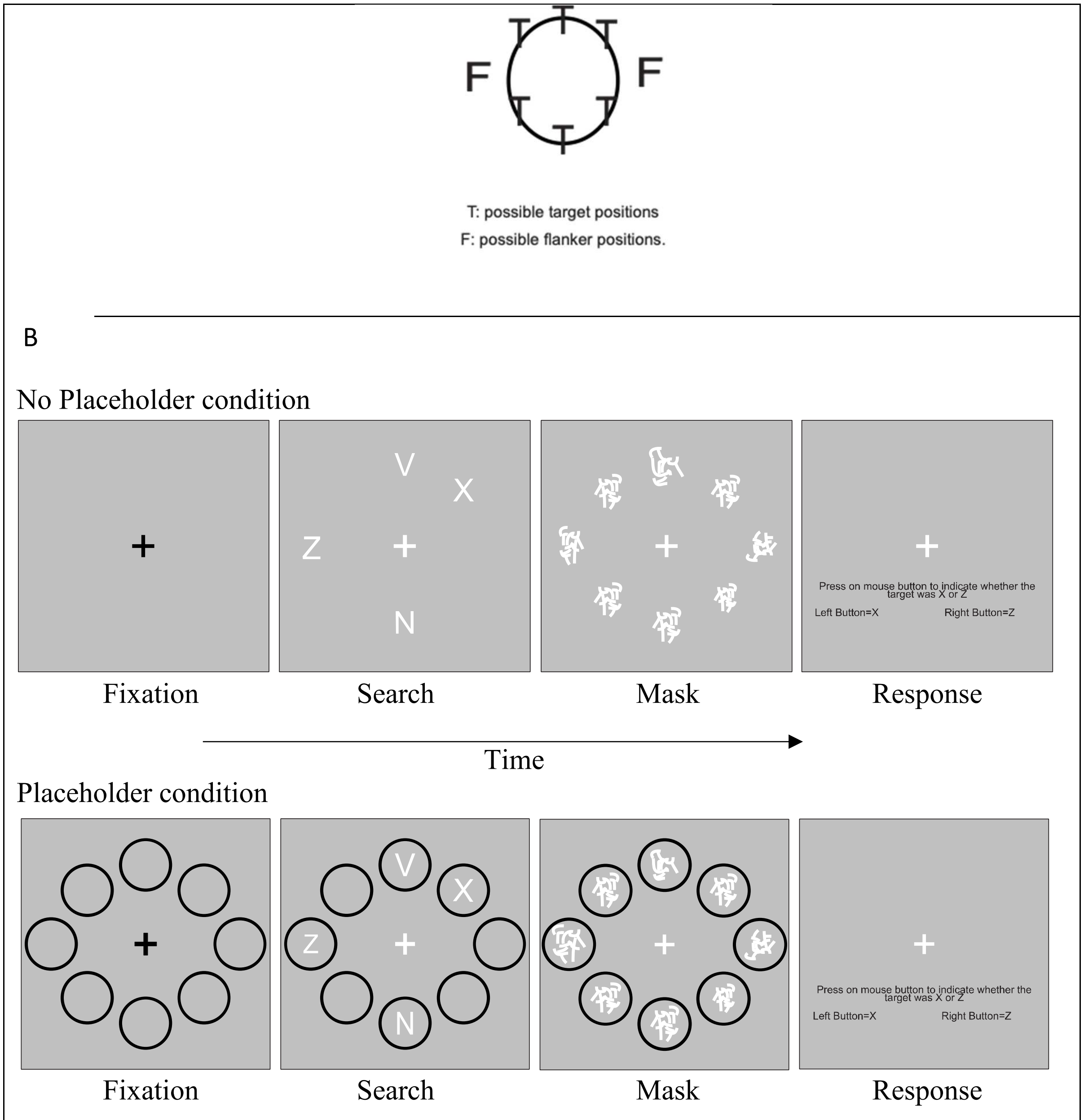

Figure 1. A shows schematic respresentation of task relevant and task-irrelevant locaitons in the task search display. B shows example of a trial sequence in the no placeholder and placeholder conditions in experiment 1.

Procedure. The tasks in both the placeholder and no placeholder conditions were un-speeded and self-paced: participants were instructed to press the space bar on the keyboard to begin the presentation of trials. Each trial began when the fixation cross changed color from black to white upon keyboard press. In the no placeholder condition, the search letters were then presented for 20 ms, 60 ms, 120 ms or 240 ms. In the placeholder condition, search letters were presented for 17 ms, 67 ms, 117 ms or 233 ms. The reason for the slight difference in exposure duration was due to the difference in the refresh rate of the monitors used for stimulus presentation. The no placeholder condition task was run on a monitor with a refresh rate of 100Hz, while the placeholder condition task was run with a refresh rate of 60 Hz. Presentation of the search letters was followed by pattern masks for 500ms. Finally, participants were prompted to respond by pressing a mouse button. On each trial, participants had to discriminate between target letters X or Z presented in the task-relevant locations of the display, while ignoring flanker letters X or Z presented in the task-irrelevant locations. Participants were instructed to be as accurate as possible in their response. Eye movements were monitored throughout the duration of the experiment using an eye tracker device (Eyelink 1000 plus, SR Research Ltd, Mississauga, Ontario, Canada; 1000Hz refresh rate). Each participant was tested over six separate, one-hour sessions.

Design. There were five key manipulations. First, the amount of the spatial information available in each task was manipulated by using placeholder circles. Second, in both placeholder and no placeholder conditions, the perceptual load of the tasks was varied by using displays of different set sizes. Set sizes of one, two, three and six letters, excluding flankers, were used in this study. Third, the flanker letters in the task-irrelevant locations in the display could either be present or absent. Fourth, flankers, when present, could be either congruent to the target letter or incongruent. Finally, the exposure duration of the search display was varied between 17ms and 240ms. Counterbalancing across all levels as well as search locations resulted in 3456 trials each in both the placeholder and no placeholder conditions.

Data analysis. There were n=6 participants each in both no placeholder and placeholder conditions. Trials faster than 200ms and slower than 1500ms were discarded. Trials with saccades were not used in analyses. Data from session 1 for participant 1 (noisy data) and session 6 for participant 6 (data not available) in the placeholder condition were not used in analyses. Participant 6 in the no placeholder condition did not have eye movement data and thus no trials were removed due to saccade. Only congruent and incongruent trials were used in the analysis to simplify comparison to load theory experiments. Trials in the distractor absent condition were included in the design for different purpose, which is outside of the scope of this study. In reporting hypothesis testing, for effects that violate sphericity, Greenhouse-Geisser corrected F values are reported. The Holm-Bonferroni correction for multiple comparisons was used for post-hoc tests in all analyses (Holm, 1979).

Results

The flanker effect (congruent- incongruent) was used as the index for distraction for both no placeholder and placeholder conditions. If spatial information is available pre-attentively (Load theory), then availability of spatial information in the placeholder condition should make no difference in distraction and the flanker effect should be the same in both the placeholder and no placeholder conditions. If on the other hand, spatial information builds up over time (Theory of visual attention), then availability of spatial information in the placeholder condition (Figure 3) should lead to reduced distraction- and reduced flanker effect- in that condition compared to the no placeholder condition (Figure 2).

To unpack the effect of spatial information on distraction, a mixed factorial ANOVA was conducted with spatial information (no placeholder, placeholder) as between-subjects factor and set size (1,2,3 and 6), congruency (congruent, incongruent) and exposure durations (no placeholder: 20ms, 60ms, 120ms, 240ms, placeholder: 17ms, 67ms, 117ms, 233ms) as within-subjects factors. There was a main effect of set size ($F(3,30)=73.10$, $p<.001$, MSE=.40,partial $\eta_p^2=.88$), such that accuracy decreased as set size increased, averaged across congruency and exposure duration in both no placeholder and placeholder conditions. There was a main effect of congruency ($F(1,10)=12.90$, $p<.01$, MSE= .36,partial $\eta_p^2=.56$), such that accuracy was higher on congruent compared to incongruent trials, averaged across set size and exposure duration in both no placeholder and placeholder conditions. There was a main effect of exposure duration (F(3,30)=321.70, $p<.05$, MSE=2.30, partial $\eta_p^2=.97$), such that performance increased with increasing exposure duration. There was an interaction between set size and exposure duration ($F(9,90)= 10.91$, $p<.001$, MSE=.03, partial $\eta_p^2=.52$), such that performance was lowest at the shortest exposure duration across all set size. For all other exposure durations, performance decreased with increasing set size. Critically, there was a significant interaction between congruency and spatial information ($F(1,10)=6.00$ $p<.05$, MSE=.17, partial $\eta_p^2=.38$). A post-hoc test showed that while there was a significant flanker effect in the no placeholder condition (congruent- incongruent=.10, SEM=.02, $t=4.27$, $p<.05$), there was no flanker effect in the placeholder condition (congruent-incongruent= .02, SEM=.02, $t=.81$, $p<.05$).

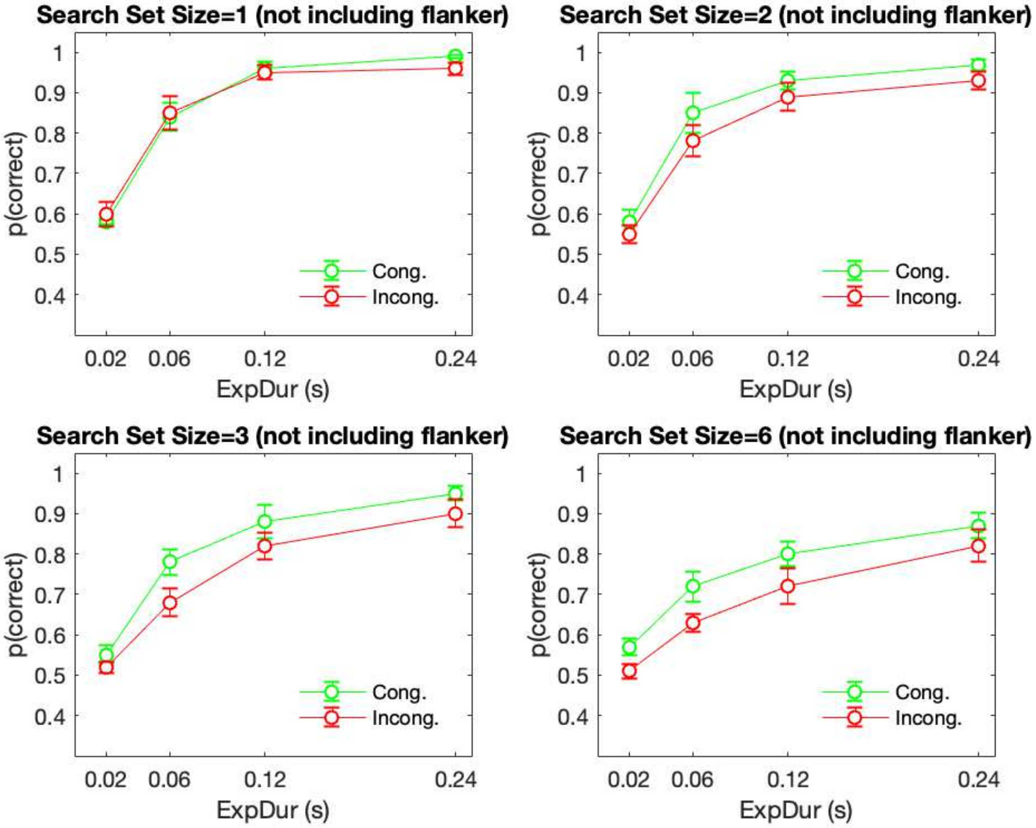

Figure 2. Percent correct as a function of congruency, set size and exposure duration in the no placeholder condition (Experiment 1). Error bars in this and subsequent figures represented ±1 SEM.

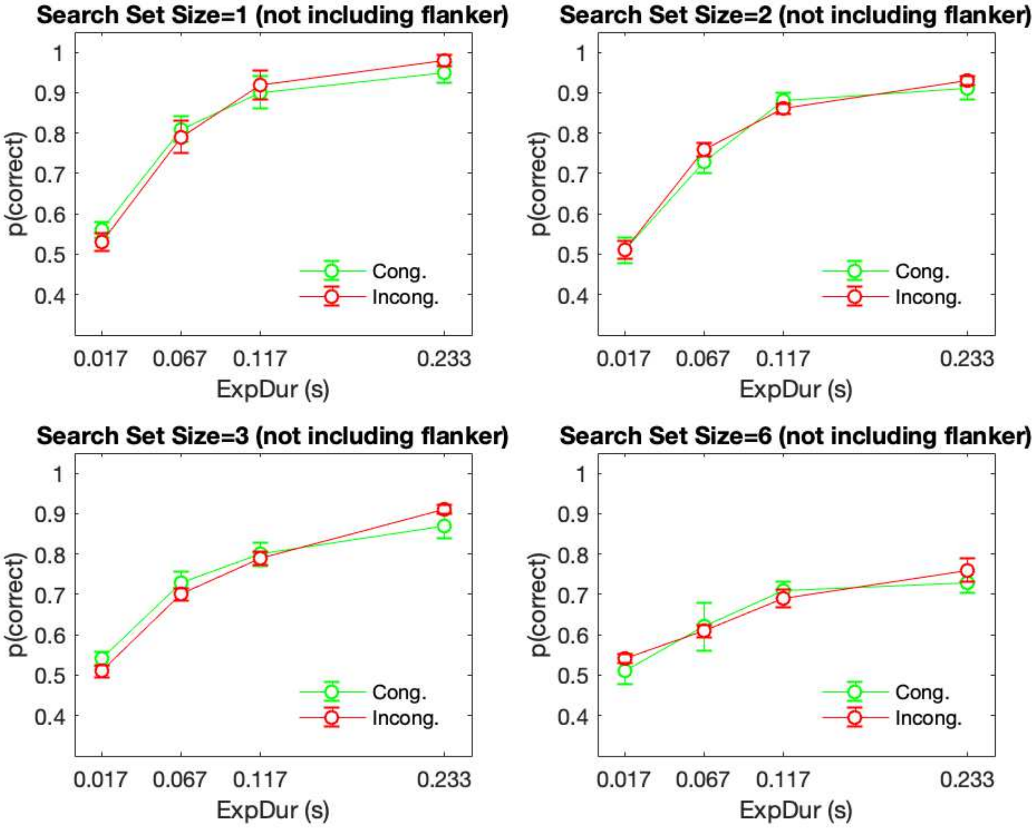

Figure 3. Percent correct as a function of congruency, set size and exposure duration in the placeholder condition (Experiment 1).

Discussion

LT (Lavie, 1995) suggests that spatial information about task-relevant and task-irrelevant objects are available pre-attentively. Thus, there should be no difference in performance in a visual search task in which spatial information is made salient versus when it is not. On the other hand, TVA (Bundesen, 1990) posits that spatial information of task-relevant and task-irrelevant objects is not available pre-attentively and builds up over time. Thus, in this scenario, availability of spatial information in a visual search task should improve performance. The current study tested these predictions. In experiment 1, availability of spatial information in hybrid visual search task was manipulated using placeholder circles. In the no placeholder condition, participants were informed where the task-relevant and task-irrelevant locations were and instructed to identity a target letter appearing in the task-relevant location while ignoring any flanker letter appearing in the task-irrelevant location. In the placeholder condition, task-relevant and task-irrelevant locations were made explicit through placeholder circles that were present throughout a trial. Comparison of accuracy between these conditions showed three key findings. First, accuracy decreased as set size increased. This is to be expected since participants had to locate the target among a greater number of non-target letters (Palmer et al., 1993). Second, performance was higher on congruent trials compared to incongruent trials, which is the standard flanker effect (Eriksen & Eriksen, 1974). Finally, flanker effect was reduced in the placeholder condition compared to the no placeholder condition. This suggests that availability of spatial information regarding task-relevant and task-irrelevant objects helped reduce the automatic distraction caused by the irrelevant flanker in the placeholder condition. This provides evidence for the assumption made by TVA that spatial information is not available and needs to be computed.

Experiment 2

Experiment 2 aimed to replicate the findings of experiment 1. The differences in the exposure durations of the search display in Experiment 1, were also accounted for here. Finally in experiment 2, participants were randomly assigned to either the placeholder or no placeholder conditions.

Method

Participants. Twelve volunteers (mean age 20.75 years old; gender data not available) from the University of California, Santa Barbara were randomly assigned to either the placeholder or no placeholder conditions. All participants were paid \$20/hour for their participants. All procedures conformed to a protocol approved by the Institutional Review Board at the University of California, Santa Barbara.

Stimuli, Procedure and Design. All aspects of this experiment were the same as Experiment 1. The only difference was that unlike experiment 1, the exposure durations for the search letters were 17ms, 67ms, 117ms or 233ms for both tasks. With this replication, the goal was to make sure that the discrepancy in exposure durations between the placeholder and no placeholder tasks in experiment 1 did not substantially change performance.

Data analysis. All procedure same as experiment 1. No participants' data were discarded. There were six participants each in no placeholder and placeholder conditions.

Results

In experiment 1, the flanker effect was compared in the no placeholder (Figure 4) and placeholder conditions (Figure 5). A mixed factorial ANOVA, with spatial information (no placeholder, placeholder) as a between-subject factor and set size (1,2,3 and 6), congruency (congruent, incongruent) and exposure duration (17-233ms) as the within- subject factor, was performed. There was a main effect of set size (F (3,30) =74.44, $p<.001$, MSE=.35, partial $\eta_p^2=.88$) such that accuracy decreased with increasing set size, averaged across congruency, exposure duration and spatial information. There was a main effect of exposure duration ($F(3,30)=174.66$, $p<.001$, MSE= 2.25, partial $\eta_p^2=.95$), such that performance increased with increasing exposure duration. There was a set size by exposure duration interaction

($F($9,90)=13.05, p<.001, MSE= .041, partial η_p^2=.56), such that accuracy was lowest at the shorted exposure duration across all set sizes. For all other exposure durations, accuracy decreased with increasing set size. There was also a set size by congruency by exposure duration interaction ($F($9,90)=2.52, p<.05, MSE=.01, partial η_p^2=.20), such that the flanker effect was low across all set sizes in the two long exposure durations compared to the two short exposure duration. Critically, there was an interaction between set size, congruency and spatial information (F(3,30)= 2.96, p<.05, MSE=.01, partial η_p^2=.23), such that the flanker effect was reduced in the low set sizes in the placeholder condition compared to the no placeholder condition. This finding shows that having spatial information reduces distraction, especially in low perceptual load conditions where participants are most prone to distraction.

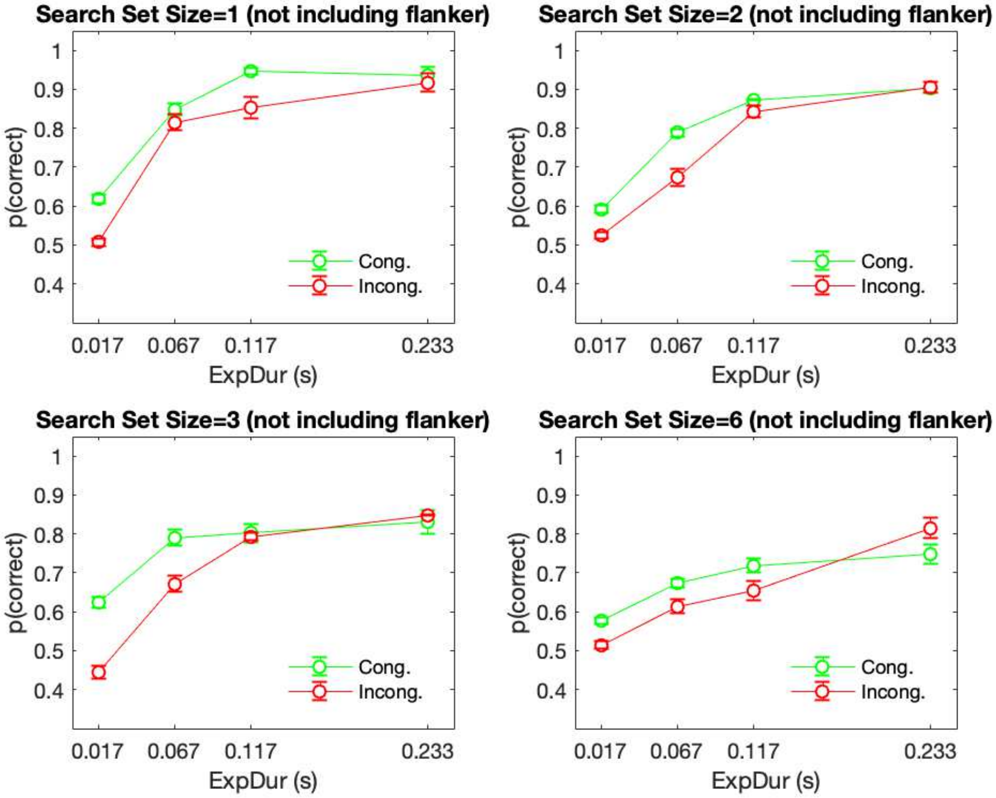

Figure 4. Percent correct plotted as function of set size, congruency and exposure duration in the no placeholder condition (experiment 2).

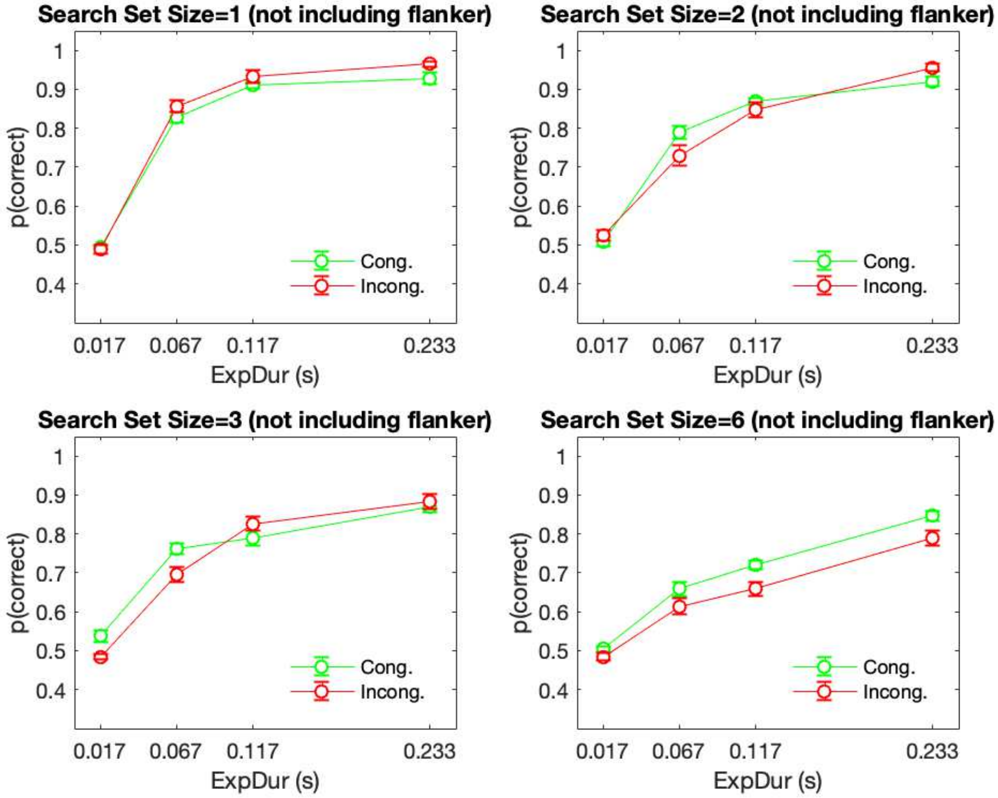

Figure 5: Percent correct plotted as function of set size, congruency and exposure duration in the placeholder condition (experiment 2).

Discussion

Experiment 2 replicated the results of experiment 1, while also controlling for the confound created by the different exposure durations used in no placeholder and placeholder conditions in experiment 1. As before, accuracy decreased as set size increased. Accuracy was higher on congruent compared to incongruent trials. Critically, the flanker effect was reduced in the lower set sizes of the placeholder condition, which according to load theory, are most susceptible to distraction by irrelevant flanker. This finding again shows that spatial information about task-relevant and task-irrelevant objects is not available pre-attentively but is beneficial when made salient.

Experiment 3

In experiment 3, the location of task-relevant and task-irrelevant items were marked by different colored placeholders. The motivation for this manipulation was to test how further distinguishing the locations of the task-relevant from task-irrelevant items impacted performance.

Method

Participants. 13 participants (mean 20.08 years old, gender breakdown not available) at the University of California, Santa Barbara volunteered to be tested in this experiment. Participants received research credits for their participation. All participants had normal or correct-to-normal visual acuity. All procedures conformed to a protocol approved by the Institutional Review Board at the University of California, Santa Barbara.

Stimuli. The stimulus presentation in this experiment was identical to placeholder task in experiment 2, with one key difference. In the current experiment, task-relevant locations were marked by a blue-colored (RGB: 17 103 241) circular placeholder. The task-irrelevant locations were marked by a red-colored (RGB: 233 0 0) circular placeholder (Figure 6).

Procedure and Design. All aspects of this experiment were identical to the placeholder task in Experiment 2.

Data analysis. In experiment 3, performance in colored placeholder condition was compared to the no placeholder (compiled from experiments 1 and 2) and placeholder conditions (compiled from experiments 1 and 2) separately. All other procedures remained the same as experiments 1 and 2. There were n=13 participants in the colored placeholder condition, n=12 participants in the no placeholder and n=12 participants in the placeholder condition.

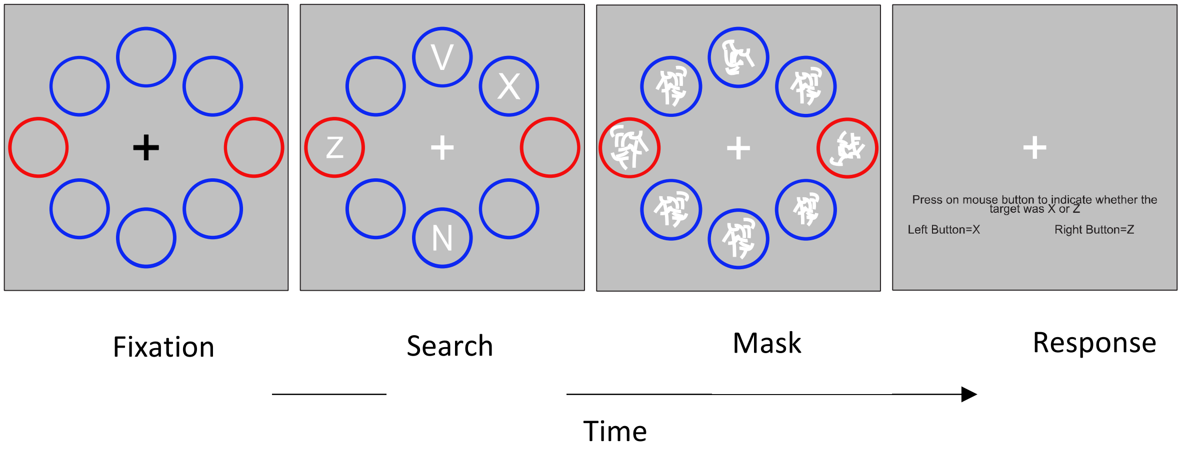

Figure 6. Shows schematic representation of a trial sequence in the colored placeholder condition.

Results

First, the flanker effect was compared between no placeholder (Figure 7) and colored placeholder conditions (Figure 8). A mixed factorial ANOVA, with spatial information (no placeholder, colored placeholder) as the between-subject factor and set size (1,2,3 and 6), congruency (congruent, incongruent) and exposure duration as within-subject factor, was performed. There was a main effect of set size ($F(3,69)=146.84$, $p<.001$, MSE=.80, partial $\eta_p^2=.87$) such that accuracy decreased with increasing set size. There was a main effect of congruency ($F(1,23)= 9.38$, $p<.01$, MSE=.40, partial $\eta_p^2=.29$), such that accuracy was higher on congruent compared to incongruent trials. There was a main effect of exposure duration ($F(3,69)= 399.55$, $p<.001$, MSE=4.21, partial $\eta_p^2=..95$), such that accuracy increased with increasing exposure duration. There was an interaction between congruency and exposure duration (*F(*3,69)=3.42, *p*<.05, MSE=.04, partial η_p^2=.13) such that the flanker effect was reduced with increasing exposure duration. There was an interaction between set size and exposure duration (*F(*9,207)= 17.87, *p*<.001, MSE=.08, partial η_p^2=.44), such that accuracy was lowest at the shortest exposure duration (17ms/20ms) across all set sizes, averaged across congruency and spatial information. Across all other exposure duration, performance decreased as the set size increased. Critically, there was an interaction between congruency and spatial information (*F(*1,23)=5.45, *p*<.05, MSE=.23, partial η_p^2=.19). A post hoc test showed that while there was a significant flanker effect in the no placeholder condition (congruent- incongruent= .08, se=.02, t=3.74, *p*<.01) there was no reliable flanker effect in the colored placeholder condition (congruent-incongruent= .01, SE=.02, t=.53, *p*<.05).

Second, placeholder (Figure 9) and colored placeholder conditions were compared to understand how the increased spatial information in the colored placeholder condition impacted distractibility. Motivation for this analysis was to understand whether having colored placeholders provided any additional benefits in reducing distraction beyond the placeholders used in experiments 1 and 2. A mixed factorial ANOVA with spatial information (placeholder, colored placeholder) as the between subject factor and set size (1,2,3 and 6), congruency (congruent, incongruent) and exposure duration (20ms,60s,120ms and 240ms) as the within-subject factor, was performed. There was a main effect of spatial information (*F(*1,23)= 4.70, *p*<.05, MSE= .53, partial η_p^2=.17), such that accuracy was higher in the colored placeholder condition compared to the no placeholder condition. There was a main effect of set size (*F(*3,69)=211.02, *p*<.01, MSE=.84, partial η_p^2=.90), such that performance decreased at set size increased. There was a main effect of exposure duration

($F(3,69)=450.62$, $p<.001$, MSE=4.59, partial $\eta_p^2=.95$) such that accuracy increased with increasing exposure duration in both placeholder and colored placeholder conditions. There was an interaction between set size and exposure duration ($F(9,207)=22.83$,$p<.001$, MSE=.08, partial $\eta_p^2=.50$) such that accuracy was lowest at the shortest exposure duration (20ms). For all other exposure durations, performance decreased as set size increased, for both placeholder and colored placeholder conditions. Finally, there was an interaction between congruency and exposure duration ($F(3,69)=4.38$, $p<.01$, MSE=.02, partial $\eta_p^2=.16$), such that there was a negative flanker effect (incongruent> congruent) at the longest exposure duration. However, the flanker effect was not significant at any exposure duration.

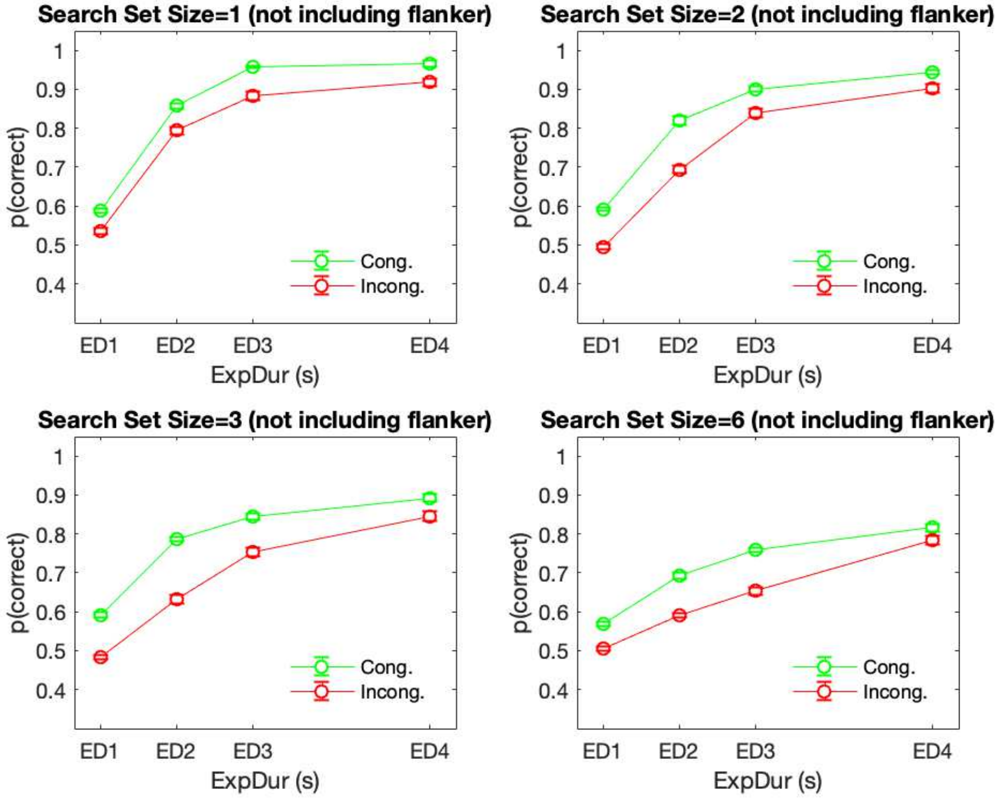

Figure 7: Percent correct plotted as function of set size, congruency and exposure duration in the no placeholder condition. This plot combines the no placeholder data from experiment 1 and 2. Since those experiments had slightly different exposure durations during the search period, exposure duration is labeled as ED in this plot.

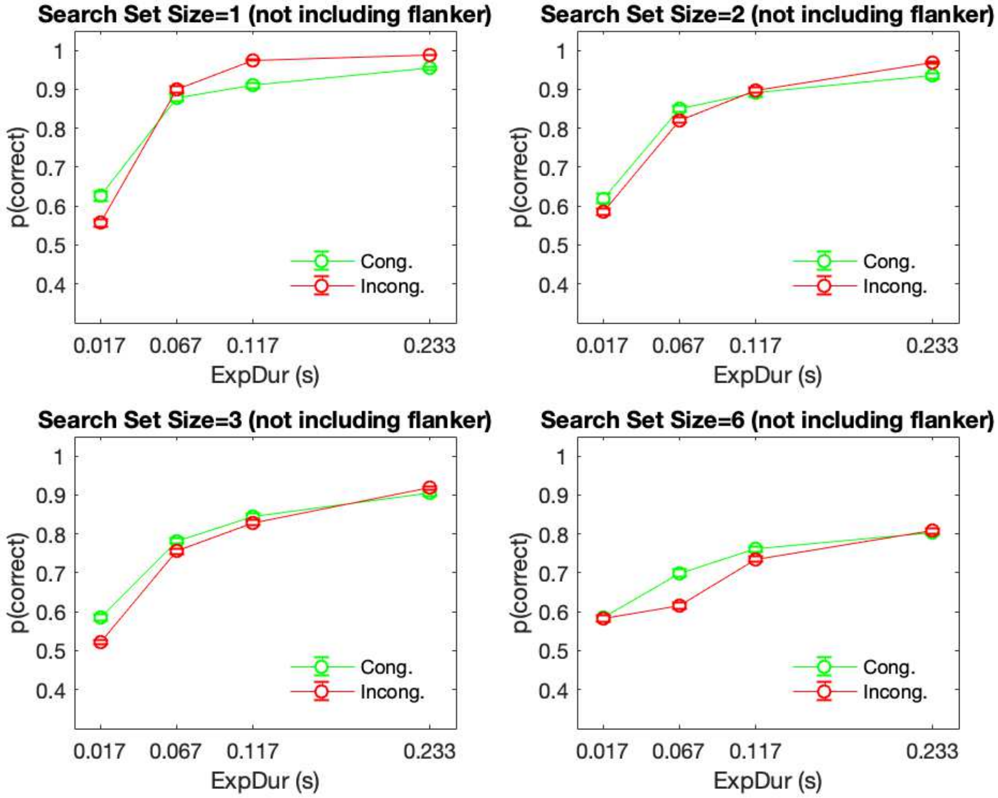

Figure 8. Percent correct plotted as function of set size, congruency and exposure duration in the colored placeholder condition.

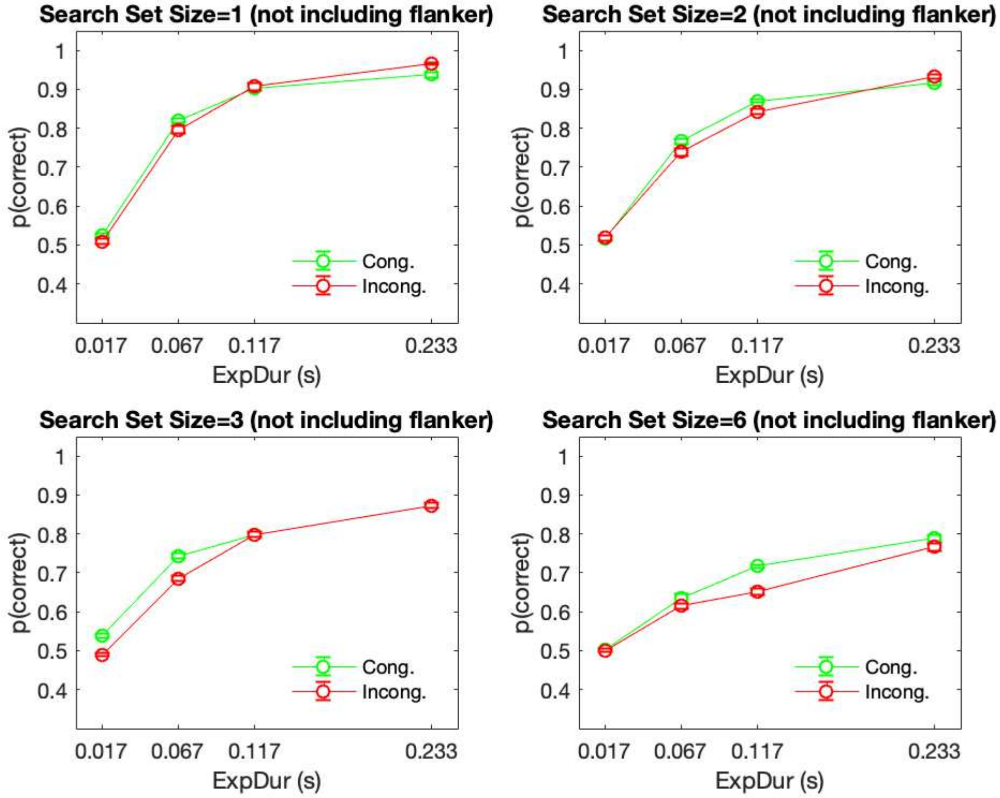

Figure 9: Percent correct plotted as function of set size, congruency and exposure duration in the placeholder condition. This plot combines placeholder data from the first two experiments.

Discussion

In experiment 3, performance in the colored placeholder condition was compared to the no placeholder and placeholder conditions. Comparing the colored placeholder to no placeholder yielded three main findings. First, as expected, accuracy was higher on congruent compared to incongruent trials. Second, accuracy was lowest at the shortest exposure duration (~17-20ms), across all set sizes. Otherwise, performance decreased as set size increased, which has consistent across previous two experiments. Third, as before, the flanker effect was reduced in the colored placeholder condition compared to the no placeholder. Thus, having salient task-relevant and task-irrelevant location information improved performance, suggesting that this spatial information is not fully available pre-attentively.

The motivation for comparing colored placeholder condition to the placeholder condition was to examine whether providing differently colored placeholders circles to indicate task-relevant and task-irrelevant locations provided any added benefit to the already reduced distraction in placeholder condition. Results show that making task-relevant and task-irrelevant locations more distinct did not provide any added benefits in reducing distraction in the colored placeholder condition.

Experiment 4

Experiment 4 further examined the role of location information on visual search by manipulating amount of location information available in a visual search task as a within-subject variable. Each participant was tested in both no placeholder and placeholder conditions. There were three major differences from the previous studies: 1. Exposure duration for the search letters was kept constant at 100ms. This is typical in LT experiments 2. No masks were used, which is also typical of LT experiments 3. Participants were required to make a speeded two alternative forced choice response. This allowed us to examine response time as well as accuracy as the dependent measures, as opposed to only accuracy in the first three experiments. Furthermore, these changes reduced the number of trials in the study, which enabled participants to finish the task in one session.

Method

Participants. Fifty-four participants (mean age 20.13 years old, gender breakdown not available) from the University of California, Santa Barbara volunteered in this experiment. Each participant was tested in both the placeholder and no-placeholder conditions. All participants received course credit for their participants. All procedures conformed to a protocol approved by the University of California, Santa Barbara.

Stimuli. Both the placeholder and no placeholder conditions consisted of a fixation display as well as a search display. Both displays had a gray background. In the fixation display, a fixation cross (0.29° X 0.29° visual angle) was presented in the center of the screen. In the search display, task-relevant and task-irrelevant search letters were presented in specific locations. There were up to six task-relevant search locations that were arranged in an imaginary circle around the fixation cross, approximately 3° visual angle away from it. There were also two possible task-irrelevant locations 3.58° visual angle away from the fixation cross, horizontally to its right or left. All search letters (XZVWNKM) were white and upper case and approximately 0.48° X 0.43° visual angle in size. In the placeholder condition, circular placeholders (0.95°X 0.95° visual angle) specified the task-relevant and task-irrelevant locations on the fixation and search display. The viewing distance was 120 cm for both tasks.

Procedure. Each trial began with the fixation cross changing color from black to white to signal the upcoming trial. The search display was then presented for 100ms. Participants were instructed to respond as quickly and as accurately as possible. As before, participants had to discriminate between letters X or Z that appeared in the task-relevant locations while ignoring flankers X or Z that appeared in the task-irrelevant locations outside the circle. Participants' answers were collected through a speeded two alternative forced choices response. Each trial was terminated by a response, at which point the fixation cross changed colors to indicate the beginning of the next trial. Eye movements were recorded throughout the experiment. Participants were also instructed to maintain fixation. Each participant was tested on both the placeholder and no placeholder conditions over an hour-long session. To minimize order effects, odd numbered participants were first tested on the no placeholder condition followed by the placeholder condition and even numbered subjects were tested in the reverse order.

Design. There were four key manipulations. First, the amount of location information in each visual search display was manipulated with the presence or absence of placeholders. Second the perceptual load of the displays was varied using four different set sizes (1, 2, 3 and 6). Third, there were flanker present and flanker absent trials. Fourth, flanker present trials consisted of trials in which the flanker letter could be congruent or incongruent to the target. Unlike experiments 1 and 2, exposure duration of the search display was kept constant at 100ms, which is consistent with load theory experiments (Lavie & Cox, 1997). There were 240 trials each in both the placeholder and no placeholder conditions.

Data analysis. Trials with saccades greater than 1 degree away from the fixation were removed. Trials faster than 200ms and slower than 1500ms were discarded. There were 63 participants at the start of data analysis. Participants with accuracy at or below chance on any condition were not used included in analysis. Participants with response times 2.5 standard deviations above or below the mean on any condition were also excluded from the analysis. Final statistical analyses were conducted on data from 45 participants.

Results

Response Time. A repeated measured ANOVA with spatial information (no placeholder, placeholder), set size (1,2,3 and 6) and congruency (congruent, incongruent) was performed. There was a main effect of set size (F(3,132)=111.38, p<.001, MSE=.51, partial η_p^2=.72), such that response time increased as set size increased. There was a main effect of congruency (F(1,44)=31.27, p<.001, MSE=.19, partial η_p^2=.42), such that response times were faster on congruent trials compared to incongruent trials. There was an interaction between set size and congruency (F(3,132)=6.62, p<.001, MSE=.03, partial η_p^2=.13), such that the flanker effect was reduced with increasing set size (Figure 10). Finally there was an interaction between spatial information and congruency (F(1,44)= 16.13, p<.001, MSE=.05, partial η_p^2=.27), such that the flanker effect was lower in the placeholder condition compared to no placeholder condition .

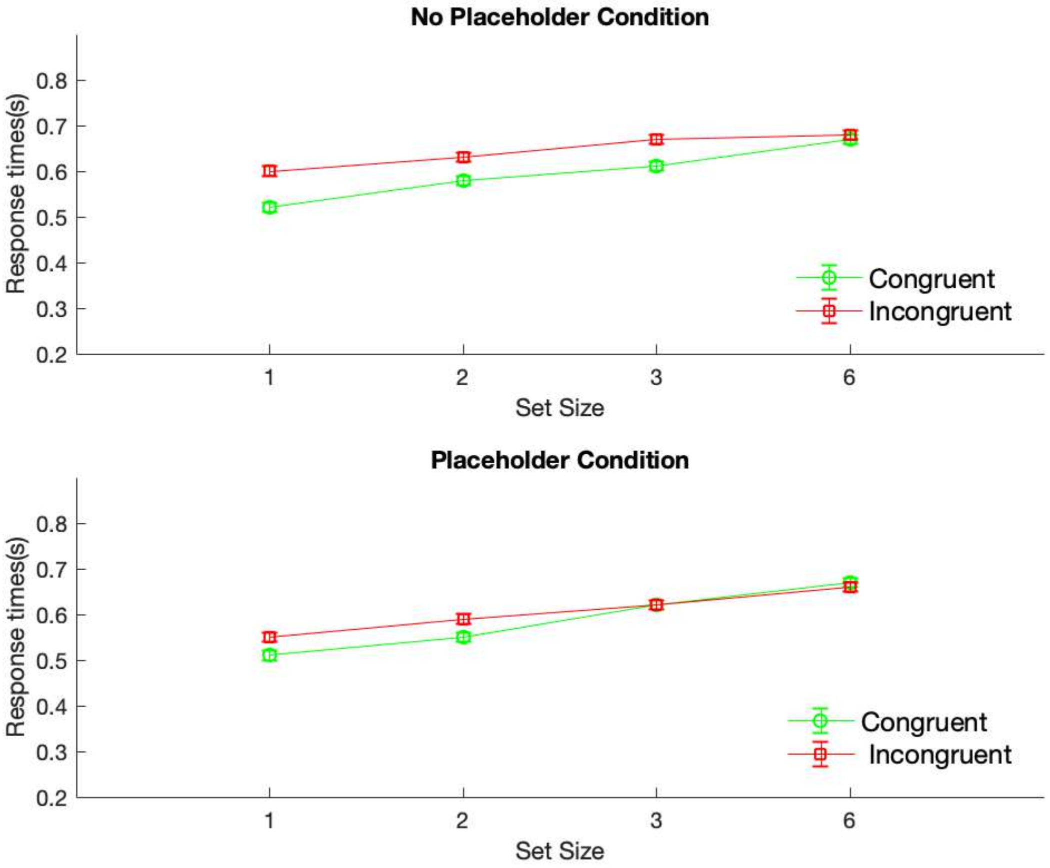

Figure 10. Mean response time plotted as a function of set size and congruency in the no placeholder and placeholder condition. Error bars=SEM.

Error rate. A repeated measures ANOVA with spatial information (no placeholder, placeholder), set size (1,2,3 and 6) and congruency (congruent, incongruent) showed a main effect of congruency ($F(1,44)= 17.27$, $p<.001$, MSE= .27, partial $\eta_p^2=.28$) such that participants were more accurate on congruent trials compared to incongruent trials. There was a main effect of set size ($F(3,132)=76.19$, $p<.001$, MSE=.41, partial $\eta_p^2=.63$), such that accuracy decreased with increasing set size. There was an interaction between set size and spatial information ($F(3,132)=6.53$, $p<.001$, MSE=.03, partial $\eta_p^2=.13$) such that effect of spatial information is larger at smaller set sizes. There was an interaction between spatial information and congruency ((F(1,44)= 9.84, p<.01, MSE= .08, partial η_p^2 =.18), such that the flanker effect was reduced in the placeholder condition compared to the no placeholder condition. There was also a set size by congruency interaction (F(3,132)= 4.21, p<.01, MSE= .02, partial η_p^2 =.09), such that the flanker effect was highest at set size 1 and lowest at set size 6. Finally there was also an interaction between spatial information, set size and congruency (F(3, 132)= 2.83, p<.05, MSE=.01, partial η_p^2 =..06), such that the flanker effect at low set size (1,2 and 3) was smaller in the placeholder condition compared to the no placeholder condition (Figure 11) .

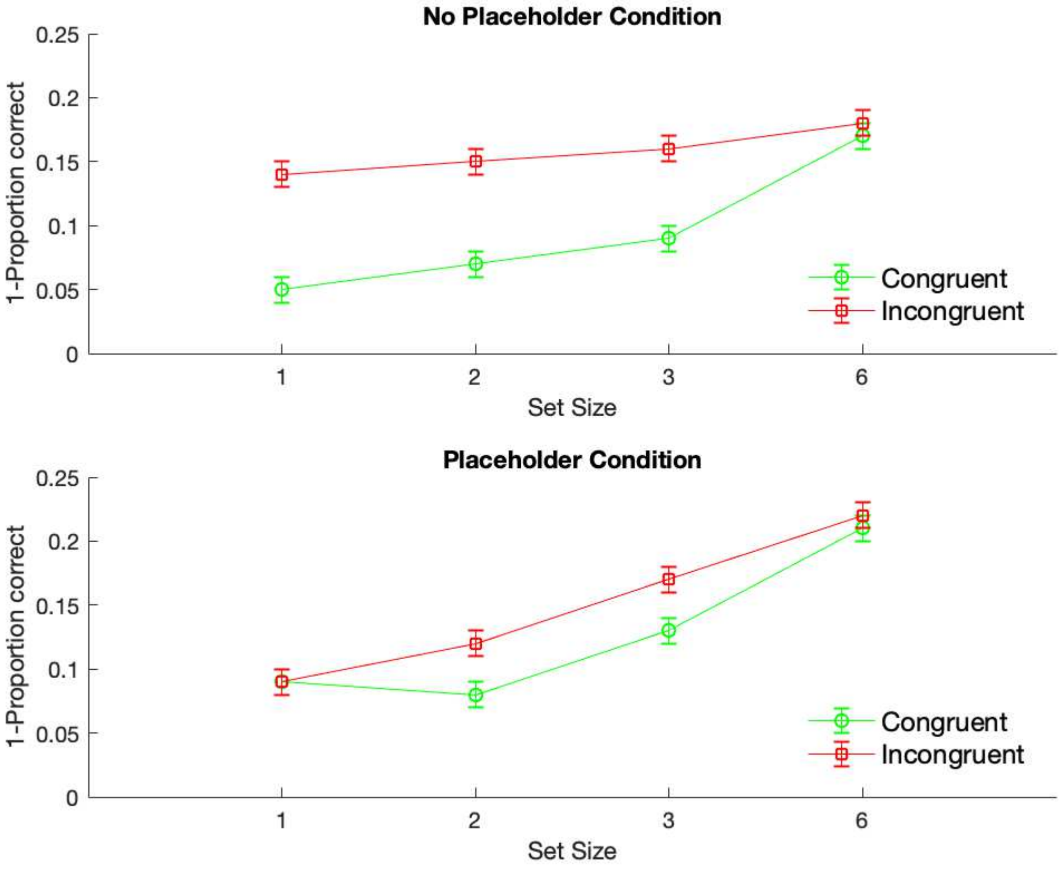

Figure 11. Error rate plotted as function of set size and congruency in the no placeholder and placeholder conditions.

Discussion

In experiment 4, placeholder and no placeholder conditions were compared in a within-subject design, using a speeded task. Both response time and accuracy showed reduced flanker effect in the placeholder condition compared to no placeholder condition. Furthermore, accuracy data showed evidence of the flanker effect being reduced in the low set sizes in the placeholder condition, which goes against a major prediction of load theory.

General Discussion

In four experiments, key assumptions, according to LT and TVA, of how visual processing capacity is allocated were tested. LT posits two steps of processing, with task-relevant stimuli being processed first followed by task-irrelevant stimuli, suggesting pre-attentive knowledge of spatial information. Consequently, manipulating saliency of stimulus spatial information should have no effect on behavior. In the first experiment, the saliency of available spatial information was manipulated in a between-subject design, using a placeholder or no placeholder circles highlighting location in a hybrid visual search task. Results showed a reduction in distraction in the placeholder condition compared to the no placeholder condition. This suggests that spatial information is not available pre-attentively, since making spatial information salient reduced distraction.

In the second experiment, findings from experiment 1 were replicated. In the placeholder condition, distraction was found to be reduced even in the lower set sizes, which according to LT are most susceptible to distraction.

In the third experiment, saliency of the spatial information provided by placeholders was made more distinct by using blue colored placeholders to indicate task-relevant locations and red colored placeholders to indicate task-relevant locations. Again, distraction was found to be reduced in the colored placeholder condition compared to the no placeholder condition. There was no added benefit of having colored placeholders compared to the usual placeholder.

In the fourth experiment, performance in placeholder and no placeholder conditions was assessed using a speeded- task and within-subject design. Results showed reduced distraction in the placeholder condition compared to the no placeholder condition. This reduction was seen in both response time and error rate data.

Together, these findings provide evidence against the notion that task-relevant and task-irrelevant spatial information is available automatically prior to search. Consequently, this finding does not support a key prediction by LT that suggests that perceptual resources are first allocated to task-relevant objects followed by task-relevant objects.

The findings in the current study also do not support the dilution account (Tsal & Benoni, 2010). According to the dilution theory, decreased distraction in high load conditions is driven by the presence of neutral letters that dilute the effect of the distractor. Lack of neutral letters in low load conditions results in high distraction in the low load conditions. This hypothesis still supports the premise that spatial information on task relevant and task irrelevant objects is available pre-attentively. Results from the current study show that providing spatial information using placeholders reduced distraction even in low load conditions, where neutral letters are absent and therefore not able to dilute effect of distractors. This suggests that dilution does not entirely capture how distractors are processed.

Results from this experiment can be explained by a biased competition framework (Scalf et al., 2013) as well as signal detection model (Eckstein et al., 2000), which do not assume a two-step attention allocation process. TVA (Bundesen, 1990), which may be regarded as a mathematical formalization of the biased competition framework, provides a parsimonious way to explain the current findings. According to TVA, all possible visual categorizations ascribing features to objects compete to become encoded into limited capacity visual short-term memory (VSTM) before it is filled up. Each categorization is supported by sensory evidence, but competition can also be biased by attentional weights and perceptual biases, such that some objects and categorizations have higher likelihood of being encoded into VSTM. The way sensory evidence and attentional biases interact is specific by the rate and weight equation. The weight equation defines the selection or filtering criteria of objects in the environment at any given time. The attentional weight of each object is determined at this stage based on the importance of the object. The weights are then factored into the rate equation along with perceptual biases, to determine the speed of processing objects (Bundesen et al., 2015; Giesbrecht et al., 2014). NTVA or neural theory of visual attention (Bundesen et al., 2005) takes the core tenets of TVA and provides a neurophysiological interpretation of TVA. In both TVA and NTVA, recognition and selection are instantiated in a unified mechanism, which side steps the need to categorize selection in early versus late mechanism. Critically, spatial information, according to TVA, is like any other feature that has to be processed.

There are several benefits of the TVA approach in explaining how attention is allocated. Compared to LT, allocation of attention happens in a single step according to TVA. Once attentional weights are computed, all available processing resources are distributed across the objects in the visual field in direct proportion to the attention weights of the objects, according to the rate equation. This one step allocation mechanism circumvents the two-stage process of LT, which brings up the question of how it is known which objects are task-relevant and which are task-irrelevant. In addition, unlike LT, TVA offers a precise definition for what constitutes as a manipulation of perceptual load. Load can be manipulated by any factor that can change the rate of processing in the rate equation in TVA. Finally, role of top-down expectation, like advance knowledge of location in the current experiments is explicitly captured in TVA, in both the rate and weight equations. LT does not account for top-down expectation.

Conclusion

The current study has shown that location of task-relevant and task-irrelevant objects in not availably pre-attentively during visual search. Results from four experiments show that performance in a visual search task is higher when location information about task-relevant and task-irrelevant information is explicitly provided versus when it is not. These findings provide evidence against Load theory's (Lavie, 1995) core tenet that attention is allocated to task-relevant objects first and any left-over attention spills over to task-irrelevant objects, which implicitly assumes that location information is known. In comparison, the data is supported by the theory of visual attention (Bundesen, 1990) and neural theory of visual attention (Bundesen et al., 2005) which assume a single step capacity allocation, does not assume that spatial information is available pre-attentively and provides a quantifiable way of explaining how attention is allocated.

Chapter III

Introduction

Visual selection of task-relevant objects is facilitated by providing accurate information about the most likely object location (Dosher & Lu, 2000; Eimer, 1994; Jonides, 1981; Posner, 1980). This cueing benefit can be observed in terms of behavior (reduced response times and improved discrimination accuracies; (Bashinski & Bacharach, 1980; Eckstein et al., 2002; Hawkins et al., 1990; Müller & Rabbitt, 1989; Posner et al., 1978) and modulations of neural responses (Mangun & Hillyard, 1991; Silver et al., 2005; Thiel et al., 2004; Van Voorhis & Hillyard, 1977) and it is thought to reflect a key consequence of selective attention. Not only does cueing the location of a task-relevant object result in processing benefits, but there is also compelling evidence for behavioral benefits when accurate information is provided about the location of a task-irrelevant distractor (Munneke et al., 2008; Ruff & Driver, 2006a). These benefits of cueing the distractor location are typically observed as reduction in the amount of behavioral interference observed when detecting or discriminating the task-relevant target and, like cueing a task-relevant target location, the benefits are also thought to reflect selective attention.

Multiple mechanisms have been proposed to explain the beneficial effects of prior knowledge of target location (for a review see Carrasco, 2011). For example, the advance location information may serve to enhance the response to the target via a top-down biasing signal that increases the excitability of the neurons that code the cued location (Hillyard et al., 1998). Alternatively, the cue may serve to reduce noise. Noise reduction could occur by attention acting as a location-based filter (e.g., (Lu & Dosher, 1998). Noise reduction could also occur because the cue reduces uncertainty by limiting the number of search locations for an observer. Reducing the number of search locations effectively eliminates irrelevant information from uncued locations, thereby, improving target discrimination (Eckstein et al., 2002; Luck et al., 1996; Palmer et al., 1993). The mechanism that mediates the beneficial effects of cueing a distractor location is less clear. However, the explanations of the target cueing effect provide insight. While signal enhancement provides a straightforward explanation of the benefits of cueing a target location, enhancement of the distractor location would likely increase interference. Instead, the reduction of distractor interference could be explained by the suppression or inhibition of the location of the distractor (Chao, 2010; Moher & Egeth, 2012; Munneke et al., 2008; Noonan et al., 2016; Ruff & Driver, 2006a). Distractor inhibition could occur as a by-product of the attention-based filter (e.g., (Lu & Dosher, 1998) as well as top-down control (Chao, 2010). Similar to target cueing, accurate information about the location of the distractor could reduce uncertainty about the location of the target, provided that the number of locations are known in advance and a target and a distractor could never co-occur at the same location (Eckstein et al., 2002). Alternatively, the benefits of distractor cueing, when they are observed, may be mediated by a mechanism that is altogether separate from the mechanism that mediates the benefit of cueing a target, and may be supported by working memory (Noonan et al., 2016).

Existing studies have largely focused on inhibition-based accounts distractor cueing. For example, to examine how foreknowledge of a distractor affects target processing, (Ruff & Driver, 2006a) provided trial-by-trial cues indicating the presence or absence of a distractor. The location of the target was also cued on every trial. The presence of a distractor interfered with target processing, but this cost was reduced when participants were cued to the presence of the distractor. Because the location of the target was validly cued on every trial, there was minimal target uncertainty. This suggests that foreknowledge of the presence of a distractor can reduce subsequent distraction by eliciting inhibitory mechanisms.

Consistent with this conclusion, (Munneke et al., 2008) further showed that this reduced distraction persists even when the target and distractor locations are variable and target location is uncertain. The task in this experiment included four locations. On each trial four stimuli were presented, a target letter, a distractor letter that was congruent or incongruent to a target, and two neutral letters (i.e., that did not map onto a target response). The location of the distractor was either cued or not cued on a trial-by-trial basis. Response times were slower on incongruent compared to congruent trials and, importantly, this effect was reduced on trials in which the location of the distractor was cued. The reduced distractor interference can again be explained by inhibitory mechanisms. Knowing where a distractor will appear can help inhibit processing and be less likely to interfere with target processing. However, comparing the neutral cue condition, which includes all possible locations for search, with the cued condition, which has one fewer potential target locations, leaves open the possibility that reduced uncertainty about the target location is the reason for reduced distraction.

Noonan et al., (2016) on the other hand, did not show evidence for distractor cue modulated inhibition. In this study, target processing was compared under different conditions: when the location of the target was cued, when the location of the distractor was cued, and when no information was provided about the location of either. The location of the target and distractor could either change on a trial-by-trial basis (flexibly, Exp. 1 and 2) or remain the same over a block of trials (blocked, Exp. 1-3). Across all experiments, the targets and distractors were highly discriminable (i.e., dissimilar) from each other (E1: target=two overlapping Gabors, distractor=single Gabor; E2: target=one of two possible shapes, distractor=overlapping shapes; E3: target=single grating, distractor=overlapping gratings). Compared to the no-cue condition, there was a benefit for target processing when the location of the target was cued, flexibly or blocked, suggesting enhancement of the cued location. However, a benefit of the distractor cue was seen only when the distractor cue and the location of the distractor were blocked. No benefit in performance was seen when the location of the distractor was cued on a trial-by-trial basis. Similarly, (Wang & Theeuwes, 2018a) failed to observe benefits of pre-cueing a distractor location in a search task in which the target was a shape singleton and the distractor was a salient, color singleton.

Furthermore, currently the neural mechanisms of distractor inhibition are unclear. There is evidence that oscillatory activity in the alpha (e.g., (Bengson et al., 2012; Foxe & Snyder, 2011; Jensen & Mazaheri, 2010; van Diepen et al., 2016) and theta (Green & McDonald, 2008) band frequency may be involved in top- down inhibition. There is also contradictory evidence suggesting alpha power may not modulate inhibition of distractors and may instead play a role in signal enhancement of target objects (Antonov et al., 2020; Foster & Awh, 2019; Noonan et al., 2016). Thus, the role of alpha and other oscillatory activity in the distractor cueing phenomena needs further examination.

The presence of a distractor cueing benefit in some studies and not in others may be indicative of some of the boundary conditions that constrain the phenomenon. However, there are two confounding factors at play that complicate the interpretation of this evidence. First, in studies that have observed benefits of cueing the location of the distractor, the conditions that are compared to reveal evidence for inhibition are typically a no-cue (or neutral cue) condition in which there is no spatial information provided about the distractor and a location cue condition that provides sometimes completely accurate information about the location of the distractor, if it is presented (e.g., Munneke et al., 2008). Importantly, knowing the location of the distractor also provides information about the location of the target. Thus, it is unclear whether the distractor cue benefit is actually due to an inhibitory mechanism or reduced uncertainty about the location of the target. Second, the efficacy of the distractor cue may depend on the discriminability between the target and distractors. The previous studies (Noonan et al., 2016; Wang & Theeuwes, 2018a) failing to provide consistent evidence of distractor cueing benefits have included distractor and target that were very different and such dissimilarity may reduce the need to use the cue (Wang & Theeuwes, 2018b). Third, in all experiments discussed above, the cue indicating the location of the distractor, when presented, was always valid. It is unclear how changing the validity of the cue would impact how the distractor is processed, and how that compares cue validity changes in target processing. Finally, it is unclear how a cue indicating the location of a distractor is processed by the brain.

Outline of experiments

The goals of the present study were two-fold: 1. To probe how advance expectation of distractor location is represented neurally and how it impacts target processing 2. To compare the effects of distractor cueing and target cueing in impacting behavior and brain activity. Two behavioral experiments were conducted to understand how advance expectation of distractor location impacts target processing. Participants were cued to the most likely location of the upcoming distractor in a visual search task. There were two key manipulations. First, the validity of the distractor cue was varied such that there could be valid, invalid and no cue (baseline) trials. In addition, the congruency of the target and distractor were also manipulated. Use of partially valid cues that were equated in the number of possible target locations allowed for controlling for spatial uncertainty. Similarly, use of the flanker effect ensured that the distractor will be automatically distracting and thus the cue would be helpful in ignoring the distractor. Finally, a third experiment was conducted using electroencephalography to understand the neural mechanism underlying distractor cueing and how it is different from target cueing. This experiment used the same task as the first two behavioral experiment, with the addition of a separate target cueing and baseline condition with a spatially uninformative cue. Alpha and theta band power were modeled using inverted encoding model (IEM) to estimate the location-selective representations of cued locations from the patterns of activity recorded during the task. The IEM technique has been successfully applied in scalp recorded EEG (Bullock et al., 2017; Foster et al., 2016) to recover location selective information from patterns coded in brain activity. Critically, previous studies have used this technique with oscillatory activity in alpha to track search targets (Foster et al., 2016) as well as theta band activity to track target and distractor items (Feldmann-Wüstefeld et al., 2021). Here the IEM technique was leveraged to reconstruct spatially selective response profiles of cued and un-cued locations in the target and distractor cueing conditions, using topographical patterns of alpha and theta band activity.

In experiment 1, performance was assessed in a visual search task in which participants had to identify a target letter while ignoring a simultaneously presented distractor letter. Critically, on each trial participants were provided with a cue indicating the most likely location of the upcoming distractor or no spatial information for the distractor. Experiment 2 replicated the findings of experiment 1 with Gabor stimuli. In experiment 3, performance on the distractor cueing task was compared to a separate target cueing task as well as a no cue or baseline task. In both target and distractor cueing conditions, participants were provided the most likely location of the upcoming target and distractor respectively. In this experiment, EEG was measured to uncover the neural mechanism underlying distractor cuing.

Experiment 1

In experiment 1, a paradigm similar to (Munneke et al., 2008) was adopted in which participants discriminated an upper case target letter presented with a lower case distractor letter, the identity of which was either the same (congruent) or different (incongruent) with the target. The difference in response times as a function of distractor congruency provided a measure of the extent to which the distractor was processed. To assess the role of trial-by-trial expectations about the location of the distractor, each target-distractor display was preceded by a central cue that indicated either the most likely location of a distractor or a no cue (henceforth described as baseline) that did not provide any information about the location of the distractor. Baseline cue trials were included to verify that our congruency manipulation was successful in the absence of any spatial cue. The cued trials were either valid or invalid (of the trials that contained a spatial cue, 80% were valid, 20% were invalid). Two types of invalid trials were presented. In *invalid-other* trials, a cue pointed to a location but neither the distractor or target appeared there. In *invalid-target* trials, a cue pointed to a location in which a target appeared, instead of a distractor. A comparison of interference between validly cued trials and invalid-other cued trials provided a measure of whether accurate distractor location can reduce interference when compared to trials in which distractor location information was inaccurate. Valid and invalid-other trials were also equivalent in the number of possible target locations, which enabled removing spatial uncertainty as a confound in comparing them. To differentiate between the competing theoretical accounts of reduced interference caused by distractor cues, valid trials were compared to invalid-target trials. If foreknowledge of the distractor location inhibits processing of an object that appears in that location, then a target appearing in that location should also be inhibited.

Method

Participants. Because the previous studies that motivated the present work did not report effect sizes (Munneke et al., 2008; Noonan et al., 2016), sample size was primarily determined based on an unpublished dataset (n=38) from a previous experiment conducted in our lab that contained a similar flanker manipulation with letter stimuli and a similar number of trials. A large effect (i.e., Cohen's d=0.8) was observed in that study. This estimate of sample size is consistent with an a priori estimate appropriate for a repeated measures design that assumes a medium effect size (Cohen's d=0.5) and 0.8 power, which results in an estimated sample size of 34. In anticipation of attrition, final sample size was forty-one. Participants (mean age 19.14 years; 31 female) from the University of California, Santa Barbara volunteered for this study. Participants received course credit for their participation. All participants had normal or correct-to-normal visual acuity.

Stimuli. Stimulus presentation was controlled using Psychtoolbox 3.0.12 (Brainard & Vision, 1997) scripts written in MATLAB. A ViewSonic Graphics Series G90f monitor (36.5 x 27.5 cm) was used to present stimulus. The task consisted of three displays: fixation, cue and search. All displays (1024 x 768 pixels) were presented on a gray background (RGB: 130,130,130, luminance: 25.67 cd/m^2). In the fixation display, a black fixation circle (0.29° visual angle) was presented in the center of the screen along with four black lines (0.92° visual angle each) pointing to the four task relevant positions on the screen. The lines pointed to 0°, 90°, 180° and 270° around the fixation circle. In the cue display, one (or all in case of baseline cue) of the lines turned red to indicate the most likely location of the upcoming distractor. In the search display, one target letter (1.38° visual angle) and one distractor letter (1.4° visual angle) was presented in the four possible locations. The distance from the center of the fixation circle to the letter was 2.3° visual angle. The target was either a B or F and the distractor was a b or f. The viewing distance from the monitor to the headrest was 100 cm. Sample stimuli are shown in Figure 1.

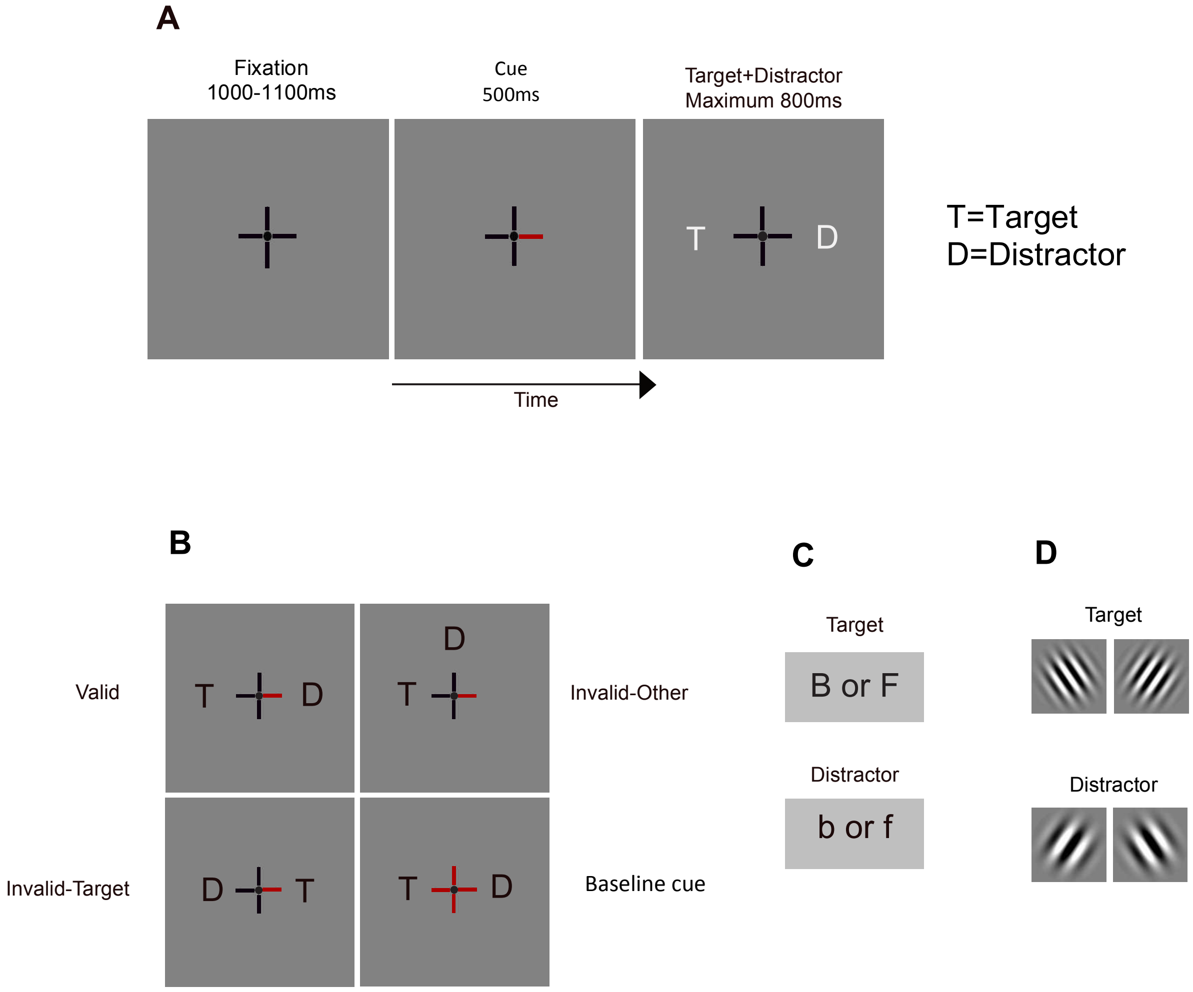

Figure 1: A) Schematic representation of a trial sequence. B) Schematic representation of cue, target and distractor presentation as a result of cue validity manipulation. C) Target and distractor identity in Experiment 1. D) Target and distractor identity in Experiment 2.

Procedure. All procedures were approved by the University of California, Santa Barbara Human Subjects Committee. Participants were instructed to press the space bar on the keyboard to begin presentation of a block of trials. Each trial began with the presentation of a black fixation circle with four lines for a variable interval (1000-1100 ms). Next, one (or all four in case of baseline cue trials) of the lines turned red for 500 ms to indicate the most likely location of the upcoming distractor. After 200-300 ms interval, one target and one distractor letter appeared for 800 ms or until the participants responded. A blank gray screen was presented for 700 ms between each trial. Participants were instructed that the cue pointed to the most likely location of the distractor and that it is be 80 percent accurate. They were asked to actively use the cue in making their decision and to respond as quickly and as accurately as possible. Participants' task was to discriminate between B or F, while ignoring b or f. Reaction time was measured using a speeded two alternative forced choice (2-AFC) response. The experiment lasted 90 minutes. Participants completed two blocks of 88 practice trials with feedback at the beginning of the experiment to become familiarized with the task. A sample trial sequence is shown in Figure 1B.

Eye tracking. Participants' eye movements were recorded during the experiment using a EyeTribe eye tracker device. Participants were seated 100 cm away from the eye tracker; their heads stabilized with a chin rest. The task was programmed to be gaze contingent. During the duration of each trial, participants had to maintain their gaze within 1.94° visual angle radius around the central fixation circle. Blinks during the trial or eye movements away from the circumference resulted in termination of the trial. All trials terminated due to blinks or eye movements were added to the end of each block and had to be repeated. This procedure prevented us from having to remove any trials due to eye movements. The sampling frequency of the eye tracker was 30 Hz.

Design. The validity of the cue was manipulated such that there were 80 percent validly cued trials and 20 percent invalidly cued trials. In the valid trials, the cue accurately indicated the location of the distractor. Of these spatial cue trials, the valid trials were the most frequent trial (80%; 384/480 trials). The invalid trials comprised 20% of the spatial cue trials and there were two types: on one type of invalid trial (invalid-other), the cue pointed to a location where neither the target not the distractor appeared (10% of spatial cue trials; 48/480); on the other type of invalid trial (invalid-target), the cue pointed to the location of the upcoming target instead of the distractor (10% of the spatial cue trials; 48/480). The congruency of target and distractor stimuli were also varied in the task. The letters presented were congruent to each other in half of trials, and incongruent in the other half. To verify the presence of distraction using the congruency manipulation independent of cue, we included baseline cue trials which presented a target and a distractor without any information about the location of either (48 trials). The addition of these trials meant that of the total 528 trials, 72.7% were valid, 18.2% were invalid (9.1% invalid-other; 9.1% invalid-target), and 9.1% were baseline cue trials. A graphical depiction of the conditions is shown in Figure 1.

Data analysis. Trials with reactions times faster than 200ms were excluded from analysis. Eight participants who performed at or below chance on any condition and those who had mean RTs > ±2.5 standard deviations away from the mean were excluded. Interpretation is based on analysis of reaction time data, although both reaction time and error rate are presented. In reporting hypothesis testing, for effects that violate sphericity, Greenhouse-Geisser corrected F values is reported. The Holm-Bonferroni correction for multiple comparisons is used for post-hoc tests in all analyses (Holm, 1979).

Results

Response Time. If distraction was modulated by cueing the location of an upcoming distractor, then a reduced flanker effect would be expected in the cued location. Furthermore, there would be reduced flanker effect in the valid distractor cue condition compared to all other cue conditions (invalid distractor cue and no/baseline cue). To unpack the impact of distractor cue validity on distraction, two analyses were conducted. First the flanker effect in the baseline condition was examined to ensure the flanker manipulation worked. There was a significant flanker effect in the baseline condition, ($t(33)=-6.77$, $p<.001$, d=-1.16) such that response time was faster on congruent trials compared to incongruent trials. Second, the flanker effect was compared across valid cue, invalid-other cue, invalid-target cue and baseline conditions. A repeated measures ANOVA with congruency (congruent and incongruent) and cue validity (valid, invalid-other, invalid-target and baseline) and showed a main effect of congruency ($F(1,33)=139.92$, $p<.001$, partial $\eta_p^2=.81$, MSE=139.92) as well as a main effect of cue validity ($F(3, 99)=3.05$, $p<.05$, partial $\eta_p^2=.09$, MSE=1821.44) but no interaction between cue validity and congruency. Response time was faster on congruent trials than incongruent trials. A post-hoc test examining cue validity showed significantly slower response times in invalid-target compared valid trials (valid - Invalid-target= -10.50, SE=3.75, t=-2.80, $p<.05$). Since there was no interaction between congruency and cue validity, there is no evidence that flanker effect is modulated by distractor cue in this dataset (Figure 2).

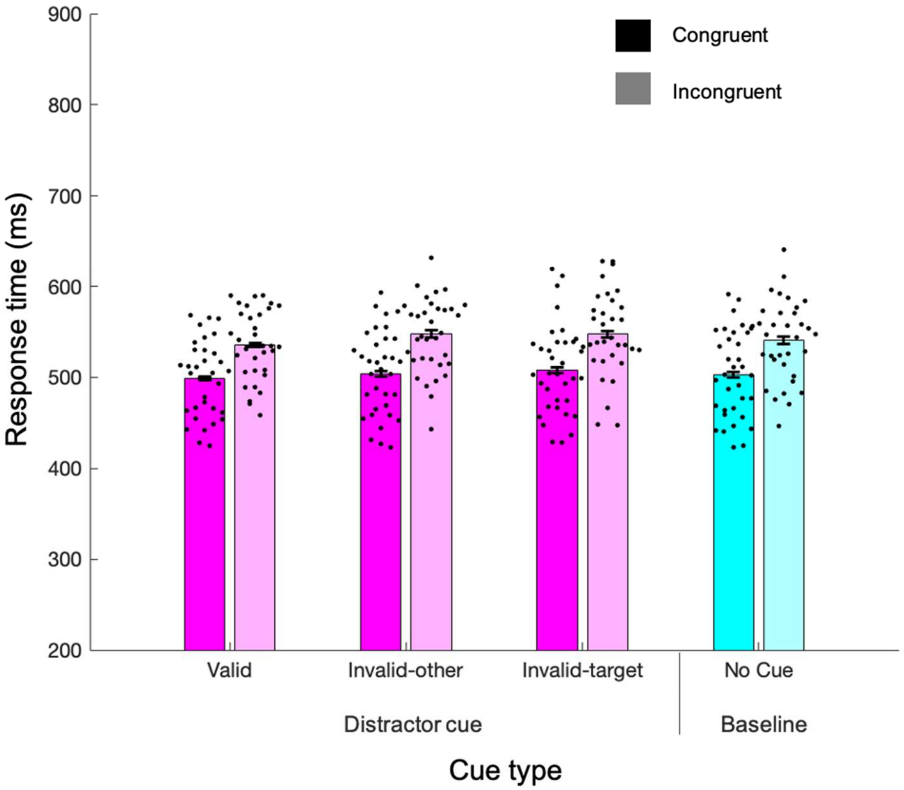

Figure 2: Response time plotted as a function of flanker effect and cue type.

Error rates. The procedure used to analyze response time data was used to examine error rates as well. There was a significant flanker effect in the baseline condition, $t(33)=5.57$, $p<.001$, Cohen's d=.98, such that accuracy was higher on congruent compared to incongruent trials. A repeated measures ANOVA comparing congruency (congruent, incongruent) and cue validity (valid, invalid-other, invalid-target and baseline) showed a main effect of congruency ($F(1,33)=68.16$, $p<.001$, partial $\eta_p^2=.67$, MSE=68.16) but no main effect of cue validity and no congruency by cue validity interaction. There was no evidence of speed accuracy trade off in this data set (Figure 3).

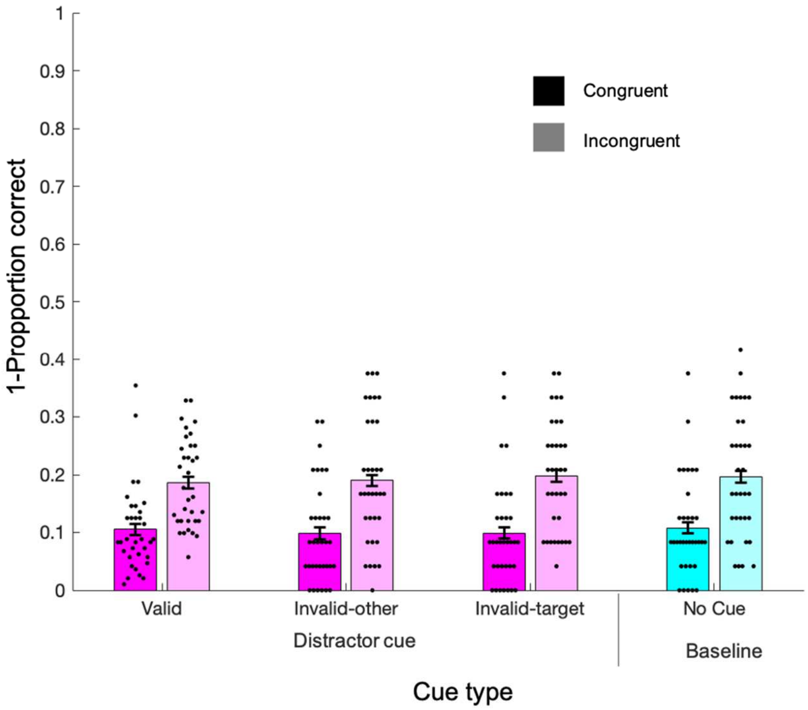

Figure 3: Error rate plotted as a function of flanker effect and cue type.

Discussion

There is mixed evidence on whether cueing the location of an upcoming distractor can reduce its interfering effects on a target task (Munneke et al., 2008; Ruff & Driver, 2006a). In these experiments, the cue indicating the location of the distractor, when presented, was always valid. Furthermore, the mechanism underlying any benefit of distractor cueing is unclear- evidence of inhibition is conflated with reduced target uncertainty. In experiment 1, the location of an upcoming distractor was probabilistically cued and the impact of cue modulation on distraction was assessed. Target location uncertainty was controlled by holding the number of possible target locations constant across the different cue types. Results from this experiment showed no evidence of distraction being modulated as a function of distractor cue. There was no evidence of distractor inhibition as function of distractor cue.

Experiment 2

Experiment 1 and other studies that have provided evidence for reduced distractor interference as a function of advance knowledge of the distractor location the stimuli (Munneke et al., 2008) have used letter stimuli as targets and distractors and relied on the congruency effect as an index of distractor suppression. However, not all studies have found evidence for reduced distraction as a function of distractor cue. (Noonan et al., 2016) compared distractor interference in a trial-by-trial, blocked and no distractor cue conditions. Targets were two superimposed orthogonal Gabor patches. Distractors were randomly oriented single Gabors. Participants' task was to discriminate the spatial frequency of the target. A benefit of distractor cueing was observed when the distractor was presented in the same location over a block of trials. However, no benefit was observed when the distractor location changed on a trial-by-trial basis. In fact, there was a performance cost when the locations of the distractor were changing. One possible reason for the difference between the results of Experiment 1, showing reduced distraction as a result of accurate trial-by-trial distractor cue, and the lack of an effect reported by of distractor cueing reported by (Noonan et al., 2016) could be the difference in stimuli. Perhaps the reduced interference is somehow contingent on the use of linguistic stimuli. Experiment 2 tested this possibility by replicating Experiment 1 using Gabor stimuli, similar to those used by(Noonan et al., 2016).

Method

Participants. Forty-one participants (mean age 20.27 years; 23 female) at the University of California, Santa Barbara volunteered for this study. Participants received course credit for their participation. All participants had normal or correct-to-normal visual acuity. Sample size was determined using the same criteria as Experiment 1.

Stimuli, Design, Procedure. All procedures were approved by the University of California, Santa Barbara Human Subjects Committee. The methods used in this experiment were same as experiment 1. The only difference was in the kind of stimulus used. Instead of letters, we used Gabors as target (1.72° x 1.72°) and distractor (1.72° x 1.72°) in the current experiment. The target was a high spatial frequency Gabor (4.38 cycles/°) and the distractor was a low spatial frequency Gabor (1.75 cycles/°). Contrast and aspect ratios (width to height) was one for both Gabors. The standard deviation of the Gaussian envelope was 0.72° visual angle for both target and distractor Gabors. The congruency of Gabors were manipulated such that their orientations could be congruent or incongruent on a given trial. They were oriented +/- 30° left or right of vertical. The distance between the fixation circle and the Gabors was 2.58° visual angle. Participants' task was to report the orientation of the target Gabor while ignoring the distractor Gabor. Sample stimuli are shown in Figure 1D.

Data Analysis. Analysis started with n=42 participants. Data analysis procedures were same as in Experiment 1. Final analyses were conducted on n=33 participants.

Results

Response Time. Purpose of experiment 2 was to replicate findings from experiment 1 and also to ensure that the findings were not being driven by the linguistic stimuli.

The baseline condition was examined to ensure there was a reliable flanker effect, as all subsequent analysis are contingent on the presence of a flanker effect. There was a significant flanker effect in the baseline condition, $t(32)=-4.710$, $p < .001$, $d=-.82$, such that participants were faster on congruent compared to incongruent trials. Second, the flanker effect was compared across different cue validity. A repeated measures ANOVA with congruency (congruent, incongruent) and cue validity (valid, invalid-other, invalid-target, baseline) showed a main effect of congruency ($F(1,32)=50.39$, $p<.001$, partial $\eta_p^2=.61$, MSE=38342.19) and a main effect of cue validity ($F(3,96)= 14.97$, $p <.001$, partial $\eta_p^2=.32$, MSE=6198.74) but no interaction between congruency and cue validity. Response time was faster on congruent than incongruent trials. A post-hoc test examining cue validity showed that compared to valid trials, response times were slower on invalid-other (valid – invalid-other=-10.85, SE=3.21, $t=-3.38$, $p<.01$) and invalid-target (valid – invalid-target=-18.05, SE=3.21, $t=-5.62$, $p<.001$). Since there was no interaction between congruency and cue validity, there is no evidence that distraction was modulated by validity of the distractor cue (Figure 4).

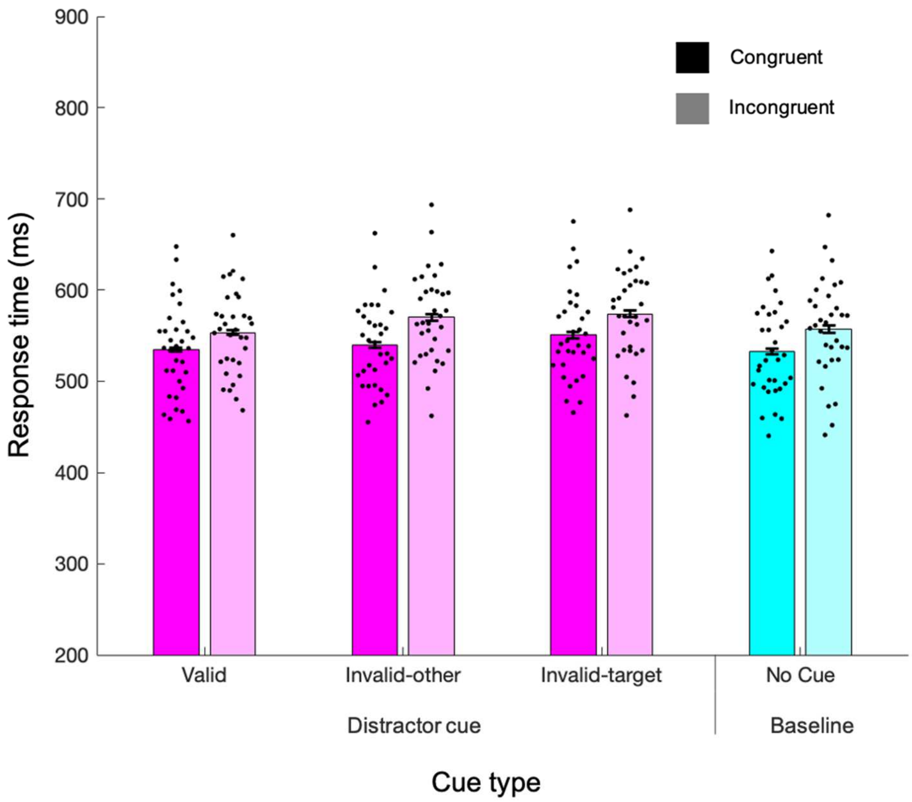

Figure 4. Response time plotted as a function of flanker effect and cue type.

Error rate. The flanker effect was not significant in the baseline condition in the error data ($t(32)=-.58$, $p< .56$. No other analysis was performed due to the lack of a reliable flanker effect. There was no evidence for speed accuracy trade off in this data.

Discussion

Experiment 2 replicated the results of Experiment 1, while using non-letter stimuli. More specifically, there was no modulation of flanker effect as a function of distractor cue validity. There was also no evidence for inhibition as function of distractor cue.

Experiment 3

In experiment 3, performance on the distractor cueing task was compared to a target cueing task as well as a baseline task. In addition to collecting behavioral responses, neural activity was also measured for each task in this experiment using EEG. The motivation for the comparison between no cue, target and distractor cue conditions was to hone into the response evoked by the cue. Sine the cue represents instruction to attend (target), not attend (distractor), no instruction (baseline), examining the cue-related activity would help illustrate how that instruction is represented in neural activity. Indexing the cue-related activity would also allow for the comparison of any subsequent preparatory pre-stimulus presentation activity between the task conditions (Giesbrecht et al., 2006; Harter et al., 1989). Specifically, cue-evoked alpha and theta band activity were examined since these frequencies are thought to be involved in prioritizing task-relevant features (alpha) and top-down control over visual selection (theta) (de Vries et al., 2020).

This experiment was a within-subject design in which all participants completed each task on a different day. For the distractor cueing condition, the same task from experiment 2 was used with two changes. First, the number of trials were increased to enable interpretation of the EEG data. Second, there were six possible locations (instead of previously used four) where the target and distractor could appear. This was done to enable modeling of the EEG data (discussed in detail in methods). The task used in the target cueing condition was the same as the one used in the distractor cueing condition, except a cue indicated the most likely location of the target on every trial. In the baseline condition, there was no spatial information for the target or distractor.

Method

Participants. Twenty-seven participants were recruited (mean age 20.11 years, 14 females) from the University of California Santa Barbara for this study. An *a priori* power analysis was conducted to determine sample size needed to get a reliable flanker effect in the baseline condition. We used the G*power software with a two-tailed repeated measures t-test, effect size .80, alpha error .05 and power .95, to get a sample size of n=23. Taking participant attrition and noise in the data into consideration, our final sample size was n=27. All participants had normal or corrected vision. All participants gave written consent and were compensated at a rate of $10 per hour for their participation. The UCSB Human Subjects Committee approved all procedures of this study.

Stimuli. The task was created using Psychtoolbox 3.0.12 (Kleiner et al., 2007)scripts written in MATLAB. The stimuli were presented to the participants on a ViewSonic Graphics Series G90f monitor (36.5 x 27 cm). The screen (1024 x 768 pixels) presented displays on a gray background (RGB: 127.5 127.5 127.5). Each trial included four displays- fixation display, cue display, post cue display and stimulus presentation display. During fixation display, a fixation circle (RBG: 0 0 0; 0.24° visual angle) was displayed in the center of the screen. Six lines (2.29° visual angle) were presented around the fixation circle pointing to six locations (45°, 90°, 135°, 225°, 270°, and 315°) on the screen. These locations were marked by placeholder circles (2.2° diameter), which were present on the screen throughout the duration of the trial, from fixation to stimulus presentation screen. During cue display, the lines around the fixation circle changed colors from black to colored lines (RBG: 122 122 0; 22 128 109; 146 111 16; 63 129 45; 140 111 78; 233 0 0; 17 103 241). During the post cue display, lines around the fixation circle changed colors to black again. During the stimulus presentation display, two Gabors (1.15° visual angle) were presented inside two of the six circles. One Gabor had high spatial frequency (1.72° x 1.72°; 4.38 cycles/°) and could be oriented left or right. The other Gabor had low spatial frequency (1.72° x 1.72°;1.75 cycles/°) and could be oriented left or right. The distance between the fixation circle and the center of either Gabor was 2.44° visual angle. A depiction of the task is shown in Figure 5.

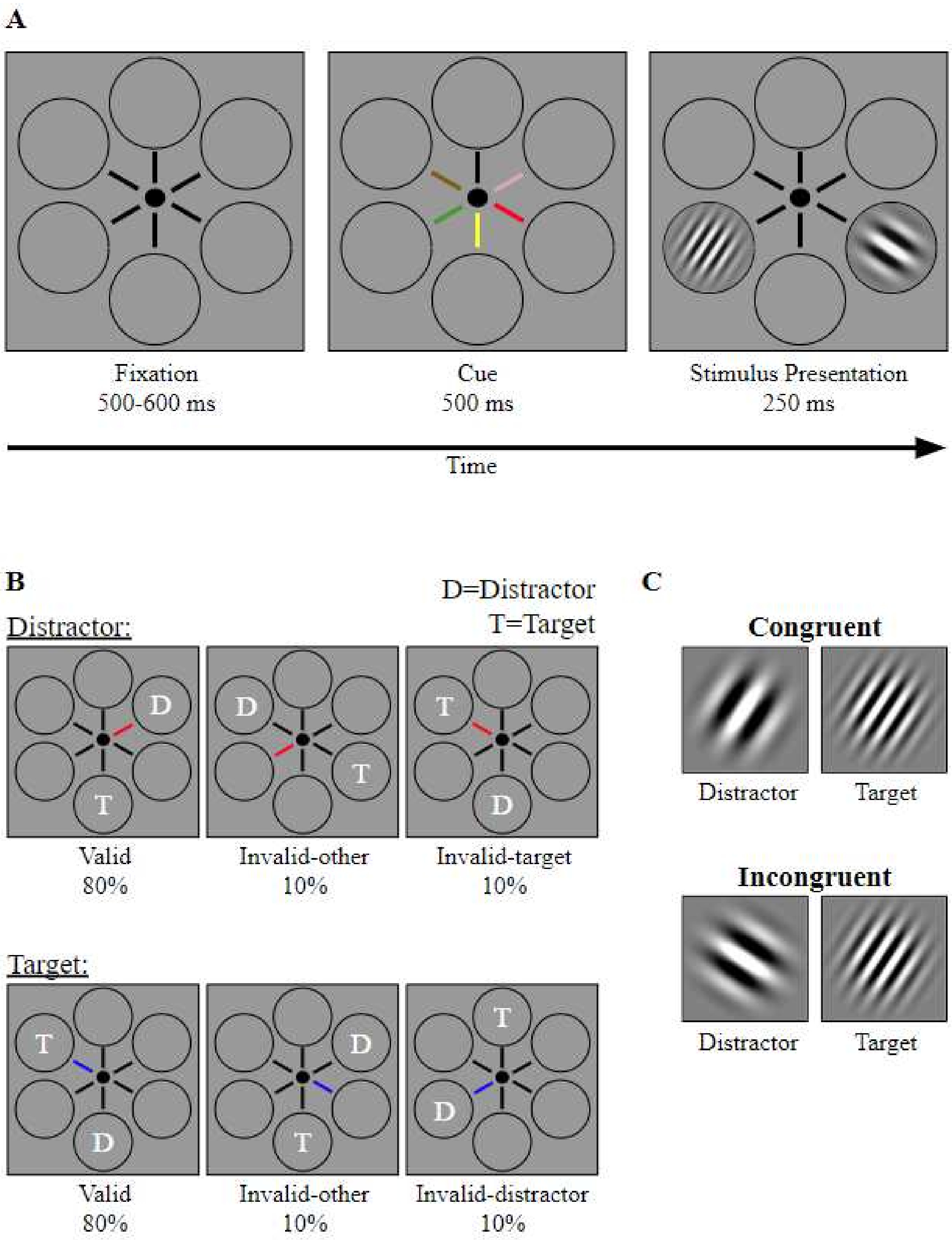

Figure 5. (A) A representation of the fixation, cue, and stimulus presentation displays of task and time elapsed during each display. (B) A representation of the cue validity manipulation. (C) A representation of the target and the distractor similarity manipulation.

Procedure. Each participant completed three tasks consisting of three cueing conditions- target cue, distractor cue and no cue or baseline. Participants were tested on the three conditions on separate days and the order of conditions was counterbalanced. The tasks were explained to the participants and informed consent was acquired at the beginning of each day. Participants were instructed that they would be doing a visual search task in which their job was to identify a target object presented on the screen while ignoring a simultaneously presented distractor object. For the target and distractor cueing conditions, participants were told that a cue would be provided on each trial that would indicate the most likely location of the upcoming target or distractor, respectively. The cue, depending on the participant, would be indicated by a red or blue line among the colored lines that pointed to six possible locations. For odd-numbered participants IDs, the distractor cue was indicated by red and the target cue by blue, and vice-versa for even- numbered participant IDs. On the baseline condition, participants were told that the colored lines would provide no location information. Participants' task was to use the cue to attend to the target and ignore the distractor.

Participants completed a practice block before starting the main experiment. Participants were seated and positioned on a chin rest that was 120 cm cm away from the computer display screen. To begin the block of the trials, participants were instructed to press spacebar on the keyboard. Each trial would begin with the fixation display for 500-600 ms. During this time participants would see a fixation circle along with six black lines pointing to six locations that were marked by placeholder circles. Following the fixation display, the cue display would be presented for 500 ms. During this time, the lines would change color. For the target and distractor cue condition, one of these colored lines (red or blue, depending on the participant) would indicate the most likely location of the target and distractor respectively. For the baseline condition, the colored lines would provide no information. Following the cue period, the colored lines returned to black for 250 ms during the post cue period. Next, during stimulus presentation display, one target and one distractor Gabor would be presented for 250 ms, followed by a black screen until participants made a response. Participants' task was to indicate whether the high spatial frequency target Gabor was oriented left or right, while ignoring the low spatial frequency distractor Gabor that could be oriented congruent or incongruent to the target. If the Gabor was oriented left, they had to press 'J' on the keyboard; if it was oriented right, they had to press 'K' on the keyboard. Reaction time was measured using speeded two alternative forced choice (2-AFC) response.

The task for each condition took approximately 1.5hours to complete. Each testing session, consisting of practice test, EEG cap application and main experiment, lasted approximately 90 minutes. A sequence of the task displays is shown in Figure 1A.

EEG. During the main experiment, EEG measurements were recorded for each participant using a Biosemi Active Two system (BioSemi, Amsterdam, Netherlands) consisting of 64 Ag-AgCl sintered active electrodes arranged in an elastic cap (Electro-Cap, USA) and placed according to the 10-20 system. Electrodes were also placed at the right and left mastoids, as well as 1cm lateral to the left and right canthi (horizontal) and above and below each eye (vertical) for EOG. The EX1 and EX2 electrodes were adhered to the right and left mastoids. Data were sampled at 1024Hz and referenced to the average mastoid signal. At the beginning of each data collection session, all impedances were <20 kΩ. Recording took place in an electrically shielded chamber to ensure minimal interference from external sources of electrical noise.

Eye Tracking. Throughout the duration of the experiment, eye movements were calibrated, recorded, and monitored using an eye tracking device (Eyelink 1000 plus, SR Research Ltd, Mississauga, Ontario, Canada). Participants' seated position and distance from the computer screen remained constant using a chin rest. The right eye was tracked at 1000Hz. The task was designed to be gaze contingent. During each trial, participants were required to maintain their gaze within .95° visual angle radius around the central fixation circle. Blinks or inability to maintain eye contact around the fixation circle would result in the trials getting aborted and the participant would need to repeat that trial at the end of the block.

Design. Like the previous two experiments there were two key manipulations in this study. The validity of the cue, when presented, was 80 percent valid. All three conditions had 1320 trials total. In the target cue condition, there were 960 valid trials, 120 invalid-other trials and 120 invalid-distractor trials. In the distractor cue condition, there 960 valid trials, 120 invalid- other and 120 invalid-target trials. In the baseline condition, there were 1200 no cue trials and 120 cue-only catch trials to ensure participants were alert during the task. We also manipulated the congruency of the target and distractor. Each trial type-valid, invalid-other, invalid-target/distractor and baseline- had half congruent and half incongruent trials. For each cueing condition, participants completed 15 blocks of 88 trials.

EEG Data analysis. For each of the three cueing conditions, the following pre-processing steps were implemented and written in custom scripts in MATLAB (version 2019a, Massachusetts, The Mathworks Inc) using EEGLAB toolbox (Delorme & Makeig, 2004). The continuous data were referenced to the average mastoid signal and then high and low pass filtered between .1 Hz and 30 Hz, respectively (EEGLAB function *pop_eegfiltnew*). Then, the data were resampled at 256 Hz (EEGLAB function *pop_resample*) to reduce computation time and memory demands. A two-step epoching approach was used to best align the EEG data with the behavioral data. First, an epoch locked to the fixation onset with 200 ms before fixation and 2000 ms after fixation was created. This captured the entire trial. Baseline correction was performed after epoching. Epochs with eye movements or any aborted trials were discarded. Finally, to examine cue related activity, a smaller epoch locked to cue onset, 200 ms prior and 1120ms after cue onset was created. Baseline correction was performed after epoching. An *a priori* list of scalp electrodes were removed as they were not important to the analyses and frequently prone to being noisy (T7, FT7, F7, AF7, Fp1, Fpz, Fp2, AF8, F8, FT8, T8, AF3, AFz, AF4). The data were then visually inspected and noisy electrodes were excluded (mean electrodes excluded across participants [mean±SEM= 22.27 ± .60]). In order to maintain consistency in the topographic distribution of electrical activity across the scalp, noisy electrodes that were excluded from one condition were also excluded from all other conditions for that subject. Trials exceeding ± 150µV in remaining electrodes were then excluded (mean percentage of trials excluded [mean±SEM excluded: 4.51±.62, baseline: 5.78±1.15, distractor cue: 3.32±.54, target cue: 4.45±1.00]). Only epochs corresponding to accurate (derived from behavioral data performance) validly cued trial data were extracted and used for comparisons. The motivation to examine only the validly cued trials in the target cue and distractor cue conditions (baseline trials had no cue information and some catch trials which were discarded) were based on two reasons. First, there were not sufficient invalid trials for reliable analysis. Also, comparison of the validly cued trials in the target cue and distractor cue conditions to the baseline condition complements the behavioral analysis making the same comparison. Additionally, within the validly cued trials in the target and distractor cue conditions, activity corresponding to both cued and un-cued stimulus could be examined thus contributing further information to what happens in those locations.

Spectral Analysis. Epoched data were filtered using a 3rd order Butterworth bandpass filter (MATLAB function *butter*) from 8-12 Hz (alpha) and 3-7 Hz (theta). A Hilbert transformation (MATLAB function *Hilbert*) was applied to the filtered signal to obtain a measure of instantaneous amplitude and phase. IEM was then performed on evoked power (activity phase locked to cue onset).

Inverted Encoding Modeling (IEM). An IEM was used to estimate spatially selective neural population (channels) response profiles based on the topographical distribution of alpha power across the scalp (Foster et al., 2016). The model first estimates the extent to which the linear combination of *a priori* canonical channel responses (basis set) captures the underlying structure of the observed data, yielding a set of regression weights. The model then uses these weights to estimate the channel response from the observed data. The parameters of these channel response estimates can be used to quantify the spatially selective response (Feldmann-Wüstefeld et al., 2021; Foster et al., 2016; MacLean et al., 2019). In the current study, IEM was used to examine whether, within the validly cued trials, cued and un-cued stimuli could be reconstructed based on location cues in the target cue and distractor cue conditions. In addition, reconstruction of the cued stimulus was compared to the baseline condition to examine brain activity in cued versus no cue conditions.

IEM was performed separately for the cued stimulus and un-cued stimulus. For the cued stimulus, location of the validly cued target was reconstructed in target cue condition, while location of the validly cued distractor was reconstructed in the distractor cue condition. The location labels were shuffled in the baseline condition. For the un-cued stimulus, un-cued target location was reconstructed in the distractor cue condition, the un-cued distractor location was reconstructed in the target cue condition. Since there was no cue in the baseline condition, the location labels were shuffled, and this condition was not used in analysis.

Prior to running the IEM, the minimum number of trials per location bin (n) was calculated across the three cueing conditions for each participant. This was done to ensure that any comparisons between conditions were not influenced by unequal trial counts because of artifact rejection. We randomly selected n-1 trials from each bin, to ensure equal numbers of trial from each location bin were entered into the model. Then, within each location bin, trials were randomly subdivided into three samples and then averaged to create averaged trials per location bin. Following averaging, each condition included 18 averaged trials (6 locations x 3 sample of averaged trials). To ensure that the outcome of the model and subsequent analysis was not influenced by some bias in the way trials were selected, this process was repeated 100 times with a randomized selection of trials entered into the IEM for each of the iterations. An independent IEM was computed for each iteration and each time point over the course of the trials (250Hz EEG sampling rate x 1.35s=338 time points).

The IEM was run separately for each sample in time (338 samples) using evoked alpha and evoked theta power within each condition for each participant. Target, distractor and baseline cue data were stored in three separate blocks, each with one averaged trial per location bin. Next, for each iteration and time point, a k-fold cross validation technique was used, where *k*=3. Training was performed using 2/3 blocks and the resulting model was tested on the remaining block. This was repeated such that each block served as the test block.

For each participant and condition, *m* represents the number of EEG electrodes in each dataset. The number of trials in the training set is denoted by n_1 (2 blocks of 6 trials), and n_2 represents the number of trial in the testing set (1 block of 6 trials).

Let *j* be the number of hypothetical location selective channels (C_1, j x n_1), composed of half sinusoidal functions raised to the seventh power as the basis set. Here the basis set was comprised of 6 equally spaced locations (j=6). B_1 (m x n_1) represents the training set and B_2 (m x n_2) the test set. A standard implementation of the general linear model (GLM) was then used to estimate the weight matrix (W, m x j) using the basis set C_1. Using GLM:

$B_1 = WC_1$ (Equation 1)

Then the ordinary least squares estimate of *W* can be computed as:

$\widehat{W} = B_1 C_1^T (C_1 C_1^T)^{-1}$ (Equation 3)

Using the estimated weight matrix ($\hat{W}$, Equation 2) and the test data (B_2), the channel responses C_2 (j x n_2) can be estimated by:

$\widehat{C_2} = \left(\widehat{W}^T \widehat{W}\right)^{-1} \widehat{W}^T B_2$ (Equation 3)

After the $\hat{C}_2$was solved for each location bin, the channel response function on each averaged trial was then circularly shifted to a common stimulus-centered referenced frame (degrees of offset from channel's preferred location bin) and the centered response functions were averaged across channels. The model was repeated for each time sample (100 times).

The final centered channel response function (CRF) was computed by averaging over the 100 iterations. This was done to ensure the robustness of the model and also to make sure that the outcome was not confounded by the way trials were selected per iteration.

Statistical Testing. To quantify the spatial selectivity, the estimated CRF were folded around 0° of offset, transforming the responses from [-135°, -90°, -45°,0°,45°,90°] to [0°,45°,90°, 135°] by averaging the response at corresponding offsets (0° and 180° were not averaged). Slope was then computed (MATLAB function *polyfit*) as the linear regression weight of evoked power across offset. Large slope values indicate greater spatial selectivity.

At this point, the data were clipped such that time points from -100ms before cue to 1000ms after cue were used in the final statistical analysis. This clipping was done to reduce edge artifacts. Final statistical analyses were conducted on 238 time points. The CRF slope was tested using a one-sample t-test or paired t-tests to examine whether CRF selectivity was reliably above chance. Since CRF may not be normally distributed, a method for non-parametric statistical testing of EEG data was used, while also controlling for multiple comparisons (Maris & Oostenveld, 2007). This non-parametric testing approach is based on clustering of adjacent time-samples. The calculation of the test statistic involves making a comparison between any two trial types of interest by means of a t-value. Then all samples, whose t-value is larger than some pre-determined threshold, are selected. The selected samples are clustered based on temporal adjacency. A cluster level statistic is then calculated by taking the sum of the t-values with a cluster. Finally, the largest of the cluster-level statistic are selected.

Data analysis. There were n=27 participants at the start of data analysis. Incorrect trials and trials faster than 200ms and slower than 1000ms were removed from the data.

Participants (n=3) with accuracy at or below chance in any condition (target, distractor, baseline) were excluded from all conditions. One participant was excluded because the EEG data in one condition had excessive CMR-DRL noise. One other participant was excluded because the EEG data did not save for one condition. Final analyses were conducted on n=22 participants. Trials removed due to threshold rejection in the EEG data were also removed from the behavioral data. In reporting hypothesis testing, for effects that violate sphericity, Greenhouse-Geisser corrected F values is reported. The Holm-Bonferroni correction for multiple comparisons is used for post-hoc tests in all analyses (Holm, 1979).

Results

Behavioral Data. To understand how distraction is modulated as function of distractor cue validity and how this compared to distraction as a function of target cue validity, five main comparisons were made. First, the flanker effect was examined in the baseline condition to ensure there was a reliable flanker effect. Second, flanker effect was compared as a function of cue validity in both the target and distractor cue condition. Third, flanker effect was compared across distractor cue and baseline conditions (replication of experiments 1 and 2). Fourth, flanker effect was compared across target cue and baseline conditions (replicating the distractor cue condition). Finally, the validly cued trials in the target and distractor cue conditions were compared to the no cue trials in the baseline condition, to examine how the flanker effect is modulated as a function of valid target cue, valid distractor cue and no spatial cue (Figure 6).

There was a significant flanker effect in the baseline condition ($t(21)=-8.67$, $p<.001$, Cohen's d=-1.84. A repeated measures ANOVA with congruency (congruent, incongruent), validity (valid, invalid-other, invalid target/distractor) and cue condition (target, distractor) was conducted. There was a main effect of congruency ($F(1,21)= 11.58$, $p<.01$, partial η_p^2

=.36, MSE=10927.64), such that response time was faster on congruent than incongruent trials. There was a main effect of validity ($F(2,42)=48.67$, $p<.001$, partial $\eta_p^2=.70$, MSE=29989.24), such that response time was faster on valid trials compared to both kinds of invalid trials, across both target and distractor cue conditions. There was a significant interaction between congruency and validity ($F(2,42)=3.93$, $p<.05$, partial $\eta_p^2=.16$, MSE=631.22), such that the flanker effect was significant higher in the invalid-target/distractor trials compared to valid trials, across target and distractor cue conditions. Finally, there was an interaction between validity and cue condition ($F(2,42)=36.57$, $p<.001$, partial $\eta_p^2=.64$, MSE=20253.49), such that response time were higher in the invalid trials in the target cue condition compared to invalid trials in the distractor cueing condition. This suggests a higher cost associated with invalidly expectation of where a target would appear compared to an invalid expectation of where a distractor would appear.

To replicate findings from experiments 1 and 2, the flanker effect was compared across distractor cue and baseline conditions. A repeated measures ANOVA with congruency (congruent, incongruent) and validity (distractor valid, distractor invalid-other, distractor invalid-target and baseline) was performed. There was a main effect of congruency ($F(1,21)=20.64$, $p<.001$, partial $\eta_p^2=.50$, MSE=12430.24) such that responses were faster on congruent compared to incongruent trials. There was no main effect of validity and no congruency by validity interaction.

To examine the impact of validity on target cueing, the flanker effect was compared across target cue and baseline conditions. A repeated measures ANOVA with congruency (congruent, incongruent) and validity (target cue valid, target cue invalid-other, target cue invalid- distractor and baseline) was performed. There was a main effect of congruency

($F(1,21)=16.24$, $p<.001$, partial $\eta_p^2=.02$, MSE=8885.44) such that responses were faster on congruent trials than incongruent trials. There was a main effect of validity ($F(3,63)=11.66$, $p<.001$, partial $\eta_p^2=.32$, MSE=135210.05) such that responses were slower in invalid- other (valid- invalid-other =-51.26, SE=13.26, t=-3.87, $p<.01$) and invalid-distractor (valid-invalid-distractor= -63.34, SE=13.26, t=-4.78, $p<.001$) compared to valid trials. Finally, there was a congruency by validity interaction ($F(3,63)=5.62$, $p<.01$, partial $\eta_p^2=.007$, MSE=2797) such that flanker effect was higher in the baseline condition (flanker valid-flanker baseline=-15.42, SE=5.49, t=-2.81, $p<.05$) than in the valid target cue condition.

The flanker effect was then compared across validly cued trials in the target, distractor and no cue trials in the baseline cue conditions, to examine distraction when there is valid expectation of where a target or distractor might appear versus no knowledge of where target and distractor might appear. A repeated measures ANOVA with congruency (congruent, incongruent) and cue condition (valid- target, valid- distractor, baseline cue) was performed. There was a main effect of congruency ($F(1,21)=37.95$, $p<.001$, partial $\eta_p^2=.64$, MSE=7589.32), such that response time was faster on congruent compared to incongruent trials. There was no main effect of cue condition. There was a congruency by cue condition interaction ($F(2,42)=11.36$, $p<.001$, partial $\eta_p^2=.35$, MSE=664.02), such that the flanker effect was lower in both validly target cued (congruent-incongruent= -8.02, SE=3.10, t=-2.59,$p<.05$) and validly distractor cued (congruent-incongruent= -14.04, SE=3.10, t=-4.53, $p<.001$) conditions compared to the baseline condition (congruent-incongruent= -23.44, SE=3.10, t=-7.56, $p<.001$). There was no difference in flanker effect between target and distractor cue conditions. Together these data suggest, validly cueing the location of a target is most effective in reducing distraction. However, compared to no spatial cue, validly cueing the location of a distractor is also beneficial in reducing distraction.

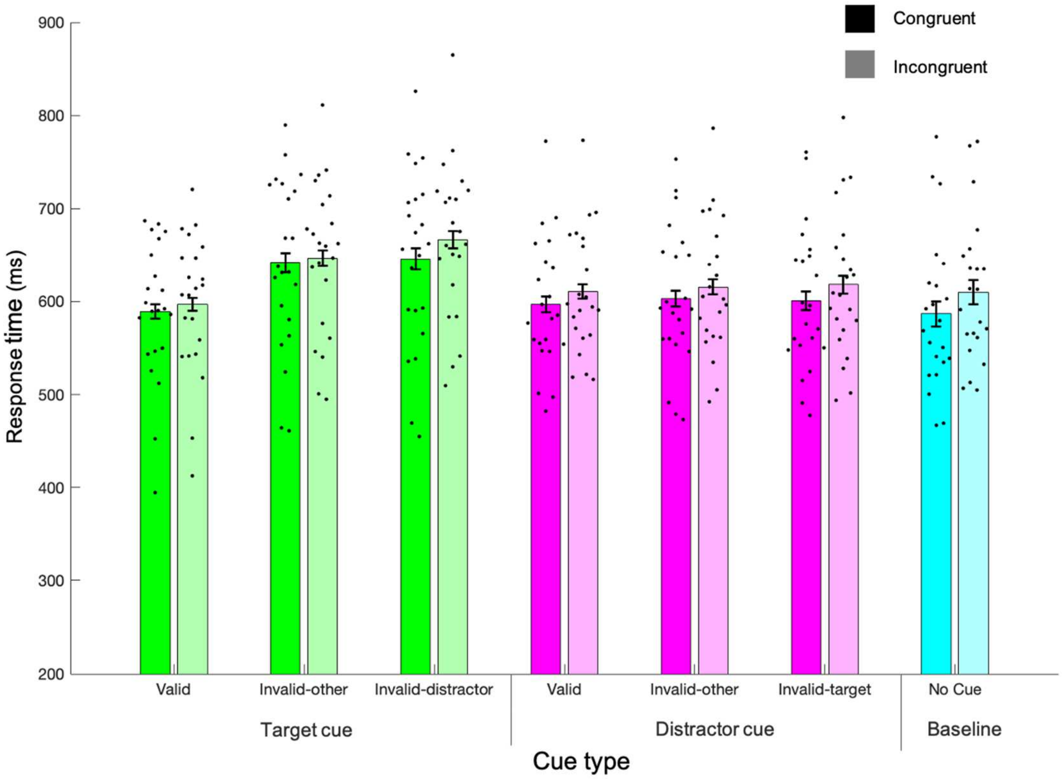

Figure 6: Response time plotted as a function of flanker effect and cue type.

Error rate. A paired t-test conducted comparing congruent and incongruent trials in the baseline condition in the accuracy data was not significant. Thus, no further analyses were conducted on the accuracy data.

IEM. IEM was used to reconstruct representations of cue and stimulus locations in alpha and theta.

Reconstructing cued stimulus locations in alpha band activity

Cued and un-cued stimulus locations were compared within each condition and across condition using one sample t-tests and paired t-tests. Reconstruction of cued stimulus locations were compared to the baseline condition. Only post-stimulus data will be discussed.

Figure 7 shows a one-sample t-test of each cueing condition, along with paired comparisons between each of the conditions. While there is reconstruction of both target and distractor location during the stimulus presentation periods, there is more sustained reconstruction of the cued target location during the cue period compared to the cued distractor location. There is some reconstruction during baseline, which is unexpected and hard to explain. Comparison of cued target versus cued distractor location, showed better selectivity of target location during cue period around 200ms. Comparison of the cued target location to the baseline showed better reconstruction of the target location during the cue period as well as during stimulus presentation. Finally, comparison of the cued distractor to the baseline condition, showed better reconstruction for distractor location during stimulus presentation period, but no difference during the cue period. In summary, in comparison to the target, representation of the cued distractor location is less sustained and delayed. There is no evidence for inhibition as a function of distractor cue.

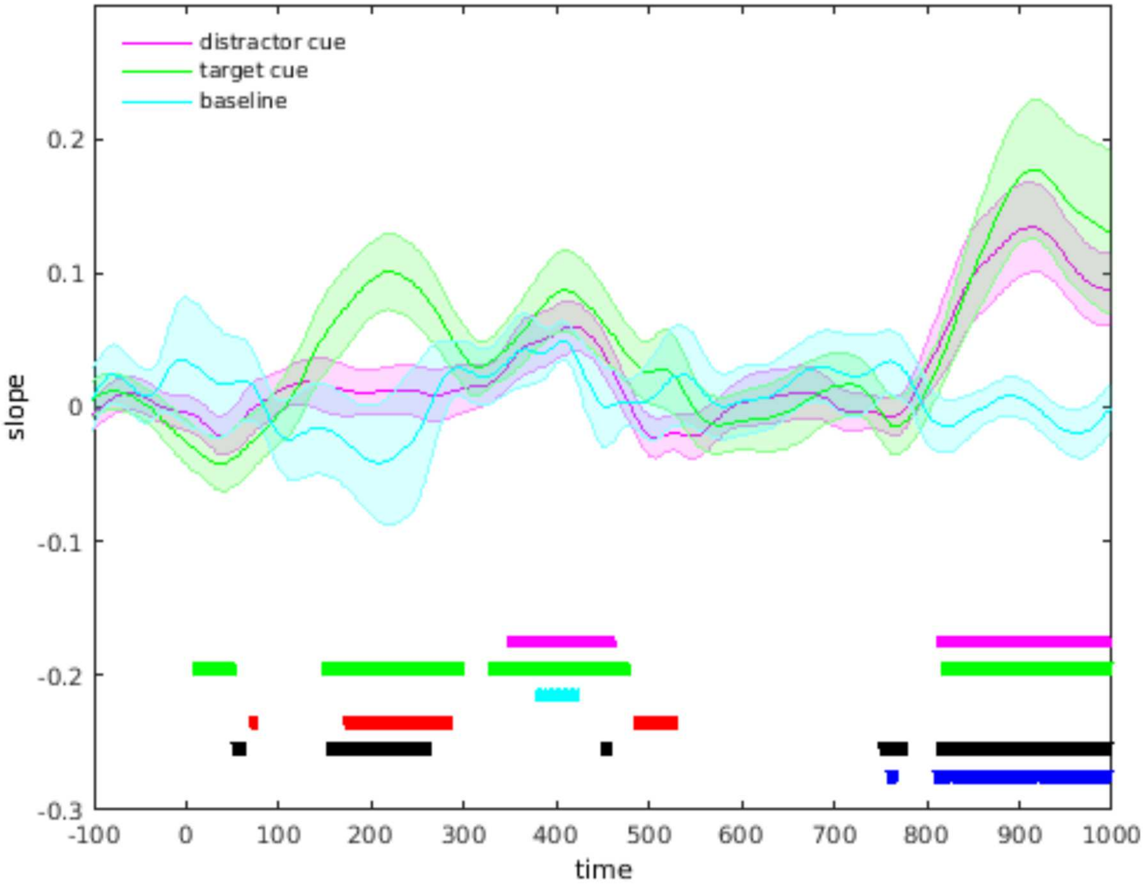

Figure 7. shows one sample t-tests of slope of CRF for each cueing condition in alpha: distractor cueing (magenta), target cueing (green) and baseline (cyan). Pairwise comparisons are also made between each condition: target cue versus distractor cue (red); Target cue versus baseline (black) and distractor cue versus baseline (blue). This and all subsequent comparisons are made at alpha .05, two-sided, cluster corrected for multiple comparisons.

Figure 8 (top) shows better reconstruction for the cued target location compared to the un-cued target location (un-cued stimulus location in the distractor cue condition) around 200ms in the cue period. Similarly, figure 8 (bottom) shows better reconstruction in the cued distractor location compared to un-cued distractor location (un-cued stimulus location in the target cue condition) around 400ms in the cue period.

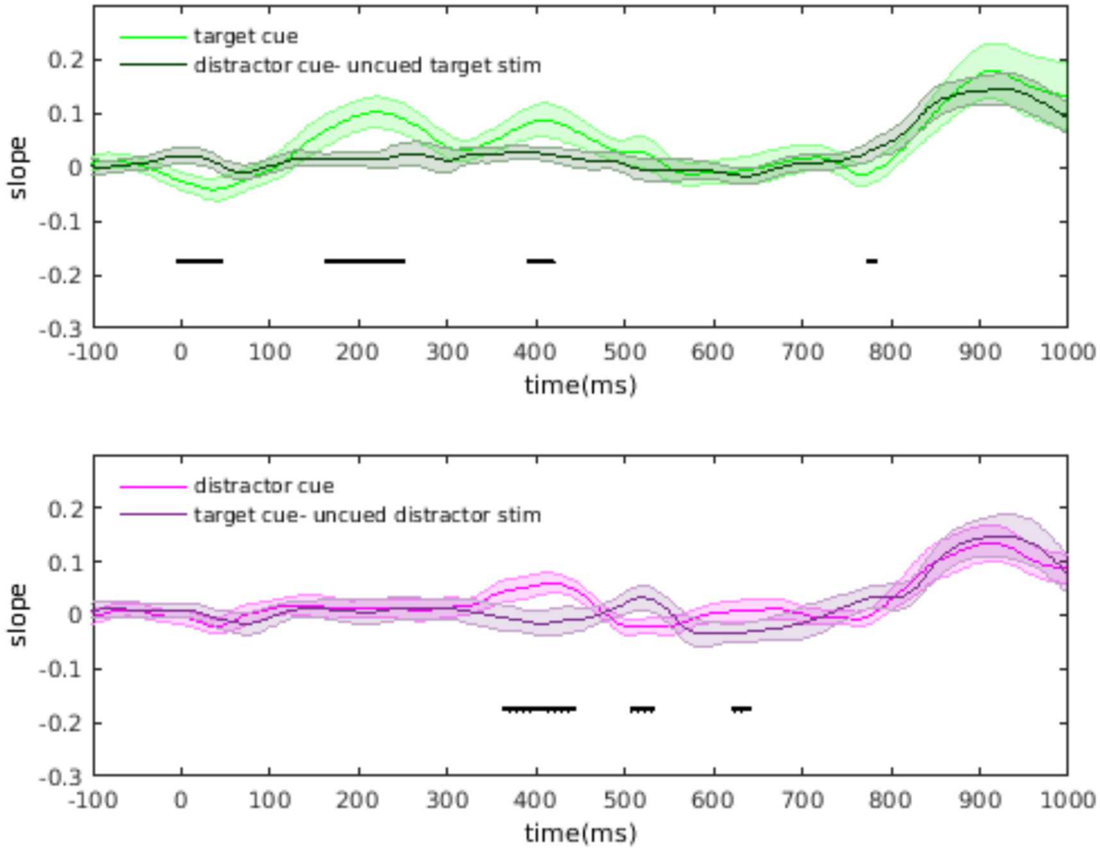

Figure 8. Top panel shows comparison between cued target location and un-cued target location at alpha .05 level. Bottom panel shows comparison between cued distractor location and un-cued distractor location at alpha .05 level.

In Figure 9 (top), there is greater selectivity in the cued target location compared the un-cued distractor location in the target cue condition, around 200ms and 400 ms during the cue period. However, in the distractor cue condition, there is very little difference between cued distractor and un-cued stimulus locations, suggesting perhaps a diffused attention state or attend away mechanism (figure 9 bottom).

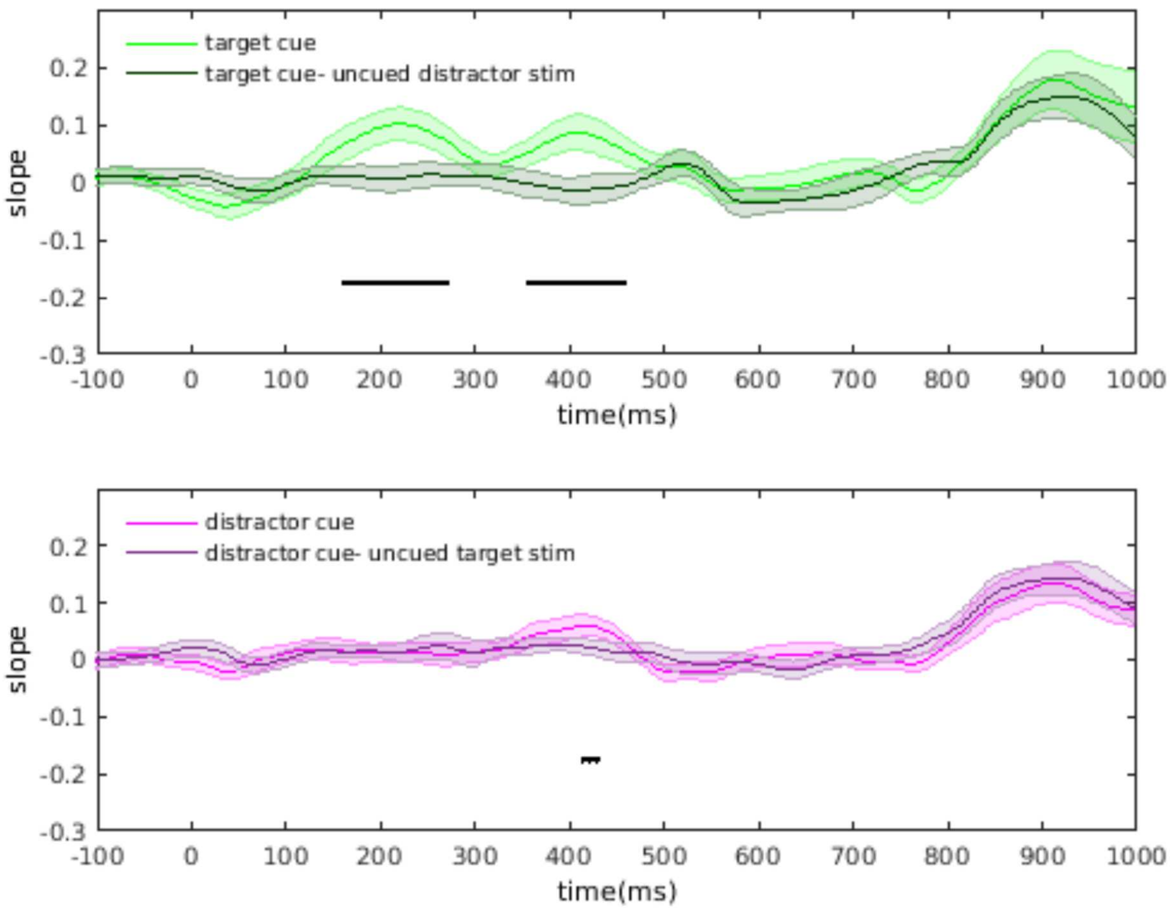

Figure 9. Top panel shows comparison between cued target location and un-cued distractor location in the target cue condition at alpha .05 level. Bottom panel shows comparison between cued distractor location and un-cued target location in the distractor cue condition at alpha .05 level.

Overall, there is reconstruction of the cued target location, suggesting this information is carried in alpha band activity. This is some evidence that the distractor location is represented in the alpha band activity, but little evidence that the representation is inhibited.

Reconstructing cued stimulus locations in theta band activity

The comparisons made above for alpha band activity were also conducted for activity in theta. Figure 10 shows reconstruction in both cued target and cued distractor locations in both cue period and stimulus presentation periods. There is greater selectivity of the cued target location during cue period compared to the cued distractor location. There is greater selectivity for cued target locations and cued distractor locations compared to baseline in both the cue period and the stimulus presentation period.

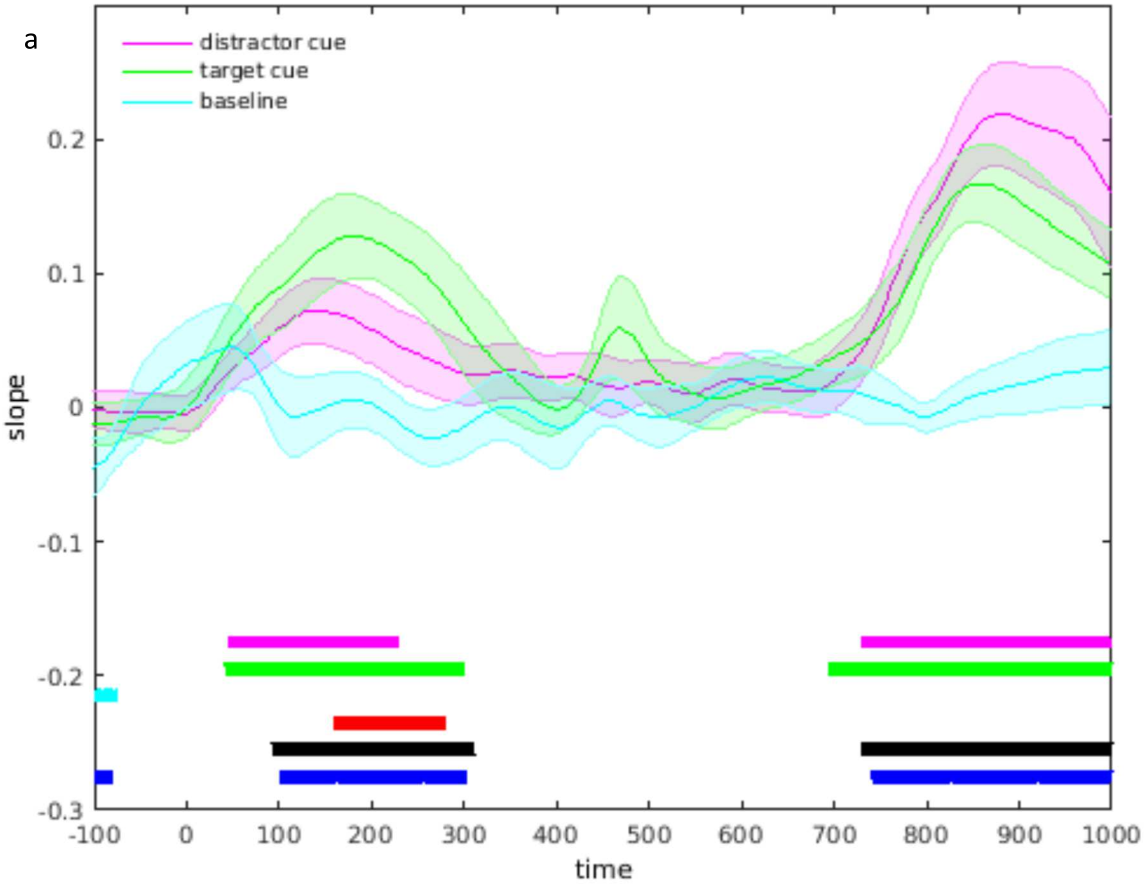

Figure 10. Plot shows one sample t-tests of slope for each cueing condition in theta: distractor cueing (magenta), target cueing (green) and baseline (cyan). Pairwise comparisons are also made between each condition: target cue versus distractor cue (red); Target cue versus baseline (black) and distractor cue versus baseline (blue). All comparisons are made at alpha .05, two-sided.

Figure 11 (top) shows greater selectivity in the cued target location compared to the un-cued target location during the cue period around 100-300ms. Similarly, figure 11 (bottom) shows greater selectivity of the cued distractor location compared to the un-cued distractor during the cue period.

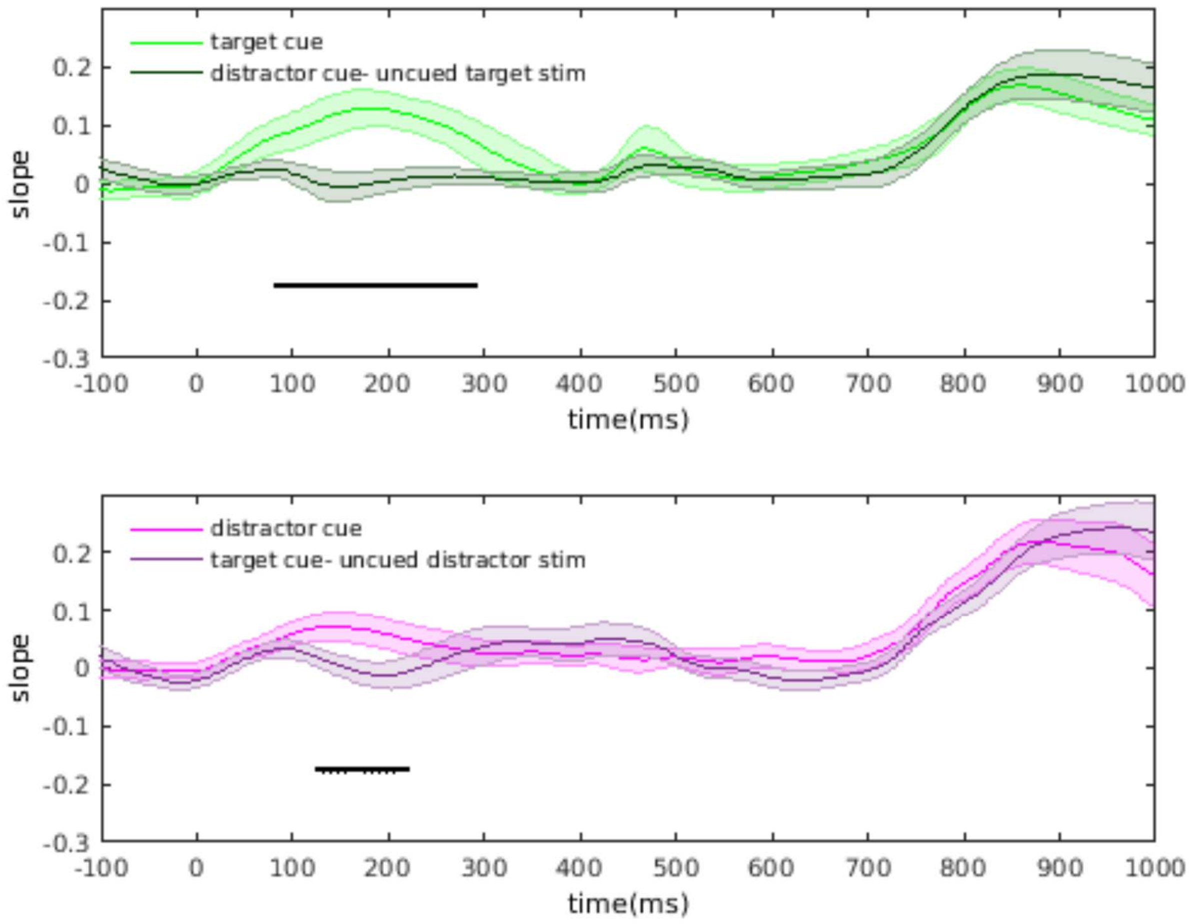

Figure 11. Top panel shows comparison between cued target location and un-cued target location at theta .05 level. Bottom panel shows comparison between cued distractor location and un-cued distractor location at theta .05 level.

Figure 12 (top) shows greater selectivity for the cued target location during cue period compared to the un-cued distractor location in the target cue condition. However, the representation of the distractor is more selectivity during the stimulus presentation period. Figure 12 (bottom) shows higher selectivity of the cued distractor location compared the un-cued target location in the distractor cue condition during cue period between 100-200ms.

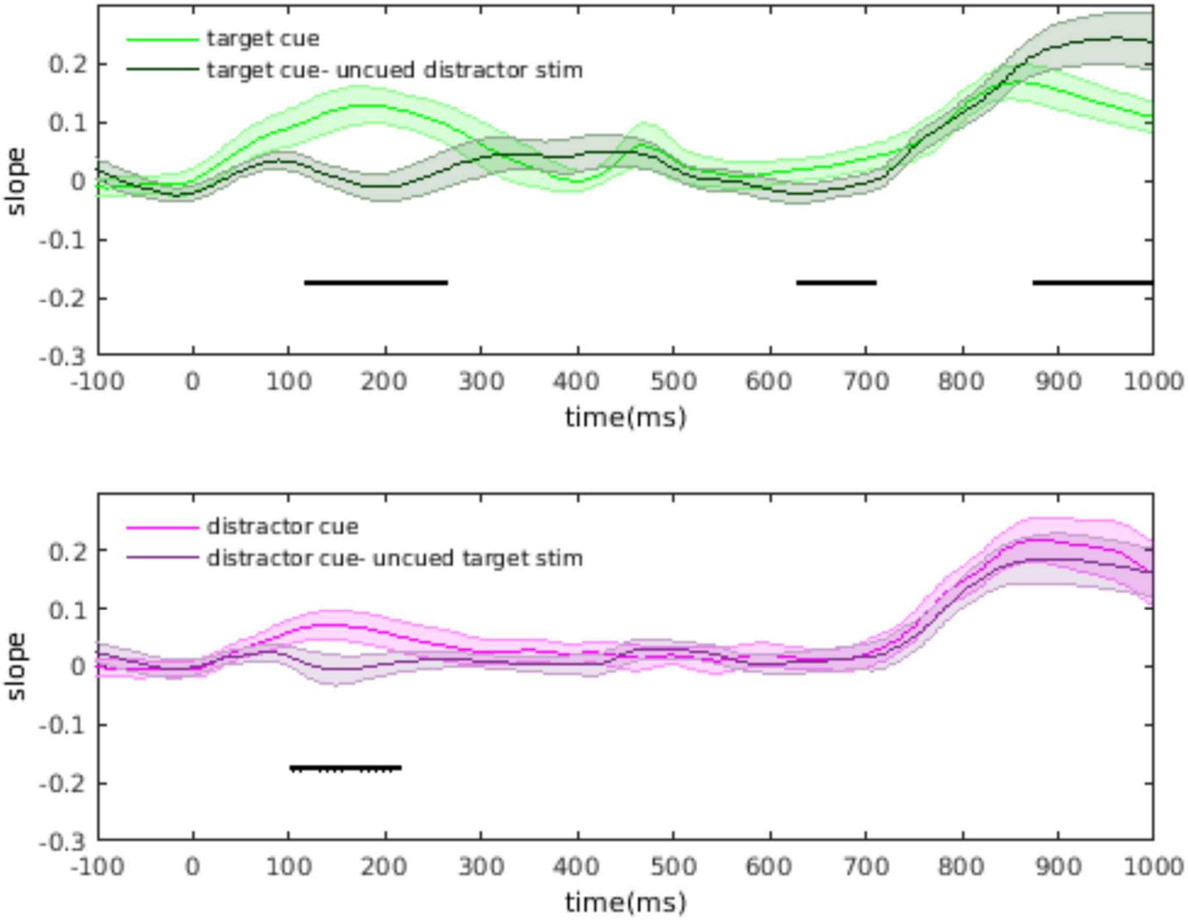

Figure 12. Top panel shows comparison between cued target location and un-cued distractor location in the target cue condition at theta .05 level. Bottom panel shows comparison between cued distractor location and un-cued target location in the distractor cue condition at theta .05 level.

Overall, these findings point to greater representation of the distractor in theta band activity. There is still no indication of inhibition of the distractor.

Discussion

In experiment 3, the location of an upcoming distractor was probabilistically cued and the impact of cue modulation on distraction was assessed. Performance on this distractor cue condition was compared to a target cue. In the target cue condition, the cue probabilistically indicated the location of an upcoming target. Both distractor cue and target cue conditions were also compared to a baseline condition, in which there was no advance information as to the location of the target or distractor. In addition to behavioral data, brain activity was also measured with EEG. IEM was used to model the EEG data to examine whether cued and un-cued stimuli in the distractor cue and target cue conditions could be reconstructed based on location cues. Furthermore, reconstructions from the cued conditions were also compared to the baseline condition.

Comparison of the behavioral data between distractor cue and baseline conditions showed no modulation of distraction as function of distractor cue validity, thus, replicating this finding across three experiments. By contrast, comparison of the target cueing condition to baseline showed reduced distraction in valid target cue condition compared to baseline. Furthermore, invalid expectation of target location was more distracting than invalid expectation of distractor location, suggesting that perhaps valid target cues are more effective in reducing distraction. Critically, however, a comparison of validly cued trials in the distractor cue and target cue condition to the baseline conditions showed reduced distraction in both validly cued target and distractor trials compared to no cue trials in the baseline condition. Together, these suggest that compared to baseline, target cueing is most effective in reducing distraction, followed by distractor cueing. It is possible that increased power in the distractor cue condition made it easier to detect reduced distraction in the validly distractor cued trials compared to the baseline condition.

IEM was used to examine whether cued and un-cued stimuli could be reconstructed based on location cues provided in validly cued target and distractor conditions as well as to compare those reconstructions to the baseline condition. Results show that location of both cued and un-cued stimuli can be resolved from the data. While there is robust representation of the target location in alpha during the cue period, there is very little representation of the distractor location in alpha, suggesting the advanced indication of distractor location during cue period may not be getting used or stored. This is especially evident in the plot that shows greater selectivity of the cued target location compared to the un-cued distractor location during cue period in target cue condition (figure 9 top). By contrast, a similar comparison of the cued distractor location to the un-cued target location shows almost no difference (plot 9 bottom), suggesting that the distractor cue is not used to inhibit the distractor location but perhaps as a signal to diffusely attend to all locations. There is better reconstruction of the distractor during the cue period in theta. Compared to the same plot in alpha, figure 12 (top) shows greater selectivity of the cued distractor location during cue period compared to the un-cued target location. Despite the selectivity observed for the cued distractor location during the cue period, there is no clear evidence that the cue activity subsequently resulted in inhibition at that location. This lack of an explicit signature of inhibition is especially clear when contrasted with a non-cueing paradigms showing evidence of inhibition. Feldmann-Wüstefeld et al. (2021) showed spatially gradient suppression as a function of decreasing distance between target and cue. Using an additional singleton paradigm in which target and distractor locations were independently positioned and thus allowed to occupy the same location, this study was able to show RT costs for singletons adjacent to the target and monotonically decrease to more distant locations. Critically, using the same IEM method using in the current study, evidence for distractor suppression was seen in an inverted channel response function, with the lowest channel activity in theta band at the position of the distractor and a monotonic increase in channel activity as distance from that position increased.

General Discussion

The findings in the current study are most closely aligned with results from Noonan et al., (2016) which had a very similar experimental set up. Noonan and colleagues found that advance knowledge of distractor location only benefits behavior when the location of the distractor was blocked over a number of trials. When distractor location was cued on a trial-by-trial basis, no benefit of this cue was observed. By contrast, benefit of target cueing was observed in both blocked and trial-by-trial conditions. Furthermore, while there were robust task-relevant changes in alpha power for target expectation, there was no evidence for a complementary signal for distractor inhibition. Using a different but complementary paradigm for inducing expectancy, Wang & Theeuwes, (2018a) show that statistical regularities can bias attention such that the location that is likely to contain distractor singleton is inhibited relative to all other locations. However, cueing the location of the distractor singleton on a trial-by-trial basis does not induce the same inhibition effect in either attention capture by the distractor or the efficiency of selection. Furthermore, his lack of active inhibition as a function of cue holds both short and long wait durations between cue and stimulus presentation. This shows evidence for selection history in driving inhibition, rather than top-down inhibition. van Moorselaar & Slagter, (2019) further examined the impact of selection history on distractor processing. In this study, expectation was generated by repeating appearance of target and distractors at certain locations. Unlike Wang & Theeuwes (2018a), in this experiment, the location of the distractor remained constant when it repeated. Behavioral results showed that both target and distractor repetition driven expectation resulted in faster reaction time compared to baseline, although distractor learning took longer to build up. Target location expectation resulted in increased neural tuning to target locations in advance, indicative of preparatory biasing. By contrast, distractor expectation did not change preparatory spatial tuning. Instead, expectation of a distractor appearing at a location reduced the Pd event related potential component, suggesting reduced distractor specific processing. This suggests that once the brain has learned that distractors can safely be ignored, it may no longer process them as distractors. These findings converge on the idea that trial-by-trial cueing the location of a distractor does not result in inhibition at that location. Rather, situations in which learning of distractor location is allowed to build up, selection history is effective in driving spatial-based selection. However, once the location of the distractor stops changing, inhibition may no longer be necessary- that location is simply not processed.

In the current study, only one out of three experiments showed a benefit of distractor cueing over baseline. While other studies have also reported a positive benefit of distractor cue (Heuer & Schubö, 2020; Munneke et al., 2008; Ruff & Driver, 2006b), the mechanism underlying this benefit has been unclear and likely not to be direct inhibition of the cued location.

Noonan and colleagues argue that underlying mechanism in trial-by-trial cueing studies showing behavioral benefits is caused by secondary inhibition, as opposed to direct inhibition of the distractor cued location (Noonan et al., 2018). In this mechanism, neural suppression is spread along inhibitory pathways as a consequence of target facilitation. In the case of the trial-by-trial cueing studies, an indication to “ignore left” is converted to a signal to “attend right” which leads to facilitation of likely target locations before intrinsic competition eventually suppressed the originally cued distractor location. This mechanism does make sense with the findings of the current study, where facilitation of likely target locations in the distractor cueing condition can provide the boosting mechanism lacking in the baseline condition.

The current findings can also be explained by a “tag and avoid” mechanism. Addleman & Störmer, (2021) provide this mechanism as an explanation for their findings. In their study both target and non-target features were cued in a search task. Both target and non-target feature cueing were found to be helpful in comparison to no cueing, however cues to target features resulted in faster response times than cues to non-target features (similar to finding from experiment 3 in current study). Both target and non-target cues were found to increase sensitivity to cued feature relative to un-cued feature. These findings are thought to reflect enhancement of the cued non-target feature, similar to cued target feature, which are then tagged and avoided during search. Since theta is known to be modulated by distractor related activity (Bočková et al., 2013; Green & McDonald, 2008) it is a good candidate for this type of tag and avoid mechanism. Since distractor location was represented during the cue period in theta band activity in the current study, this mechanism is plausible.

Conclusion

Together, these studies suggest that distractors are suppressed when they compete for representation against goal-relevant targets or repeatedly encountered in the visual environment. However, there is little evidence for top-down inhibition of a distractor location as function of a trial-by-trial cue. It is more likely that a cue or preview of distractor location or feature enables an attend away or a tag and avoid mechanism.

Chapter IV

The goal for this study was to examine how distractors are processed. In part I, distractor processing was examined as a function of spatial information available in the display. The motivation for this comparison was to assess predictions made by two theories of attention: LT and TVA. LT posits that attention goes to targets first and any left-over processing capacity goes to distractors. This assumed that location of the target and distractor is known pre-attentively. By contrast, TVA suggests that spatial information is not available pre-attentively and that both target and distractors are processed simultaneously, rather than in a two-step process. By this logic, it was reasoned that explicit knowledge of target and distractor location should make no difference in distraction according to LT, whereas such spatial information would reduce distraction according to TVA. To test these predictions, distraction was compared across displays in which possible target and distractor locations were marked with placeholders to displays in which no spatial information was provided. Result from four experiments show reduced distraction when spatial information was provided compared to when it was not. This shows that 1) spatial information is not available pre-attentively; rather it is computed or builds up over time and 2) in the absence of any expectation or bias, both target and distractors are processed simultaneously.

In part II, the extent to which advance knowledge of distractor location impacts distractor processing was examined. This study was motivated by mixed evidence of reduced distraction when a cue indicates the location of an upcoming distractor. It was also unclear how a distractor cue is represented neurally- whether it results in inhibition at the cued location or a signal to attend away from the location. Furthermore, distractor cueing was also compared to target cueing to examine which has a bigger impact on behavior. To test this, in two behavioral experiments, distraction was measured as a function of a cue that indicated the most likely location of an upcoming distractor or provided no spatial information. Then in a third experiment, the distractor cue task was compared to a target cue task as well as a baseline task. In both the distractor cue and target cue tasks, the cue indicated the most likely location of the distractor or target respectively. In the baseline task, no spatial information was provided. In addition to behavioral data, EEG was also measured to examine cue-evoked activity at the neural level. Results shows mixed benefit of cueing the location of the distractor- reduced distraction as a function of distractor cue was seen only in one out of the three experiments. Comparing the different cueing tasks, cueing the target showed the biggest impact on behavior, followed by cueing the distractor, both of which showed faster response times compared to baseline. Finally, there was no evidence that any benefit observed from distractor cueing was due to inhibition at the cued location.

In summary advance knowledge of distractor location does seem to provide some behavioral benefit against distraction. However, this benefit is not likely due to inhibition and is not as explicit as when advance knowledge of target location is available. This dichotomy suggests a precedent for facilitating goal relevant information in guiding behavior.

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