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Conjunction Search Onset Following Single-Feature Preview: Equating Visual Transients

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CONJUNCTION SEARCH ONSET FOLLOWING SINGLE-FEATURE PREVIEW: EQUATING VISUAL TRANSIENTS

BY

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Bachelor of Science, Saint Mary's University, 2008

THESIS

Submitted to the Faculty of Psychology
in Partial Fulfillment of the
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Master of Science

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Abstract

What happens to visual selection if the features of objects in a scene are viewed incrementally rather than simultaneously? According to Olds et al. (2009), it depends upon which feature is presented first. Olds et al. (2009) used the feature-preview search paradigm to cue conjunction search items by presenting observers with a preview display that contained 1 of 2 features for all of the search items. Prior exposure to some features facilitated subsequent visual selection more than prior exposure to others; overall, size-preview offered the greatest search facilitation, followed by color-preview, and lastly, orientation-preview. Some feature-preview conditions, however, contained luminance transients, while others did not. In the present study, we equated relative differences in luminance onsets, across the different feature-preview conditions in order to determine whether or not feature-preview effects are mediated by luminance transients. The general pattern of results obtained by Olds et al. (2009) was replicated and different feature-previews continued to have differential effects on subsequent search; relative differences in luminance transients did not mediate feature-preview effects. Alternative theories are proposed and discussed.

Introduction

People do a lot of multi-tasking: we make decisions and execute appropriate motor actions while considering incoming information from a number of sensory modalities, at once. Our cognitive resources, however, are limited and our brains compensate for these limitations by selecting only some pieces of sensory information for deeper processing. In considering just vision alone, our physical environment is often constructed of highly complex and volatile visual information; trying to fully process it all would exhaust our mental abilities, leaving no resources for other processes. Our visual system, however, can quickly dissect the physical environment into meaningful fragments and is generally able to allocate further attention to only those fragments appropriate to the task at hand. Since selection of task-relevant visual stimuli is so important, identifying the mechanisms responsible for visual selection may prove vital for fine-tuning our own performance during a variety of tasks.

To examine selective attention, researchers may ask observers to locate a pre-specified target from amongst a set of other items (distractors) in a visual display. In a feature search task, the target differs from all other items on the basis of just one feature (e.g., a red target amongst blue distractors). In a conjunction search task, the target differs from the distractors on the basis of a combination of two or more features (e.g., a red horizontal target amongst blue horizontal and red vertical distractors). By manipulating target and distractor features, researchers can deduce through relative response times the feature differences that most mediate selective attention.

Feature Integration

Before an object can be properly identified, it must first be perceptually segregated from its surrounding environment. Perceptual grouping occurs automatically, with no focused attention, and in parallel across all items in the display (e.g., Treisman & Gelade, 1980). Gestalt psychologists found that perceptual grouping is strongly mediated by similarity, proximity, and common movement among elements of a visual display. Treisman and Gelade (1980) extended those findings with their Feature Integration Theory. Feature Integration Theory proposes that during the parallel perception of features, each feature type is represented within a separate map in the brain. Feature search yields rapid target detection, regardless of the number of items in the display [i.e., response times (RTs) are independent of set-size], and is therefore now generally thought to occur by rapid parallel processing. Object features are perceived first, automatically and in parallel across all items in the visual display; the correct identification of a *conjunction* of features, however, can only follow second and only with focused attention to each item in the display sequence in order to determine whether or not it contains the correct combination of features. Target detection for conjunction search is slower than for feature search, and RTs increase with increases in set-size (the number of items in the search display): a serial search, where each item is processed in sequence until the target is either detected or declared absent (Treisman & Gelade, 1980). Since our visual surroundings are rarely composed of objects that differ on the basis of just one feature, researchers have been interested in understanding the mechanisms driving conjunction search.

Feature Integration in Conjunction Search

Wolfe, Cave, and Franzel (1989) proposed a modification to Feature Integration Theory after noticing an unexpected facilitative effect of parallel feature perception on serial processing. In Wolfe et al.'s (1989) Guided Search Model, instead of sequentially considering items in a random or a pre-set stereotyped order, the serial process uses the feature maps to determine the order of the items to consider, and guides attention first to the item that contains the greatest number of correct features. During parallel processing (the *first* stage), each item is represented across all relevant feature maps. The spatial location to elicit the greatest amount of activation across all maps corresponds to the item that exhibits the greatest number of target-congruent features. The spatial location occupied by that item will in turn tend to gain precedence during serial search, the *second* stage of conjunction search (Wolfe et al., 1989). The theories concerning feature integration suggest that the pre-attentive perceptual organization of features in a display affects succeeding stages of visual processing.

The Preview Benefit

Wolfe et al. (1989) demonstrated that pre-attentive processing guides the path of focused attention (second stage of conjunction search); the prioritization of items in visual search, however, is not always positive. In some cases *de*-prioritization can facilitate performance. In general, if previously viewed distractors are *de*-prioritized, search should be faster because attention will be guided away from those (non-target) items towards the subsequent consideration of other items. If the target appears as a new item after some of the distractors are already present in the display, then search may be even faster (Watson & Humphreys, 1997).

Prior to presenting observers with a conjunction search display (a blue "H" target amongst blue "M"s and green "H"s), Watson and Humphreys (1997) provided observers with one set of distractors that differed from the target on the basis of one feature (green "H""s). When the target was subsequently added to the display, along with the second set of distractors (blue "M""s), conjunction search efficiency matched feature search efficiency for when the first set of distractors was not present (i.e., blue "H" among blue "M"s). In other words, search time was shorter when observers were provided with a preview of half the distractors prior to full exposure to the complete conjunction search display (i.e., "the preview benefit"). Watson and Humphreys (1997) reasoned that prior exposure to half the items (green "H"s) allowed for their inhibition ("visual marking"), which led to the positive prioritization of subsequently presented, newer, items (blue "M"s and the blue "H" target).

Other paradigms have presented different types of partial information before a difficult search display. One example involves color feature search. Color can be described as a location in 3-dimensional space according to luminance, hue, and saturation. Pop-out search occurs for targets that are linearly separable from all other distractors in a display (whose color, for example, can be separated by a line [plane, in 3D] from all other colors in color space; see Bauer et al., 1996). Targets that cannot be linearly separated from all other distractors in the display are detected by difficult search, and search time increases with set-size. The two types of processes are, however, not encapsulated; Olds et al. (2000) showed that pop-out search and difficult search interact. Partially processing a pop-out search display facilitates target detection during the subsequent addition of a set of distractors, when those distractors cannot be linearly segregated from the target. They showed this using a technique in which partial display information was presented prior to an intact search display, but this technique, however, was different from "visual marking" experiments. Olds et al. (2000) interrupted target detection during a pop-out search display, adding a set of distractors that made the pop-out search difficult; observers detected the target more quickly than when presented with the difficult search display alone (i.e., with no prior exposure to the partial information); see Olds et al. (2000) for a description of the analysis used. Even on trials in which the initial display did *not* produce target detection, prior exposure to half the distractors produced partial processing (indicating either target location or target absence) that was available to other, slower search processes.

Feature Preview during Conjunction Search

The visual system's limited capacity produces the need for selective visual attention, and in many cases, mechanisms that prioritize visual sources in an efficient order are necessary when multiple feature dimensions are relevant to a task. Since prior exposure to a portion of the *intact* search display (i.e., a subset of the intact search items) facilitates target detection for a conjunction search (Watson & Humphreys, 1997) or for nonlinearly separable colour search (Olds et al., 2000), Olds and Fockler (2004) reasoned that prior exposure to a *portion of the features* in a display may also serve to speed target detection. Olds and Fockler (2004) presented observers with a color-orientation conjunction search task: a yellow horizontal target among yellow vertical and pink horizontal distractors. Prior to viewing the conjunction search display, observers were first presented with a preview that revealed the location and either the color, or the orientation, of each item in the final conjunction search display. In the **color-feature preview** items were represented by equal sized yellow or pink squares; in the following search display, pink squares lost their top and bottom portions to become pink horizontal bars, and yellow squares lost two sides to become yellow vertical bars (except for one of the yellow squares which lost a top and bottom to become the yellow horizontal target). In the **orientation-feature preview**, items were initially displayed as vertical or horizontal orange bars; in the following conjunction search display, vertical bars became yellow and horizontal bars became pink (except for one of the horizontal bars, which became the yellow target) (refer to Figure 1 for a similar description of a color and orientation-feature preview). RTs for subsequent conjunction search following each feature-preview were compared to each other and to the **control color-orientation conjunction-search** (with no feature-preview) RTs. One striking result was that the two preview conditions had different effects on the efficiency of subsequent conjunction search; color-preview facilitated conjunction search, while orientation-preview hindered it.

Feature Discriminability

The ease of feature search can be manipulated via the target-distractor relationship: when one of the relevant feature dimensions is more distinguishable than another, observers tend to rely more on that easier feature dimension for guidance (Sobel & Cave, 2002). The color and orientation previews used by Olds and Fockler (2004) were not equated for their relative salience. If the colors chosen were easier to discriminate than the orientations, this could explain why the color-feature preview facilitated conjunction search and the orientation-feature preview did not. However, when Olds et al. (2009) roughly equated the orientation and color feature dimensions (based on overall RT vs. set-size slope for feature search), the color-preview still provided more help than the orientation-preview for these stimuli. To extend the findings beyond the combination of color and orientation, Olds et al. (2009) also tested color-*size* conjunction search: previewing item sizes produced more efficient conjunction search than previewing item colors, even though the color *feature* search was easier than the size *feature* search. Feature discriminability therefore cannot predict how effective a particular feature preview is at facilitating subsequent conjunction search. Hannus et al. (2006) provided support for this conclusion by demonstrating that search efficiency in feature search, for a given feature, is not always a good predictor of attention in conjunction search. When observers were provided with only a short time to locate a conjunction search target (approximately the time needed to complete feature search), initial saccades moved to the correct color significantly more often than to the correct size or the correct orientation, even while feature search performance was equal for all feature types.

Attentional Capture by New Item Onset

Given that Olds et al.'s (2009) feature-preview paradigm is related to Watson and Humphreys' (1997) preview-benefit paradigm, the mechanisms suggested to operate on the preview-benefit may apply to Olds et al.'s feature-preview effects. Although Watson and Humphreys (2007) attribute the preview benefit to the inhibition of previously viewed items, it has also been suggested that the benefit is due to the capture of attention by new items and their accompanying luminance onset (Donk & Theeuwes, 2001) or offset (Pratt et al., 2007). Onset stimuli that are presented with a rapid increase in luminance capture attention automatically (Yantis & Jonides, 1984), and when new items appear without a luminance change, the preview benefit fails to occur (Donk & Theeuwes, 2001; Pratt et al., 2007;).[1]

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[1] Jiang et al. (2002) explain the preview benefit another way. Old and new items are separated based upon differences in their temporal onset, and attention is selectively allocated to the new items because they are known to contain the target. Although this theory may be a plausible explanation of the preview benefit, it cannot explain Olds et al.'s (2009) feature-preview effects because there is no temporal segregation between target-congruent

Another aspect of this preview benefit has yielded debate regarding the role of top-down and bottom-up processes. Watson and Humphreys (1997) interpreted the absence of the preview benefit at blank durations less than 400 ms to mean that the inhibition of old items requires time to *develop*; Donk and Theeuwes (2001) attributed this absence, instead, to insufficient time for attention to *disengage* from old luminance onsets before being able to be captured by the new onsets. Donk and Verburg (2004) provided further support for this luminance onset capture explanation by demonstrating that a brief (50 ms) preview prevents the prioritized selection of new over old items (i.e. prevents the preview benefit) only if both the old and the new items appear with luminance onset. When old items were equiluminant to the background, and only the new items were presented with luminance onset, the preview effect still occurred.

It is important to note that the two suggested mechanisms proposed to explain the preview benefit, visual marking and new onset capture, are inherently very different. While the inhibition of previously viewed items involves top-down processes, the automatic capture of attention by luminance onsets operates via bottom-up processes. Attentional capture by new luminance onset/offset is therefore resistant to observer intentions and the influence of instructions while visual marking can be, although not always is, actively manipulated.

Although the evidence supporting the automatic capture of attention during the preview benefit is compelling, it fails to account for results obtained in other studies related to preview effects and does not fully eliminate top-down visual marking as a valid mechanism.

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and target-incongruent search items. Although there is a difference in the temporal onset of preview versus conjunction search items, all of the items are actually presented at once (during the preview) and undergo changes at the same time (during the transition from preview to conjunction search display). Furthermore, temporal asynchrony of feature appearance also fails to explain feature-preview effects since presenting some item features first (e.g., orientation) was not as helpful as presenting other item features first (e.g., color).

Equiluminant elements are found to yield a preview effect with a preview of 3000 ms (Braithwaite et al., 2006), suggesting that visual marking may take longer to emerge with equiluminant items since the marking of old locations is less efficient without the initial capture of attention. Furthermore, while attentional capture by new luminance onset is restricted to 3 or 4 items (Yantis & Johnson, 1990; Yantis & Jones, 1991), visual marking is not and can extend to the inhibition of 30 items (Jiang et al., 2002). Recall that the hypothesized visual marking processes operate via the top-down inhibition of previously viewed items while attentional capture via new item onset operates through bottom-up processes; probe dots are harder to detect at old item locations only when observers are intentionally trying to inhibit old stimuli (Agter & Donk, 2004), suggesting that the preview effect may in fact be subject to observer influence, providing evidence against a purely bottom-up process. Furthermore, Braithwaite et al. (2005) showed that attentionally demanding tasks, if introduced during the preview, can disrupt the preview benefit; this suggests that the preview benefit is not solely bottom-up.

Perhaps more relevant to the feature-preview effects observed by Olds et al. (2009), is the differential effects that luminance transients have on different types of features: the preview benefit is hindered when luminance transients are paired with old items that differ from the new on the basis of shape, but no amount of luminance change to old items (a sufficient change in luminance to existing items can mark them as new items to the visual system; Rauschenberger, 2003) affected the preview benefit when both the new and old items differed on the basis of color (Watson et al., 2008). Why should attentional capture by new luminance onset operate during the selection of shapes, but not during the selection of colors?

Present Study

Can the pattern of results obtained by Olds et al. (2009) be attributed to the bottom-up capture of attention via any luminance transients that occur during the transition from the preview display to the subsequent conjunction search display (or can they be explained in terms of something else)? Some conditions contain relatively large luminance transients (e.g., color-preview before a color-orientation conjunction search, where portions of each preview item decreased in luminance while the items become rectangles) while others were more subtle (e.g., orientation-preview, before color-orientation conjunction search) (refer to Figure 1). For example, since items in the color-preview were accompanied by a change in luminance when they lost tops or sides to become oriented conjunction search items, attention may have been preserved at those locations (because luminance changes capture attention), allowing for their continued prioritization and making subsequent target detection efficient. Items in a orientation-preview display, however, were accompanied by less of an equiluminant change (mainly a change in color). If attention is properly allocated to items in the orientation-preview display, their transition into conjunction search may interrupt attention at those locations, making subsequent target detection slower. It may be argued, therefore, that differences in luminance transients across the different conditions have caused different effects of feature-preview types on conjunction search.

The above rationale, however, cannot fully apply to Olds et al.'s (2009) feature-preview effects. In the color-feature preview conditions, *all* of the items were accompanied by a change in luminance and prioritizing *all* elements in the preview display would not lead to efficient conjunction search. Feature-preview conditions that did contain luminance transients and that did help subsequent conjunction search contained both target-congruent items (e.g., red preview items for a red horizontal conjunction target) and target-incongruent items (e.g., green preview items for a red horizontal conjunction target). Luminance changes to target-incongruent preview items (e.g., green preview items) should disrupt attentional capture of target-congruent feature-preview items (e.g., red preview items), making these feature-previews actually less efficient. Even if the above rationale applies to some of the conditions, it does not apply to all. Olds et al. (2009) reported better size-orientation conjunction search performance after size-preview than after color-preview; however, color-preview involves greater change in luminance at item locations than size-preview (refer to Figure 3).

The substantial amount of evidence against a purely bottom-up explanation of the preview benefit may also serve to argue against a purely bottom-up explanation of Olds et al.'s (2009) feature-preview effects. If the preview benefit is mediated exclusively by the automatic capture of attention via new luminance onset, luminance changes to old items should disrupt the efficiency of attentional capture by new items. Shape changes to old items during the presentation of new items hinder the preview benefit, while color and luminance changes do not (Watson & Humphreys, 2002); and recall, while luminance changes paired to old preview items that differed from the new on the basis of shape hinder the preview benefit, luminance transients paired with differences in color do not (Watson et al., 2008). New luminance transients cannot fully account for differences observed between search for shape and search for color during the preview benefit, and we similarly predict that relative differences in luminance transients will also fail to explain the feature-preview effects observed by Olds et al. (2009).

Overview

To investigate the role that luminance transients may play in the effects of feature-preview on subsequent conjunction search, we modified the paradigm used by Olds et al. (2009); to eliminate the *differential* luminance transients when the conjunction search display appeared across the different conditions, we inserted a blank screen in between the feature-preview display and the full conjunction search display. The blank screen ensures *all* final conjunction search items appear with luminance onset across all of the feature-preview conditions. If attention capture via luminance transients is responsible for the search facilitation afforded by feature preview, the luminance onsets across all of the feature preview conditions should ensure than either all or none of the feature-previews in the present experiment result in conjunction search facilitation.

Experiment 1 sought to replicate Olds et al's (2009) findings to determine whether color-orientation conjunction search is more efficient after color-preview than after orientation-preview, even when the same luminance onsets occur during when the search display appears, in both conditions. To investigate the role of luminance transients further, and to ensure that the results generalize beyond color-orientation conjunction, Experiments 2 and 3 investigated the effects of feature-preview before color-size conjunction search and size-orientation conjunction search. Trials in the different conditions in Experiments 1-3 were presented blocked, so Experiments 4-6 sought to solidify the results obtained by presenting the conditions within intermixed trials. If the present pattern of results resembles the pattern observed by Olds et al. (2009), i.e., if color-preview is more helpful than orientation-preview while size-preview is more helpful than both, we can conclude that differential luminance transients play a minimal role in determining the degree to which a feature-preview will assist subsequent conjunction search.

Experiment 1

Experiment 1 sought to compare the effects of previewing color and previewing orientation before a color-orientation conjunction search, while roughly equating luminance changes that occur between the feature-preview display and the conjunction search display.

Method

Observers

Nine observers with normal or corrected-to-normal vision, including an author, participated in the experiment. Seven of these observers completed Experiment 1 before any of the other experiments described in the present study. Observers were financially compensated for their time.

Stimuli

All search tasks were created using MATLAB and the Psychophysics Toolbox (Brainard, 1997), and performed on a Macintosh G5 computer with Apple Cinema Display.

The conjunction search display consisted of a reddish horizontal target amongst 7, 15 or 23 greenish horizontal and reddish vertical distractors (i.e., set-size of 8, 16, or 24). The search display sequence resembled that used by Olds et al. (2009): each trial began with a 400 ms fixation display. The color-preview display was composed of 8, 16, or 24 reddish (x,y=.345, .328, luminance approximately 8 cd/m2), and greenish (x,y=.338, .365, luminance approximately 8 cd/m2) squares, positioned in the locations of the upcoming conjunction search items. The orientation-preview display was composed of 8, 16, or 24 bluish (x,y =.309, .298; luminance 5.5 cd/m2) horizontal or vertical bars. A blank gray screen followed the feature-preview display for 200 ms. The conjunction search display then appeared and persisted until the observer responded (see Figure 1). For the search display, each item contained a small "L" or "T" in its center; the observer was instructed to press the key that corresponded to the target's letter (as in Olds et al., 2009).

Each bar subtended approximately 0.5 x .03 degrees visual angle, at a viewing distance of approximately 60 cm. The search items were randomly arranged in a search display that was divided into an invisible 6x6 array of potential locations. The whole array of items subtended approximately 7 degrees visual angle.

Procedure

Observers were individually tested in a darkened room. They were asked to make the appropriate key response upon locating the reddish horizontal target in the conjunction search display. The observer was presented with feedback after each trial in the form of a "+" to indicate a correct response and a "-" to indicate an incorrect response; this symbol also served as a fixation stimuli for the following trial. There were 4 experimental sessions. Each experimental session included one block of trials for each of the three experimental conditions (orientation feature preview, color feature preview, and conjunction search), each included 5 practice trials followed by 96 experimental trials. Each observer completed a total of 1,152 experimental trials. We decided to use few observers with many trials in order to minimize between subjects variability. We reduced fatigue effects by conducting two sessions per day and offering observers many opportunities to take a break throughout the session trials.

Results

RTs more than three standard deviations away from the mean for each condition and observer were removed. This procedure resulted in the removal of 1.6% of trials overall. Figure 2 plots the mean RTs and error rates vs. set-size, for the three conditions.

RTs for correct trials, from all three conditions, were entered into an ANOVA with condition and set-size as factors. The main effect of set-size was significant [$F(2,18)=107.10$, $p<=.0001$]; in all analyses below this effect was significant and it will not be mentioned further. The main effect of condition was significant [$F(2,18)=18.622, p<=.0001$], as was the interaction of set-size and condition [$F(4,36)=6.1247, p=.0009$]. Mean RT, and the effect of set-size on RT, differed between the three conditions. Both of these results replicate those found by Olds et al. (2009); recall that they tested search *without* inserting a blank screen in between the feature-preview display and the search display.

Conjunction search control vs. Conjunction search preceded by color-feature preview and blank screen: Correct RTs from the conjunction control condition and the color-preview condition were entered into an ANOVA with condition and set-size as factors. The main effect of condition was significant [$F(1,9)=22.379$, $p=.0015$]: color preview made search faster overall. The main effect of set-size was also significant [$F(2,18)=95.905$, $p\leq 0.0001$], however, the interaction of set-size and condition was not significant [p>.4]: the effect of set-size on RT did not differ between the two conditions. Both of these results (i.e., significant main effect but no significant interaction) replicate those found by Olds et al. (2009) *without* blank screen in between feature-preview display and search display.

Conjunction search control vs. Conjunction search preceded by orientation-feature preview and blank screen: The main effect of condition did not reach significance [marginally significant; F(1,9)=4.3358, p=.0709]. The finding that the main effect did not quite reach significance is the only difference between this set of results and the results found by Olds et al. (2009), despite the potentially major difference that in the present study a blank screen intervened between the partial/feature information and the full search display. The interaction of set-size and condition was significant [F(2,18)=10.675, p=.0011] in this experiment, just as we found previously (Olds et al., 2009). This significant interaction can be seen in the graph as a greater set-size slope for the orientation-preview condition.

Color-feature preview vs. Orientation-feature preview: The two feature-preview conditions were compared in a separate ANOVA. Both the main effect of condition [F(1,9)=38.810, p=0.0003] and the interaction of set-size and condition [F(2,18)=7.8207, p=0.0043] were significant. Both of these results replicate those found by Olds et al. (2009). The present purpose is not so much to compare individual conditions in the present experiment to those same conditions in the previous study; instead we seek to focus on the overall pattern of results, comparisons between the different conditions, *within* each of the two studies.

Error rates from all three conditions were entered into an ANOVA with condition and set-size as factors; no effects reached significance.

Discussion

Even with a blank screen inserted in between the feature-preview display and the color-orientation conjunction search display, color-preview was more helpful to search than orientation-preview. This difference in feature-preview usefulness cannot be attributed to luminance transients, given that the conjunction search display appeared with luminance onset across all three conditions. Something about color makes it more useful than orientation in serving as advance information preceding conjunction search that cannot be explained in terms of automatic attentional capture via luminance onsets; can the same be said when comparing effects of other feature-previews?

Experiment 2

In order to ensure that conclusions based on the results in Experiment 1 generalize across different types of feature dimensions, we replicated Experiment 1 for a color-size conjunction search. We compared the effects of previewing color and previewing size before a color-size conjunction search, while roughly equating luminance changes between the feature-preview displays and the conjunction search displays by inserting a blank screen in between the feature-preview display and the conjunction search display.

Method

Observers

Nine observers (including two authors) participated, all with normal or corrected-to normal vision. Two of these observers had participated in Experiment 1 previously, while 2 others had previously participated in Experiment 3. Observers were financially compensated for their time.

Stimuli

The conjunction search display in Experiment 2 consisted of a small reddish target (.3 x .3 degrees visual angle) amongst large reddish items (.5 x .5 degrees visual angle) and small greenish distractors. The reddish and greenish colors were the same as used in Experiment 1. All other aspects were the same as in Experiment 1, but with size-feature preview replacing orientation-feature preview, and color-size conjunction search replacing color-orientation conjunction search. (Refer to Figure 3).

Procedure

The procedure was the same as that of Experiment 1.

Results

RTs more than three standard deviations away from the mean for each condition and observer were removed; this resulted in the removal of 1.4% of trials overall.

Figure 4 shows the mean RT and error rate versus set-size, for the three conditions. RTs for correct trials from all three conditions were entered into an ANOVA with condition and set-size as factors. For the three conditions taken together, the main effect of condition was significant [F(2,18)=9.9926, p=.0015], along with the interaction of set-size and condition [F(4,36)=7.3721, p=.0003]; just as for Olds et al. (2009) despite the addition of a blank screen in between the present feature-preview display and the search display.

Conjunction search control vs. Conjunction search preceded by color-feature preview and blank screen: The main effect of condition was *not* significant [p>0.8] in the present study. With no differences in luminance transients, color preview, at present, did not facilitate color-size conjunction. This is a difference between the present study and that of Olds et al. (2009), who found this particular main effect to be significant, based on much slower search for color-preview for set-size 24 (Figure 4 shows that this trend exists in the present results as well) and no difference between conditions for set-size 8. The present interaction of set-size and condition was significant [F(2,18)=13.626, p=.0004] (just as for Olds et al., 2009); search slowed with increasing set-size more if search followed color-preview than if it did not.

Conjunction search control vs. Conjunction search preceded by size-feature preview and blank screen: For control conjunction search versus search after size-feature preview, we saw two differences from the previous Olds et al. (2009) study: in the present experiment, the main effect of condition *was* significant [F(1,9)=26.580, p=.0009], whereas it was not significant, for Olds et al. (2009). On the other hand, the present interaction of set-size and condition did not reach significance [p>.15]; it did however reach significance, for Olds et al. (2009).

Color-feature preview vs. Size-feature preview: The main effect of condition [F(1,9)=14.519, p=0.0052], and the interaction of set-size and condition [F(2,18)=5.6038,p=0.0143], were both significant. These two results replicate those of Olds et al. (2009). Again, we seek to replicate not individual statistics or mean RTs, but an overall pattern of results (which in both studies are within-subject), for which we provide this comparison.

Error rates from all three conditions were entered into an ANOVA with condition and set-size as factors; no effects reached significance.

Discussion

While size-feature preview helped color-size conjunction search, color-feature preview did not. Luminance transients cannot account for this difference in feature-preview effects because the blank screen ensured that all of conjunction items, in all the conditions, appeared with luminance onset.

In the present study the size-preview made search faster overall (significant main effect), whereas Olds et al. (2009) reported faster conjunction search for size-preview of smaller set-size *only* (leading to an *increase* in apparent set-size slope, i.e. *decreased* efficiency, but no main effect of condition for this comparison). In both studies, size-preview was more helpful than color-preview; the difference is for which set-sizes this occurred (this comparison is not exact, because the present study included three set-sizes (8, 16, 24) while Olds et al. (2009) used only two (8, 24). In Olds et al. (2009) [the transition from size-preview to color-size] appearance of the color-size conjunction search display involved less luminance transients than in the present study, and although search after size-preview was at present more efficient, what is important for the present purposes is that size-preview was more helpful than color-preview in *both* studies. Recall that color-feature preview helped color-orientation conjunction search in Experiment 1; pairing *size* with color, however, somehow interfered with the color-preview's potential to aid conjunction search, and this difference is independent of luminance transient effects. What effect will pairing *orientation* and size have on feature-preview for orientation-size conjunction and will luminance transients again fail to play a significant role?

Experiment 3

Experiment 3 compared the effects of orientation-feature preview and size-feature preview on an orientation-size conjunction search, while roughly equating luminance transients in both conditions.

Method

Observers

Six observers, including two authors, all with normal or corrected-to-normal vision, participated in the experiment. Two of these observers had not participated in any of the experiments prior to participating in Experiment 3.

Stimuli

The method was the same as for Experiment 1 but for size-orientation conjunction search rather than the color-orientation conjunction search, and with size-feature preview rather than color-feature preview. (See Figure 5)

A small horizontal target was presented among large horizontal distracters and small vertical distractors. All the search items were blue-gray (x,y=.309, .298; luminance=8 cd/m2).

Procedure

The procedure was the same as that for Experiment 2.

Results

RTs more than three standard deviations away from the mean for each condition and observer were removed (1.8% of trials overall). Figure 6 shows mean RT and error rate, versus set-size, for the three conditions. RTs for correct trials from all three conditions were entered into an ANOVA with condition and set-size as factors. The main effect of condition was significant [F(2,12)=22.270, p=.0002], as was the interaction of set-size and condition [F(4,24)=5.8759, p=.0027].

Conjunction search control vs. Conjunction search preceded by orientation-feature preview and blank screen: For this comparison, the main effect of condition was not significant [p>.1] but the interaction of set-size and condition was [F(2,12)=12.085, p=0.0021]. This pattern of results replicates exactly that of Olds et al. (2009), who also found this interaction to be significant, but not the main effect of condition.

Conjunction search control vs Conjunction search preceded by a size-feature preview and blank screen: This comparison yielded a significant main effect of condition [F(1,6)=47.841, p=.0010] but the interaction of set-size and condition was *not significant* [p>.4]. This is again the same pattern of results as that of Olds et al. (2009).

Orientation-feature preview vs Size-feature preview: This comparison yielded a significant main effect of condition was significant [F(1,6)=27.572, p=.0033] and the interaction of set-size and condition [F(2,12)=6.3239, p=.0168], again just as for Olds et al. (2009).

Discussion

Size-preview was much more helpful than orientation-preview, for size/orientation conjunction search. In fact, orientation preview interfered with this conjunction search (in particular for larger set sizes, see Figure 6).

Note that in the comparison between search after orientation-preview and search after size-preview, both situations involved some sort of luminance transient at the location of each item when the conjunction search display appeared, (in the present study *and* in that of Olds et al., 2009). Thus transients were generally equivalent and the difference between search after size-preview and search after orientation-preview cannot be explained as disruption by transients in some items and not others. In the present study the transients have been made still more equal, by the insertion of a blank screen in between the feature-preview display and the subsequent conjunction search display.

Experiment 4

Experiment 1 found that color-preview facilitates color-orientation conjunction search more than orientation-preview, even when luminance transients were equal across all conditions. Experiment 4 sought to replicate those findings while presenting the conditions in mixed, instead of blocked, trials so that observers are not informed of the nature of the task or target before the trial even commences. Feature-preview conditions without the blank screen were also added in order to *statistically* compare the effects of having differential expression of luminance transients with not having those differential expressions, instead of only relying upon Olds et al.'s (2009) prior results as a comparison. Trials with feature-previews not followed by blank screens (before the search display) [and therefore characterized by differential expressions of luminance transients] were compared to trials with feature-previews that were followed by a blank screen that persisted for either 200 or 500 ms (and then the search display). Two different blank screen durations were used in order to compare the effects of both a recent, and perhaps a stronger, feature-preview representation and a slightly more decayed feature-preview representation.[2] The general pattern of feature-preview effects obtained by Olds et al. (2009), were also obtained in Experiments 1-3 of the present study. If the pattern is again replicated across Experiments 4-6, then any conclusions made would be supported by three different sets of experiments.

Method

Observers

Nine observers (including two authors) participated, all with normal or corrected-to normal vision and normal color vision. Five of these observers had participated in Experiment 1-3 prior to Experiment 4.

Stimuli

Experiment 4 included the same stimuli as used in Experiment 1 but with a few minor modifications to the trial sequences used: Experiment 4 included all three conditions from Experiment 1, but with two blank screen durations (200 and 500 ms) and, in addition, feature-

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[2] Inhibition of return (IOR) (Klein, 1988), the impaired detection of a previously selected target location, occurs at an SOA between 350 ms- 1500 ms (Posner and Cohen, 1984; Klein, 1988). If feature-preview effects are replicated at both blank screen durations, we may be able to also exclude IOR as a determinate of these feature-preview effects.

previews with no blank screen. There were 432 trials per session and each observer completed two sessions for a total of 864 trials. Trials from all of the conditions were presented intermixed and in a random order.

Procedure

The procedure was the same as that from Experiments 1-3.

Results

RTs more than three standard deviations away from the mean for each condition and observer were removed resulting in the elimination of 1.4 % of the trials overall.

RTs for correct trials from all three conditions were entered into an ANOVA with condition and set-size as factors. Figure 8 shows mean RT and error rate, versus set-size, for the three conditions (at three different blank-durations: 0, 200 ms, and 500 ms). The main effect of condition was significant [F(2,18)=31.388, p<.0001]. The interaction of set-size and condition also reached significance [F(4,36)= 3.2485, p=.0241]. The main effect of set-size was significant in all of the present experiments. In all of the following comparisons, RTs for correct trials were entered into an ANOVA with condition and set-size as factors. Blank-duration was included in the comparison of the two feature-previews in all of the experiments from this point forth.

Conjunction search control vs. Conjunction search preceded by color-feature preview with and without a blank screen: This comparison generated a significant main effect of condition [F(1,9)=42.965, p=0.0002]. Color-feature preview generated faster response time than conjunction search alone, and search time increased with increases in set-size across both conditions. These findings replicate both the findings in the present Experiment 1, which did not include feature-preview trials with blank screens, and those of Olds et al.'s (2009) which did *not* include trials with blank screens.

Conjunction search control vs Conjunction search preceded by an orientation-feature preview with and without a blank screen: The main effects of condition [F(1,9)=7.2381, p=0.0275] was significant for this comparison. Search was actually worse when conjunction search followed an orientation-feature preview than when it was presented alone. There was also a significant interaction of condition and set-size [F(2,18)=7.7495, p=.0044]. The present findings are the same as those of Olds et al. (2009), but different than those of Experiment 1. Experiment 1 generated no significant main effect of condition, and no significant interaction of condition and set-size. Although the differences in findings across the three different experiments do not impact the general conclusion that can be made about each, that orientation feature-preview did not help conjunction search regardless of differences in luminance transients, it is important to note the differential effects of blocked (Experiment 1) versus inter-mixed (present experiment) conditions.

Color-feature preview vs Orientation-feature preview: a significant main effect of condition [F(1,9)=31.421, p=0.0005) was observed for this comparison: search after color-feature preview was performed more quickly than search after an orientation feature-preview. This comparison also yielded a significant main effect of blank-duration [F(2,18)=4.8898, p=.0220] meaning that the two feature-previews are affected in the same way by both set-size and blank-duration; search time increased with increases in set-size and blank-duration across the two conditions.

Discussion

When the relative differences in luminance transients between color-feature preview and orientation-feature preview were eliminated in Experiment 2, both feature-previews still had different effects on subsequent color-orientation conjunction search. Inter-mixing all conditions in Experiment 4, including trials without a blank-screen (i.e., that were not controlled for relative differences in luminance transients), did not change the pattern of effects: color-feature preview facilitated subsequent conjunction search while orientation-feature preview did not.

Experiment 5

Experiment 2 found that while size-preview facilitates color-size conjunction search, color-preview does not. Experiment 5 sought to replicate those findings while presenting trials from the different conditions in intermixed order, and along with trials without a blank screen, in order to *statistically* compare the effects of luminance transients (within one experiment).

Method

Observers

Twelve observers (including two authors) participated, all with normal or corrected-to-normal vision and normal color vision. Nine of these observers hard participated in prior experiments.

Stimuli

Experiment 5 included the same stimuli as Experiment 2, but with two durations of blank screen (200 or 400 ms) rather than just one, and color-feature and size-feature preview trials with no blank screens. Each observer completed two sessions, 432 trials in each, for a total of 864 trials. Trials from all of the conditions were presented intermixed and in a random order.

Procedure

The procedure was the same as that from Experiment 1-4.

Results

RTs more than three standard deviations away from the mean for each condition and observer were removed (1.6% of trials overall). Figure 10 shows mean RT and error rate, versus set-size, for the three conditions across the different blank-durations. RTs for correct trials from all three conditions were entered into an ANOVA with condition and set-size as factors. The main effect of condition did not reach significance [F(2,24)=3.1209, p= 0.0641], while the main effect of set size [F(2,24)=166.46, p= 0.0104) did. The interaction of set-size and condition was also significant [F(4,48)= 5.603, p= 0.0010]. RTs for correct trials were entered into an ANOVA with condition, set-size as factors for all of the following comparisons.

Conjunction search control vs. Conjunction search preceded by color-feature preview with and without a blank screen: The main effect of condition was not significant. There is no difference in search time for color-size conjunction search when presented alone or when presented following a color-feature preview. There was, however, a significant interaction between condition and set-size [F(2,24)=10.479, p=0.0006]. Figure 10 shows that color-feature preview did not have a significant effect on subsequent color-size conjunction search, but it was, however, less efficient than control color-size conjunction search. Experiment 2, which did not include feature-preview trials without blank screens, also failed to produce the significant main effect of condition that was produced by Olds et al. (2009). These differences in findings, however, do not change the general pattern of results. Equating the relative differences in luminance transients between color-preview conditions failed to equate their relative effects on subsequent conjunction search. (Figure 10 includes three plots, one for each blank-duration, depicting RT versus set-size across the three conditions; refer to the dark solid line, and light gray circles across the three panels to see the difference in RT for conjunction search and color-preview, respectively)

Conjunction search control vs Conjunction search preceded by a size-feature preview with and without a blank screen: The present comparison generated a significant main effect of condition [F(1,12)=8.4014, p=0.0145]. Previewing size facilitated subsequent search for color-size conjunction target. These findings are the same as in Experiment 2. Size-feature preview facilitated search overall.

Color-feature preview vs Size-feature preview: The main effect of condition was not significant and there were therefore no significant differences in search time for size-feature preview conditions and color-feature preview conditions. The only significant main effects generated by this comparison other than set-size was blank-duration [F(2,24)=4.9751, p=0.0165]. This pattern of results does not entirely reflect that obtained in Experiment 2 which did yield a significant main effect of condition when color-feature preview was compared to size-feature preview. It, however, does not change the general pattern of results: although color-preview and size-feature preview are not significantly different in the present experiment they are different enough to have different effects on final conjunction search even when they are characterized with equivalent levels of luminance transients.

Discussion

Although there was no significant main effect of condition between size-feature preview and color-feature preview, the general pattern of results still follows that obtained in Experiment 2 and by Olds et al (2009): size-feature preview facilitated color-size conjunction search while color-feature preview did not.

Set-size had a significant effect on search time across all of the conditions, although it affected some conditions more than others: color-feature preview was more effect by increases in set-size, and therefore less efficient, than color-size conjunction search. Inserting the blank screen after a feature-preview was intended to control for relative differences in luminance transients. If differences in feature preview effects were solely dependent upon differences in luminance transients, then inserting the blank screen should have equated the amount of search facilitation afforded by each feature-preview, under *all* circumstances; which it did not as there were still differences in the effects of size-feature preview and color-feature preview on conjunction search. Furthermore, equating relative differences in luminance transients in the Experiment 4 failed to have as large an effect on orientation-feature preview as it did on color-preview in the present experiment. Inserting the blank screen, therefore, influenced some feature-previews more than others suggesting that this interaction has less to do with luminance transients and more to do with the nature of the feature. Perhaps something about previewing color in the present experiment interacts better with equating luminance transients than previewing orientation in the past experiment. This idea is discussed further in the general discussion below and is explained by theories that extend beyond just differences in luminance transients.

Experiment 6

Experiment 3 found that while size-preview facilitates color-orientation conjunction search, orientation-preview actually hindered it. The goal of Experiment 6 was to replicate those findings while presenting the conditions in mixed, instead of blocked, trials. As in Experiment 4 and Experiment 5, feature preview conditions without the blank screen were also included into the group of conditions.

Method

Observers

Nine observers (including two authors) participated, all with normal or corrected-to-normal vision and normal color vision. Six of the observers participated in experiments prior to Experiment 6.

Stimuli

Experiment 6 included orientation-feature and size-feature preview conditions that did not contain any blank screens, along with orientation-feature and size-feature preview conditions that did contain blank screens (either 200 or 400 ms duration). Each observer completed a total of 864 trials, split into two sessions of 432 trials. Trials from all of the conditions were presented intermixed and in a random order.

Procedure

The procedure was the same as that from Experiment 1-5.

Results

RTs more than three standard deviations away from the mean for each condition and observer were removed (1.9% of the trials overall). Figure 10 shows mean RT and error rate, versus set-size, for the three conditions across all three blank-durations. RTs for correct trials from all three conditions were entered into an ANOVA with condition, and set-size as factors. The main effect of condition [F(2,18)=27.078, p<0.0001], was significant.

Conjunction search control vs. Conjunction search preceded by orientation-feature preview with and without a blank screen: The main effect of condition was not significant when comparing conjunction search control to conjunction search preceded by an orientation-preview. Even when all preview items were made to appear with new item onset, orientation-feature preview still failed to facilitate subsequent conjunction search. The only significant main effect produced by this comparison is set-size [F(2,18)=89.697, p≤0.0001], which is also the only difference between these findings and both those of Experiment 3 and those obtained by Olds et al. (2009). In Experiment 3 and Olds et al. (2009) this comparison generated a significant interaction between set-size and condition. In the present experiment, orientation-feature preview failed to help conjunction search.

Conjunction search control vs Conjunction search preceded by a size-feature preview with and without a blank screen: This comparison generated a significant main effect of condition [F(1,9)=28.999, p=0.0007]: conjunction search was performed more quickly if it followed a size-feature preview than when it was presented alone. This was the same as was shown in Experiment 2 and for Olds et al. (2009).

Orientation-feature preview vs Size-feature preview: The main effects of condition [F(1,9)=51.669, $p\leq0.0001$] and blank-duration [F(2, 18)=6.2986, p=0.0096] were significant. Size-feature preview produced significantly faster conjunction search than orientation-feature preview at all set-sizes in the present experiment. This effect is slightly different than the results obtained in Experiment 3 and for Olds et al. (2009) who reported a significant interaction between set-size and condition.

Discussion

In accordance to the findings obtained in Experiment 3 and by Olds et al. (2009), size-feature preview was more effective than orientation-preview at facilitating orientation-size conjunction search.

The present experiment included the same feature-previews used by Olds et al. (2009) in addition to feature-previews that were followed by a blank screen (for either 200 or 500 ms) before the final conjunction search display appeared. The general pattern of results extended across all three studies. Relative differences in luminance transients are not responsible for relative differences in feature-preview effects.

General Discussion

The variety of feature-preview effects on conjunction search, as initially shown by Olds et al. (2004; 2009), cannot be attributed to different patterns of luminance transients across the different conditions. The present Experiments 1-3 showed that even when a blank screen is inserted after a feature preview, so that all search items appear as luminance onsets, from a blank background-colour screen, in all conditions (as they do during normal conjunction search) previewing different feature types still results in differential effects on subsequent conjunction-search: size-preview consistently produced faster target identification, while orientation-preview produced slower target identification. The effect of color-preview depended upon the feature dimension that color was paired with: color-preview facilitated search more when it appeared before a color-orientation conjunction search (Experiment 1) than when it appeared before a color-size conjunction search (Experiment 2).

Experiments 4-6 *statistically* compared search in displays whose appearance involved equivalent luminance transients to those for normal conjunction search, because of an inserted blank screen (including two different durations of this blank screen) with search in displays that immediately followed the feature-preview display (as in Olds et al., 2009). Recall that when a blank screen is inserted in between the feature-preview display and the final conjunction search display, all search items appear with luminance transients in all of the conditions equivalently; three different blank screen durations were used: 0 (no blank screen), 200 ms, and 500 ms. Experiments 4-6 replicated the general pattern of results obtained by Olds et al. (2009) and those obtained in the present Experiments 1-3, and showed that differences in luminance transients do not predict differences in feature-preview effects. However, Experiments 4-6 also yielded a number of results that require further scrutiny.

In Experiments 4-6, some of the comparisons generated significant main effects of blank-screen duration and for *some* of the conditions, search was faster for longer blank-screen-durations. These results can be interpreted in one of many ways. They may, however, offer further support in favour of an alternative explanation to the automatic capture of attention via relative differences in luminance transients. Donk and Theeuwes (2001) interpreted the absence of the preview benefit at blank-screen-duration less than 400 ms to mean that attention did not have sufficient time to disengage from old preview items before being available for subsequent capture by new items. This conclusion, however, was made in reference to the preview-benefit which differs from the feature-preview search paradigm in some very distinct and important ways. In the preview-benefit search paradigm, *all* preview items serve as distractors in both the preview and subsequent search display and the target always appears in a *new* location, independent of any changes that may occur to the preview items. *All* preview items can therefore be homogenously processed and negatively inhibited. In the feature-preview search paradigm, all search items are presented at once during the preview search display as *partially* intact items so that half of those items contain target-congruent information (e.g., red preview items if color-orientation conjunction search target is a red horizontal item) while the other half contain target-incongruent information (e.g., green preview items). The presence of both target-congruent preview information and target-*in*congruent preview information requires the binary task of having to positively prioritize target-congruent items *while* inhibiting target-incongruent items. Therefore, in order to receive guidance from the preview display, attention should only be disengaged from some of the preview items (target-incongruent) and not from others (target-congruent). If, according to Donk and Theeuwes (2001), attention is sufficiently disengaged during longer blank-screen-duration (in the preview-benefit) this disengagement of attention would only be beneficial to the present search task if it can be selective so that attention is only disengaged at certain preview items (target-incongruent), for disengaging attention from all preview items would imply that target-congruent items are also released from attention. Since, in the present study, increasing the blank screen duration tends to increase the facilitation afforded by the feature-preview, the feature-preview may accordingly be building in strength with increased blank-screen-duration (this idea is discussed further below). If attention can be sufficiently disengaged from *only* some preview items (i.e., suppression of target-incongruent), then that allocates a role to top-down influences. If top-down processes are playing a role in the present findings, then these feature-preview effects cannot be solely attributed to differences in their relative luminance transients. If attention cannot be sufficiently disengaged from *only* the target-incongruent items, then this effect of blank screen duration still cannot be solely related to luminance transients; if items are more likely to be disengaged from attention with longer blank-durations, then all items would be released from attention and, with increases in blank-duration, the feature-preview would be less likely to aid conjunction search. In either case, attention cannot be fully under bottom-up control even within a single search condition, and differences between the different feature-preview effects are even less likely attributed to solely bottom-up explanations of attention allocation (i.e., luminance transients).

Although the present pattern of results resembles those of Olds et al. (2009) overall, the present data show the need to modify Olds et al.'s (2009) conclusion that facilitation by feature-preview depends upon two prerequisites: (1) it must be easy to perceptually group items that share that feature (i.e., color or size; not orientation), and (2) the transition from feature-preview display to search display must not involve disruptive expansion/recession signals. In the present study, insertion of the [200-ms] blank screen drastically reduced the impression of expansion/loom during the transition from color preview to color-size conjunction (satisfying number (2) above). Color was also easy to group (Beck, 1972; Treisman & Gelade, 1980) (number (3) above); yet color-preview still failed to facilitate color-size conjunction search. The two-part rule proposed by Olds et al. (2009) thus requires modification in order to accommodate these new data.

Although the automatic capture of attention via luminance transients has been ruled out as a solitary determining factor in the feature-preview effect, a number of other hypothetical mechanisms may be involved. Several likely possibilities are discussed below.

Strategic Control of Attention

In the present feature-preview search paradigm, observers are presented with a preview that shows target-congruent information (e.g., red preview items before a search for a red horizontal target), target-incongruent information (e.g., green preview items). To maximize search efficiency, it would make strategic sense to inhibit the selection of target-incongruent preview item locations, while prioritizing the selection of target-congruent preview item locations. This strategy, however, would have to rely, at least in part, on the strategic control of attention during the early parallel processing of visual features. The validity of this hypothesis depends upon the visual system's ability to bias attention towards prioritizing some features, while, simultaneously, inhibiting others (based upon foreknowledge regarding the identity of the conjunction target to come).

Whether or not attention can be strategically controlled during parallel processing is a question that has been met with much controversy. Many theories include a role for both bottom-up and top-down selection (e.g., Wolfe et al., 1989); some studies, however, promote bottom-up, stimulus-driven mechanisms (Theeuwes, 1991, 2004), while others assign dominance to top-down observer-driven mechanisms (Callaghan, 1989; Folk et al., 1992). Advocates of stimulus-driven theories of control show that attention selects salient objects in their locations regardless of task relevance (Theeuwes, 1991), but a great deal of evidence supports observer-driven influence. For example, the contingent involuntary orienting hypothesis posits that current task sets can mediate attentional capture of salient distractors *only* when those distractors contain features that are task-relevant (Folk et al., 1992). Also, when manipulating the ratios of different distractors, search is limited to only those distractors that are task relevant to a color defined target (Moore & Egeth, 1998). ERP data, paired with behavioural studies, shows that spatially uninformative target-color cues capture attention while task irrelevant distractor-color cues do not (Eimer et al., 2009). Furthermore, and especially pertinent to the present study, irrelevant objects, and even object features (Nobre et al., 2006), can be inhibited from competing for selection with target-relevant objects (Watson & Humphreys, 1997; Gibson & Jiang, 2001; Olivers & Humphreys, 2002; Braithwaite & Humphreys, 2003).

Given that the strategic control of attention may be possible during early visual processing, this control may be playing a key role in the present feature-preview effects through the inhibition and selection of certain preview information; and it may be playing its role more effectively in some feature-preview types (e.g., color or size) than in others (e.g., orientation). The top-down inhibition of irrelevant preview items brings us back to discussing visual marking mechanisms proposed to explain facilitation in preview-benefit experiments (Watson & Humphreys, 1997).

Visual Marking

Watson and Humphreys (1997) originally proposed that visual marking operates through the active inhibition of previously viewed irrelevant objects; however, it has been more recently suggested that visual marking is in fact a product of both object inhibition and target anticipation (Watson & Humphreys 2002; Humphreys et al. 2005). Observers inhibit the location of previously viewed items, while adopting an anticipatory set for new item features; inhibition is location-based in order to spare the visual system from having to process both object location and object feature, and the anticipatory set is feature-based given that target detection relies upon feature discrimination.

Having eliminated the bottom-up capture of attention via differential luminance transients as a main causal mechanism by which the feature-preview effects occur, we can now refer back to visual marking and the top-down inhibition of old items as a possible source of information for explaining the present results. How might the top-down inhibition of irrelevant items and the positive anticipation of relevant item features apply to the present study?

Top-down inhibition of irrelevant items

While the *top-down inhibition* of irrelevant items was first proposed by Watson and Humphreys (1997) in their visual marking hypothesis, evidence in support of *intentional* inhibitory mechanisms were later provided by probe detection studies, where probes are difficult to detect at old item locations *only* when observers are engaged in new target detection (Olivers

& Humphreys, 2002). Some studies show that inhibition of old items is location based, and a change in color to preview items does not disrupt the preview effect, suggesting that inhibition does not operate at the feature level (Watson & Humphreys, 1997, 2002; Olivers et al., 1999); and that inhibition is feature-based only during dynamic displays when the locations of the preview items change (and observers must rely upon feature inhibition). Other studies show that feature-based inhibition may be possible even during static displays, given that target-detection (when presented with new items) is delayed when the target shares a common feature (same color) with the old preview items (Gibson & Jiang, 2001; Braithwaite et al., 2005). Either way, one main component to the visual marking hypothesis is the top-down inhibition of old item locations and/or features that are no longer relevant to new item search (Watson & Humphreys, 1997, 2002; Olivers & Humphreys, 2002; Humphreys et al.; 2005).

As previously mentioned, inhibiting the selection of target-incongruent features for subsequent consideration during the following conjunction search would maximize search efficiency (in the present study). If observers are in fact inhibiting the location of target-incongruent preview items, it could be that the inhibition of some features (e.g., locations of items with particular orientation) is not as effective as the inhibition of other features (e.g., locations of items with particular color or size), leading to the differential effects of feature preview type on subsequent conjunction search.

Interestingly, although color and orientation are both mediators of perceptual grouping (e.g., Beck, 1972; Treisman & Gelade, 1980) a series of older experiments conducted by Wolfe et al. (1995) reveals a difference in their relative ease of grouping; while three gradients of *different* orientation grouped well, three gradients of *different* color did not; and while three gradients of the same color produced stronger grouping than three gradients of different colors, the same could not be shown for orientation. This difference in grouping could also influence the efficiency of inhibition and prioritization in the present study. Wolfe et al. (1995) suggest that some features (e.g., some dimensions of color) are represented in sub-feature maps so that each feature dimension is represented on a separate map (e.g., in the present study, one map to encode for 'green', another to encode for 'red'), while others (e.g., orientation) are encoded on only one map regardless of the sub-feature. Recall the present search task: observers were presented with a feature preview where the location of half of the items indicated where the conjunction target would not appear, and the other half of the items indicated where the target might appear; so although top-down inhibition may operate on target-incongruent locations or features, the positive prioritization of target-congruent locations or features may also be occurring at the same time (inhibition of irrelevant items can indeed occur concurrently to the amplification of relevant items (Whur & Frings, 2008)) If some features, like color, do indeed support the presence of sub-feature maps, it might make sense that inhibiting one incongruent feature dimension, and therefore one sub-feature map, is more efficient than inhibiting multiple locations on a feature map that encodes all of the dimensions of a given feature, like orientation. Further still, if the inhibition of irrelevant preview items is in fact paired with the positive prioritization of target-congruent preview items, it may be easier to prioritize one sub-feature map of the target-congruent color (red) while inhibiting one sub-feature (separate map) of the target-incongruent color (green) as opposed to having to prioritize multiple target-congruent orientations (horizontal) and inhibit many other target-incongruent orientations (vertical) within the *same* single feature map.

This application of top-down inhibition is, however, not enough to accommodate all of our results; recall that although color-preview facilitated color-orientation conjunction search, it did not facilitate color-size conjunction search. If color-preview aided color-orientation conjunction search due to its efficient inhibition, then color-preview should also aid color-size conjunction search for the same reason; the fact that this second result *did not* occur suggests that, even if inhibition of target-incongruent preview information does play a role in the present experiments, it is the interactive processing of both the particular feature-preview, and the addition of the second feature dimension that produced these feature-preview effects.

Anticipatory set for second feature addition

It was proposed that the preview benefit occurs because of the interaction between top-down inhibition of old irrelevant items, and the anticipatory set for new items (Watson and Humphreys, 1997, 2002; Humphreys et al., 2004; Braithwaite et al., 2005). Braithwaite et al. (2005) showed that the preview-benefit is hindered when old preview items change their color (at the time of new item-onset) to match the anticipated color of the known target item that appears with the new items, suggesting that the benefit of anticipatory set was eliminated when old items changed to the anticipated color. Search was also slow when the target was the same color as preview items, even while the target color was actually unknown, suggesting that since no anticipatory set existed, detecting a color during search was difficult to do when that color was being inhibited during the preview. This highlighted the importance of prioritized feature attributes to the preview-benefit.

Although visual marking can be explained in terms of top-down inhibition of old items and anticipatory set for new item features, the present search paradigms are different than the search paradigms used by Watson and Humphreys (1997), and are therefore subject to different influences. Watson and Humphreys' (1997) search paradigms included intact preview items where all of them could be excluded as potential targets, and therefore all could be inhibited, followed by a search display where all of the new items served as potential targets. In the present experiments, the preview displays only contained *partial*-information; items whose features eliminated them as a potential target *and* items whose features marked them as potential targets; observers could be engaged in either top-down inhibition or prioritization, or both, during the feature-previews in the present study. *All* of the preview items changed, in the present study, so that *all* final items in the conjunction search display contained new information; changes to one group of preview items (target-congruent features vs. target incongruent features) could disrupt the processing of the other, and further still, the efficiency of the anticipatory set for the new item features. The present feature-preview effects must therefore include an explanation that extends beyond that for visual marking and the preview benefit.

Recall that in the present study, size-preview was consistently helpful regardless of the second relevant feature, orientation-preview was consistently harmful regardless of the second added feature, but color-preview only helped when orientation addition followed and not when items underwent a change in size; is it possible that some feature changes are inherently more disruptive than others? If so, it would not be due to what feature is actually being added to the item, since adding color to an item defined by size did not slow search but adding color to an item defined by orientation did, but more so due to the interaction between the old feature and the second added feature. If the degree to which an object feature will be selected, or will interfere with selection, is not a fixed value and varies with respect to the feature it is paired with, one might assume that features are competing for selection; it might be that for any conjunction of features, one feature will dominate in the competition for attentional resources;

complicating both the inhibition and the prioritization of items during feature-preview and the anticipatory set for target-congruent item features during the transition into conjunction search.

Competing for Selection in Visual Attention

The selective nature of visual attention invokes competition among visual sources of information so that objects in the visual field compete for representation or control. This competition, however, is biased in favour of visual sources that are most relevant to the task at hand and this biased selection is reflected in the neuronal properties of the visual system.

There are at least 30 visual cortical areas responsible for processing visual information. These visual cortical areas are shared between two neural streams that extend from the primary visual cortex (V1). The dorsal stream travels to the posterior parietal cortex and is responsible for spatial perception and visuomotor performance and processes the "where" of an object. The ventral stream extends from V1 to the inferior temporal cortex, and generally processes information related to object identification, in order to determine "what" and object is. Since objects in our visual field often compete for selection and recognition, this competition might be reflected in the ventral stream (See Desimone & Duncan, 1995).

As the ventral stream extends from VI to different areas in the inferior temporal cortex, the neuronal areas change in both selectivity and the size of their receptive fields; different object properties, such as shape or color, are processed by different areas, and as the ventral stream extends from V1 to area TE in the inferior temporal cortex, the receptive field of individual neurons gets progressively larger. Within a large receptive field, Desimone and Duncan (1995) suggest that object identification becomes ambiguous since it would be difficult to separate one object from another when both are being processed within the same receptive field. Since increasing the number of objects in a visual field, decreases the amount of information that will be available for each within the ventral stream, objects need to compete for processing. Evidence of this hypothesis is provided by studies that reveal a reduction in the response to a stimulus, in a neuron's receptive field, when paired with another stimulus (as opposed to when presented alone). This suggests that objects being viewed concurrently interact to mutually suppress each other, so that neither is processed independently (See Kastner, 2001).

It is suggested that competition is mediated by a bias; for example, new items, relevant items, recently viewed items, prior knowledge about an objects location, and familiarity with an item can all serve to bias selection in both a top-down and a bottom-up manner (See Desimone & Duncan, 1995). Is it plausible that visual attention can also be biased towards an individual feature (e.g., color) as opposed to another (e.g., orientation), within one, or within a group, of objects?

Feature Dominance

There are some examples, in the visual search literature, that highlight differences in the relative strength of object features. Callaghan (1989) showed that variations in form did not interfere with hue segregation, even when the form differences were easier to discriminate than hue differences, while variation in hue segregation, however, did interfere with effective form segregation. Chen (2009) showed that although attending to an object's form or color inadvertently resulted in the automatic processing of an object's location, attending to location did not result in the involuntary processing of the accompanying form or color; suggesting that processing location is more efficient than processing form or color. Hannus et al. (2006) found that, although features elicit equal discrimination during feature-search, when observers searched for a conjunction target, initial eye saccades moved significantly more often to correct color first than to correct size, and even more often than to correct orientation. Since features were equally discriminated when isolated during feature search, but showed differences in discriminability when paired during conjunction search, Hannus et al. (2006) suggest that features interact so that they are not processed independently of one another, and can therefore compete for attentional resources [Please see Rutishauser and Koch (2007) for similar findings].

These findings imply that, under some conditions, some features are in fact processed more effectively than others. The exact mechanisms that mediate this competition and that will determine which feature will dominate cannot be determined given our present results but possible theories are discussed below.

Preview Items become New Items

Rauschenberger (2003) demonstrated that a sufficient change to an existing object's feature may result in characterizing that object as a new item. In the present study, feature-preview items changed in order to serve as conjunction items. It may be that the changes to some of the feature-preview items (e.g., changing an oriented-preview item by changing its color) are large enough to mark those items as new objects, eliminating the preview-benefit. It is not known how much change in an existing object's feature is required to characterize that object as a new item, and it is not known which features are most sensitive to change; but the amount of change required, according to the present results, would have to rely upon the relative strength of the existing feature and the feature added: changing a color's orientation was not sufficient enough of a change to mark the preview item as new (i.e., Experiments 1 and 4), but changing a pre-existing color's size was (i.e., Experiments 2 and 5). Further research into the subject is required before this theory can be further applied to the present findings.

Conjunctively Tuned Channels

Hannus et al. (2006) suggest that attention more often selects color first as opposed to size or orientation because feature search and conjunction search operate through different sets of channels that are tuned to respond to a given feature with different degrees of sensitivity. They propose that the color-orientation and the color-size channels, for example, are more sensitive to differences in color than to differences in orientation or size.

During the present experiments, it may be that the addition of the second feature (to the first feature-preview during a feature-preview conjunction search) disrupts information gathered from the feature-preview if the conjunction visual channel is more sensitive to the second feature. According to this reasoning, information gathered from color or size feature-previews should endure the addition of orientation information when the color-orientation conjunction search display and orientation-size conjunction search display, respectively, appear. Having inhibited the target-incongruent preview items in the color or size-feature preview display, conjunction search should now be reduced to only half of the items (target-congruent preview items) subsequently resulting in search facilitation; search was facilitated when color-preview proceeded color-orientation conjunction search and size-feature preview proceeded orientation-size conjunction search.

Introducing color or size to orientation-preview items should disrupt the inhibition and the prioritization of target-incongruent and target congruent oriented items, respectively; not only does this disrupt any guidance that the orientation-preview could have provided, but it may serve to hinder search further while the visual system tries to recover from this disruption; in the present experiment, adding color or size information to orientation search did result in deficient conjunction search.

In line with this application of feature-sensitivity, adding color to size-feature preview should hinder search, while color-feature preview should be resilient to disruption by size addition; this was not the case in the present study. This exception, however, can be explained. Recall that inhibition and prioritization are thought to operate on feature locations and not the actual features; during size-feature preview conditions, the preview items are consistently occupying the same space whenever they are presented in the search displays and any information gathered from the feature-previews is fixed and unchanging in terms of spatial location. Although color is a stronger mediator of saccadic eye movements than size, size is still a strong competitor (related to orientation), and perhaps the addition of color is not strong enough to disrupt the information gathered from the size-preview; due to color's ability to mediate attention quickly, it serves, instead, to aid in the detection of the target from amongst the already prioritized target-congruent feature items. During the color-feature preview condition, the preview items do not occupy the same space as the conjunction search items, and therefore the representation of the inhibited and/or prioritized feature-locations must be readjusted to accommodate these changes to spatial information. Size is a moderately strong mediator of saccadic eye movement: its addition to the color-feature preview, paired with the visual system having to allocate resources to the realignment of spatial information, results in a disruption to any help that could have been provided by the color-feature preview. [3]

Some of the findings in the present study support the above rationale. Recall that the search time was shorter for feature-preview conditions containing the blank screen. Since equating relative luminance transients across different feature-preview effects failed to equate

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[3] The same does not occur when orientation is added to color or size-feature previews because orientation is not a strong enough competitor to interfere with the inhibition and/or prioritization of preview information or the readjustment of their corresponding spatial information.

their relative effects on subsequent conjunction search in all of the above feature-preview comparisons, the search facilitation offered by the blank screen insertion therefore cannot be explained in terms of luminance transients alone. Perhaps the longer blank screen duration is facilitating search time by providing observers with more time to organize and solidify information gathered from the feature-preview conditions, reducing the amount of disruption caused by the appearance of the second feature in the conjunction search display. As previously mentioned, the contents of visual working memory can serve to bias the selection of visual information. The cortical representation of a stimulus can be maintained in working memory, via top-down processes, after the stimulus is no longer present in the visual field; Downing (2000) showed that actively maintaining an object in working memory also serves to bias the subsequent selection of that object. In the current study, the blank screen inserted after a feature-preview may provide observers with a window of opportunity to solidify the information gathered from the feature preview by actively maintaining that information in working memory.

In order for the above rationale to apply, our feature-preview effects would have to be a product of a number of different mechanisms and cannot be explained in terms of one alone. We suspect that our feature-preview effects reflect an interaction between the inhibition and prioritization of preview-information and the subsequent attempt to select the target-congruent feature dimension introduced during the conjunction search.

Conclusion

According to our results, a preview benefit can only occur when the information gathered from feature-preview is resilient to interruption from the addition of the second feature. This resilience can be determined by an interaction of two things: (1) spatial consistency of the items throughout the feature-preview search trial and (2) the relative strength of the feature previewed and the feature added. If the feature previewed is a relatively strong mediator of attention (e.g., color), then significant changes in its spatial consistency over time (throughout the trial) can only be paired with the addition of a feature that is a weak mediator of attention (e.g., orientation); adding a feature that mediates attention well (e.g., size) threatens to exploit too much of the attentional resources needed to continuously process the changing color-feature, causing disruption to that representation, and in turn, to information gathered from the feature-preview.

The present findings indicate that feature-preview effects cannot be explained in terms of luminance transients, and more generally, are not mediated by a purely bottom-up mechanism. It is also worth noting that the feature-preview paradigm is particularly different from the preview-benefit paradigm, and visual marking, therefore, also cannot explain the present effects.

Given that feature-preview effects are distinct, further exploration into the mechanisms guiding these effects may serve to extend our own knowledge regarding attention orientation and subsequent source selection. Furthermore, since top-down processes do play a role in feature-preview effects, understanding the mechanisms involved may also serve to improve our own performance during a variety of tasks that require search and rapid performance.

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Appendix

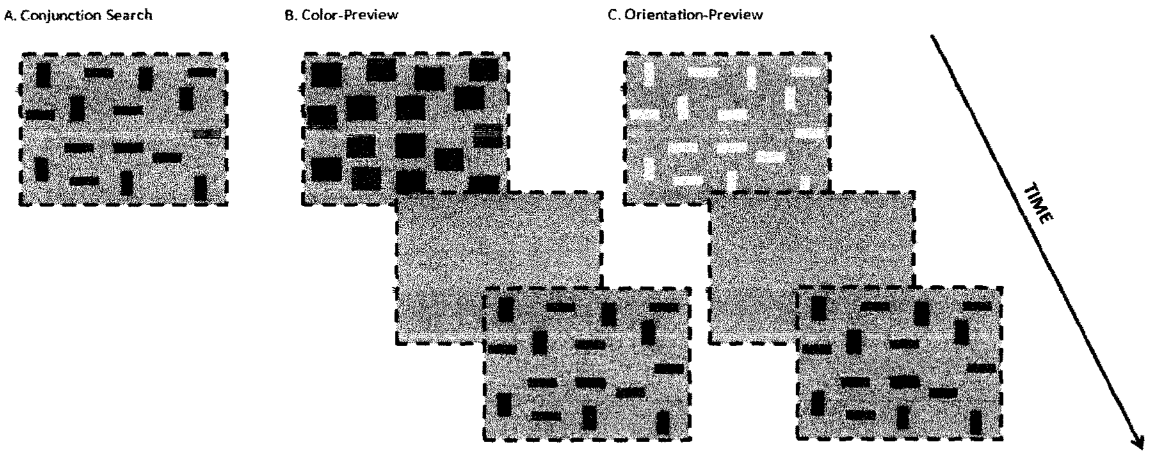

Figure 1. Illustration of the stimuli used in Experiment 1: (A) control color-orientation conjunction search condition, (B) the conjunction search display is preceded by a color-preview display and a blank screen, (C) the same conjunction search display is preceded by an orientation-preview display and a blank screen.

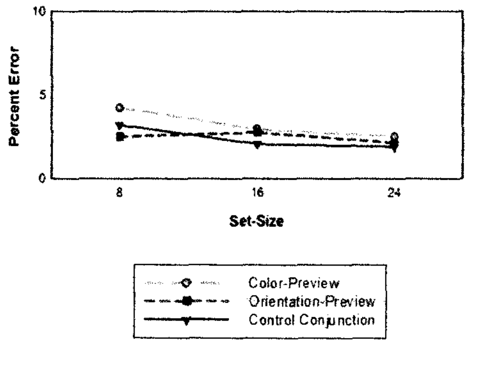

Figure 2. Results for Experiment 1: Mean RT and Percent Error vs. Set-Size plotted for orientation-preview, color-preview, and control color-orientation conjunction search.

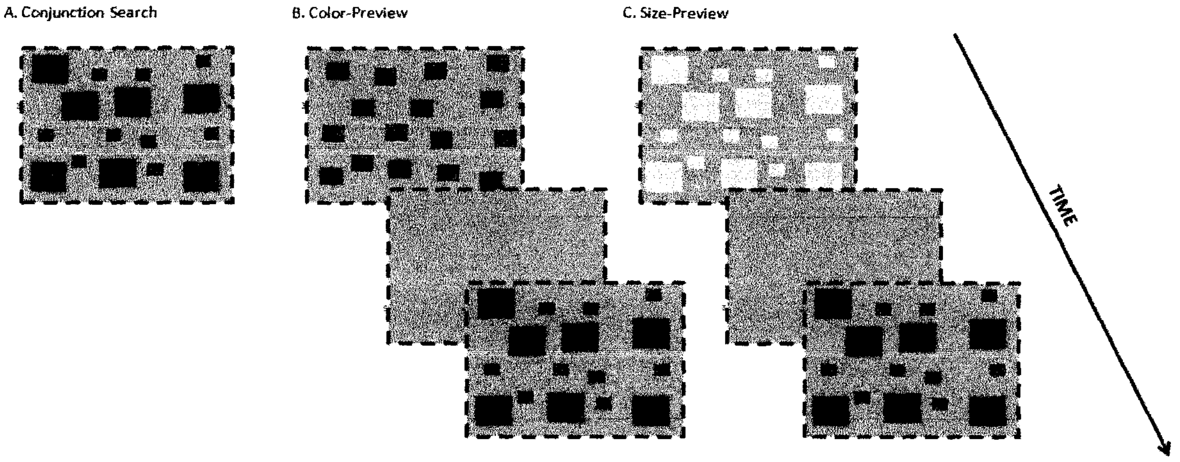

Figure 3. Illustration of the stimuli used in each condition for Experiment 2: (A) control color-size conjunction search; (B) the color-size conjunction search is preceded by color-preview and a blank screen; (C) the same conjunction search is preceded by size-preview and a blank screen.

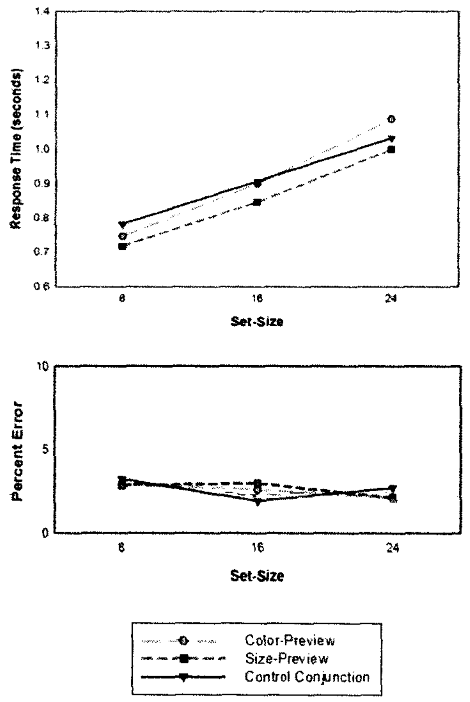

Figure 4. Results for Experiment 2: Mean RT and Percent Error vs. Set-Size plotted for color-preview, size-preview, and control color-size conjunction search.

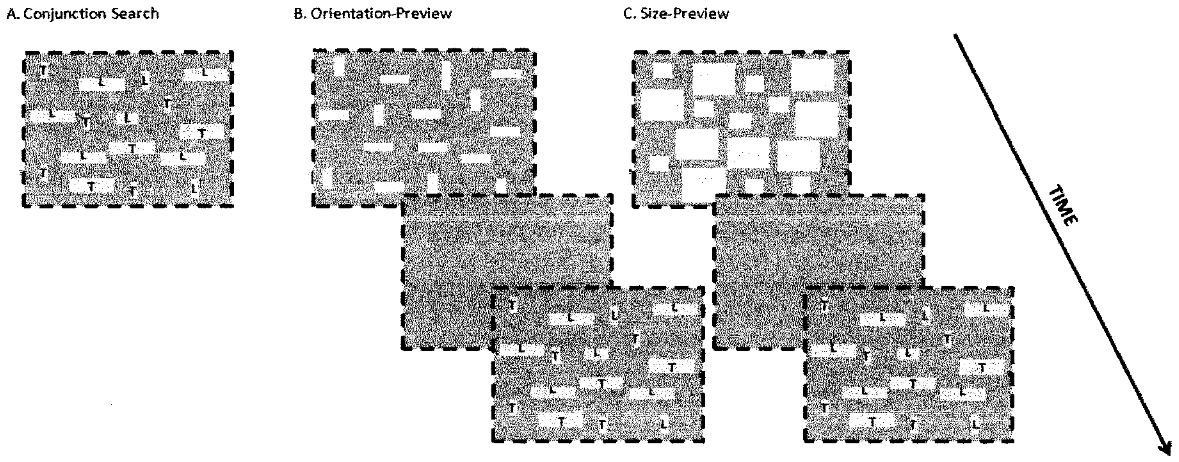

Figure 5. Illustration of the stimuli used in condition for Experiment 3: (A) control size-orientation conjunction search (B) conjunction search is preceded by size-preview and a blank screen (C) conjunction search is preceded by orientation-preview and a blank screen.

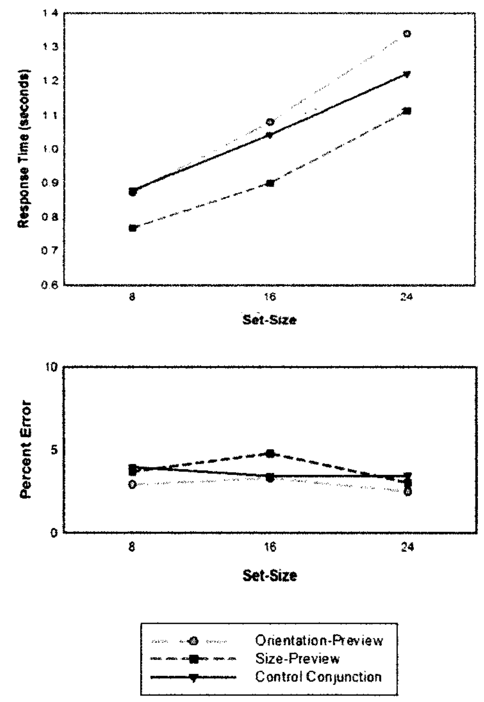

Figure 6. Results for Experiment 3: Mean RT and Percent Error vs. Set-Size plotted for orientation-preview, size-preview, and control orientation-size conjunction.

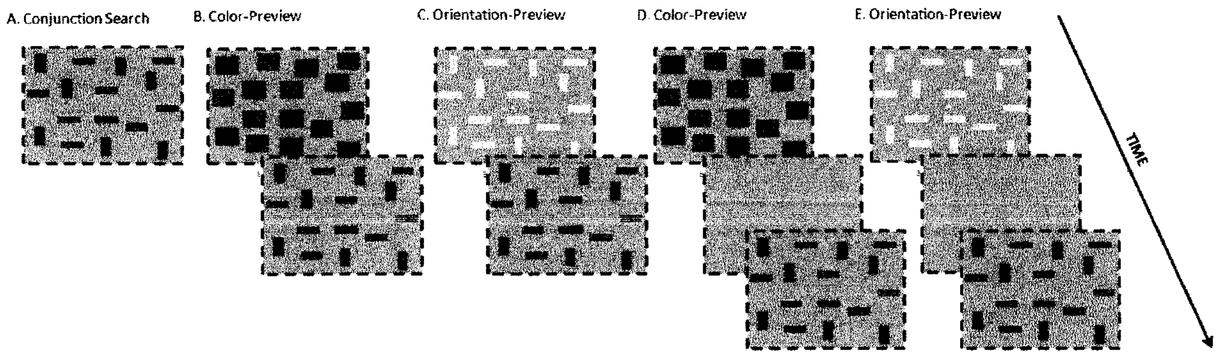

Figure 7. Illustration of the stimuli used in Experiment 4: (A) control color-orientation conjunction search condition, (B) the conjunction search display is preceded by a color-preview, (C) the same conjunction search display is preceded by an orientation-preview display. Experiment 5 also includes trials where (D) the conjunction search display is preceded by a color-preview display and a blank screen, and (E) the same conjunction search display is preceded by an orientation-preview and a blank screen.

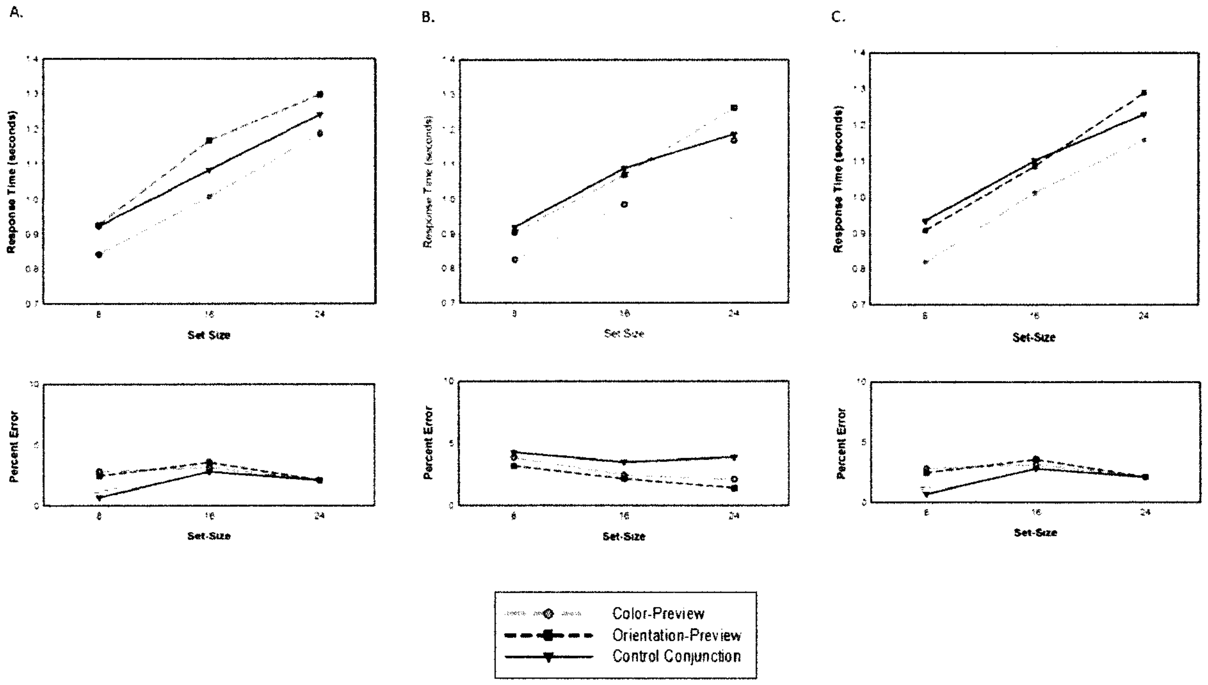

Figure 8. Results for Experiment 4: Mean Response Time and Percent Error vs Set-Size plotted for size-preview, orientation-preview and control color-orientation conjunction search during trials that contained (A) no blank screen, (B) blank screen with 200 ms duration, and (C) blank screen with 500 ms duration.

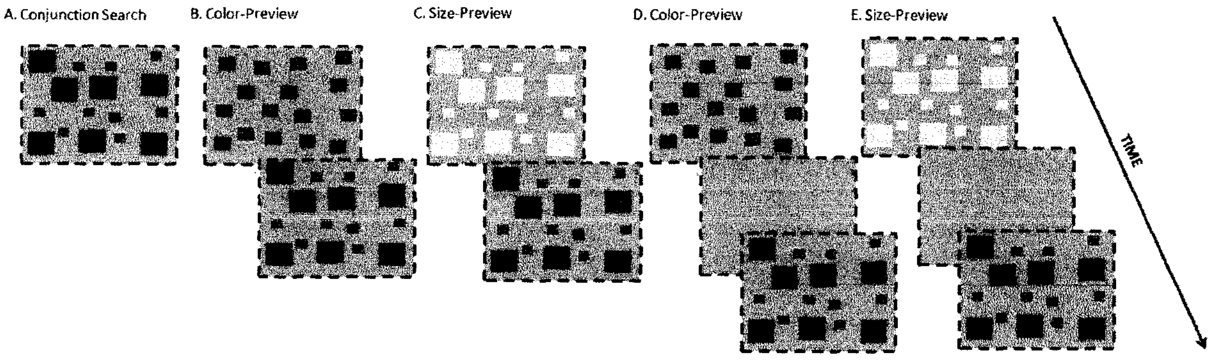

Figure 9. Illustration of the stimuli used in Experiment 5: (A) control color-orientation conjunction search condition, (B) the conjunction search display is preceded by a color-preview, (C) the same conjunction search display is preceded by a size-preview display. Experiment 5 also includes trials where (D) the conjunction search display is preceded by a color-preview display and a blank screen, and (E) the same conjunction search display is preceded by a size-preview and a blank screen.

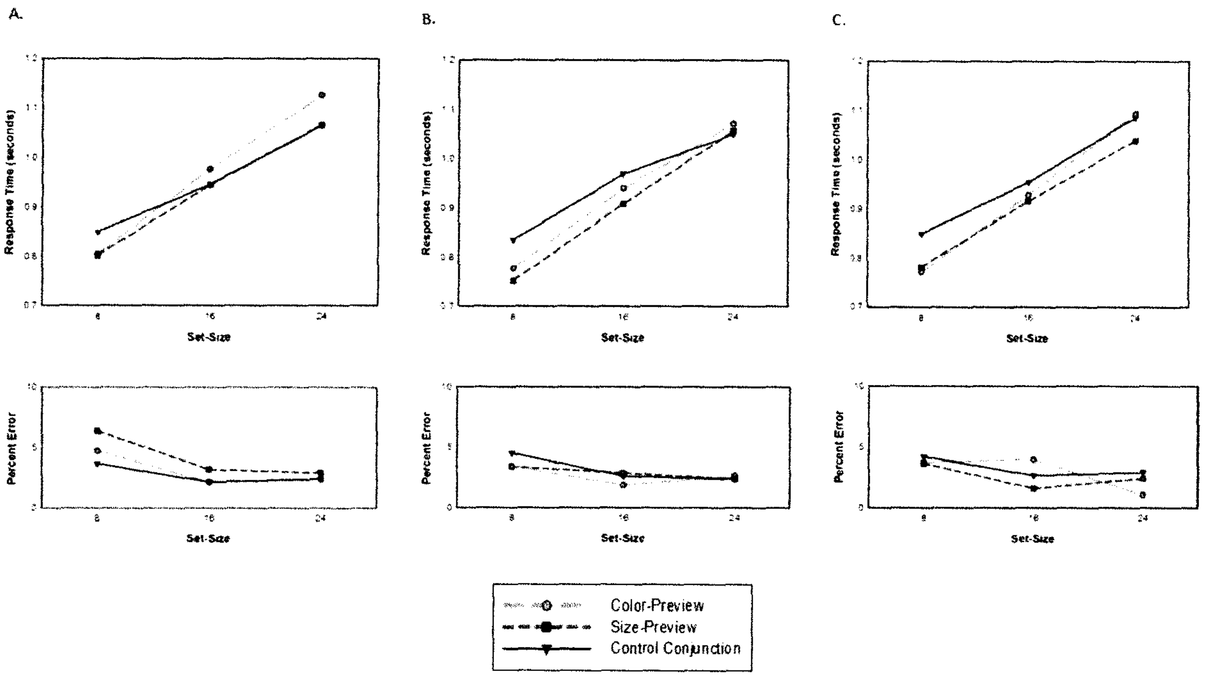

Figure 10. Results for Experiment 5: Mean Response Time and Percent Error vs Set-Size plotted for color-preview, size-preview and control color-size conjunction search during trials that contained (A) no blank screen, (B) blank screen with 200 ms duration, and (C) blank screen with 500 ms duration.

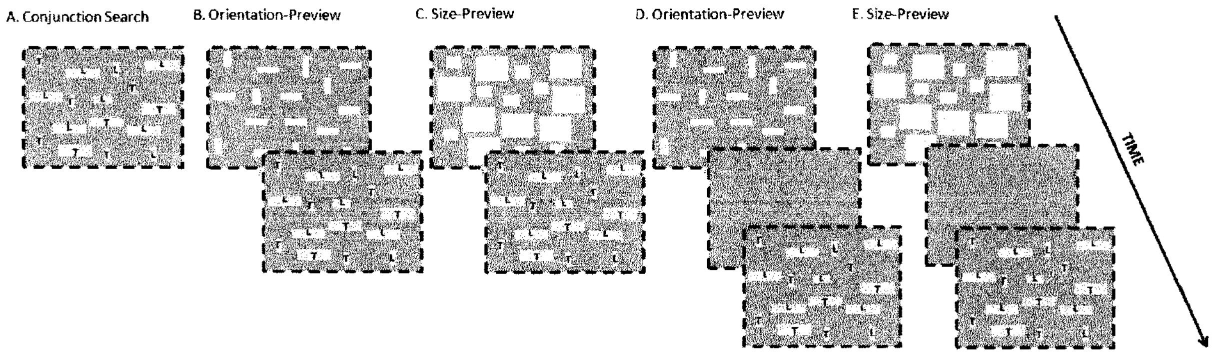

Figure 11. Illustration of the stimuli used in Experiment 6: (A) control orientation-size conjunction search condition, (B) the conjunction search display is preceded by an orientation-preview, (C) the same conjunction search display is preceded by a size-preview display. Experiment 6 also includes trials where (D) the conjunction search display is preceded by an orientation-preview display and a blank screen, and (E) the same conjunction search display is preceded by a size-preview and a blank screen.

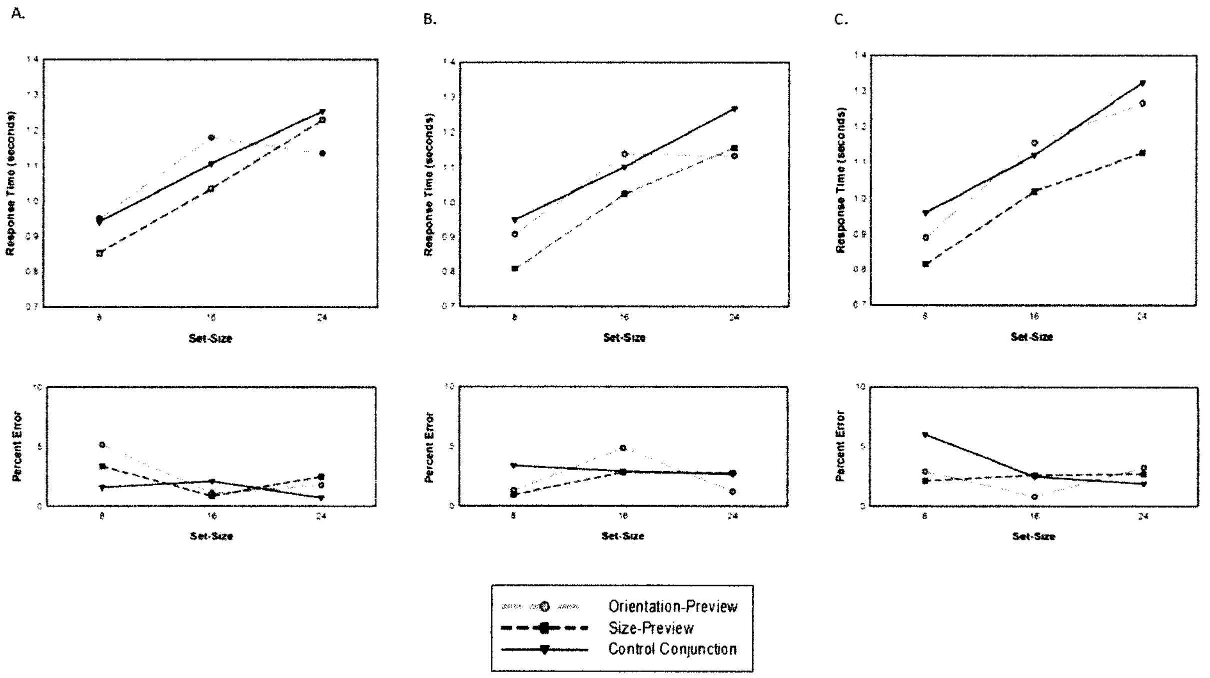

Figure 12. Results for Experiment 6: Mean Response Time and Percent Error vs Set-Size plotted for orientation-preview, size-preview and control orientation-size conjunction search during trials that contained (A) no blank screen, (B) blank screen with 200 ms duration, and (C) blank screen with 500 ms duration.