行政院國家科學委員會補助專題研究計畫成果報告

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計畫主持人：葉素玲

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執行單位：台灣大學心理系

中 華 民 國　91 年 9 月 16 日

行政院國家科學委員會專題研究計畫成果報告

注意力與視覺的關係探討

Attention and Vision

計畫編號：NSC 90-2413-H-002-021

執行期限：91 年 8 月 1 日至 92 年 7 月 31 日

主持人：葉素玲　執行機構及單位名稱: 台灣大學心理系

一、中文摘要

本研究擬採三年時間探討注意力與視覺的關係，今年的主題在探討哪些刺激情況容易吸引注意力，以及突現刺激是否在攫取注意力上有其獨特的優先地位。在八個實驗中，我們操弄了干擾物的性質(顏色、突現）、目標物的性質（突現與否、是否具定義特徵)、干擾物與目標物的時距、以及刺激總數。結果發現：突現的無關干擾物在刺激數目多且時距長的情況下，較易攫取注意力。干擾物是否具有與定義目標物的特徵相同，似乎只對刺激數目少的情況下其攫取注意力的效果造成影響。除非干擾物與目標物二者共享的特徵在刺激系列呈現時產生變化，否則干擾物與目標物具有相同的特徵並不保證干擾物一定可以攫取注意力。

關鍵詞：注意力攫取、注意力設定、定義特徵、突現、顏色

Abstract

The goal of this 3-year project is to examine the role attention plays in visual information processing. The current study examined the conditions under which stimulus-driven attentional capture is possible. A letter discrimination task was used in which the participants responded differentially to one of the two possible target letters (H or U) among multiple irrelevant letters. A distractor was shown before the target display to see whether the distractor affected the response to the target. In eight experiments, we manipulated the ways the distractor (color or onset) and the target (no-onset or onset, with or without defining features) were presented, as well as their SOA and display size. Our results showed that increasing the display size increased the chance of capture by salient stimuli, especially at longer SOAs, and the absence or presence of a defining feature for the target seemed to affect only the small display size conditions. Sharing common features with the target did not guarantee attentional capture by the distractor in the small display size conditions, unless it accompanied changes in the feature dimension between the distractor and the target displays.

Keywords: attentional capture, attentional setting, defining feature, onset, color

INTRODUCTION

William James (1890) proposed that “immediately sensory domain” (or “passive mode”) and “voluntary intellectual domain” (or “active mode”) were involved in the control of attention. Ever since, these two components, stimulus-driven (bottom-up) and goal-directed (top-down) processes, have been investigated intensively. More recently, the issues of whether irrelevant stimulus can receive attentional priority involuntarily and to what extent it is modulated by goal-directed control have been hotly debated.

Some researchers emphasized the importance of the bottom-up component, and provided evidence that stimulus-driven attentional capture occurs whenever the irrelevant stimulus is salient enough in the feature dimensions of luminance, color, form, or motion (e.g., Theeuwes, 1992, 1994, 1995; Johnson, Hutchison, & Neill, 2001; Turatto & Galfano, 2000; Gellatly, Cole, & Blurton, 1999), or when a new object appears in a form of abrupt onset (Yantis & Jonides, 1984; Jonides & Yantis, 1988; Yantis & Hillstrom, 1994; Yantis, 1993, 1996, 1998). Others doubted about the possibility of purely stimulus-driven capture and proposed instead that the apparent stimulus-driven capture by a particular feature is ultimately contingent on the attentional control settings for the feature that defines the target (Folk, Remington, & Johnston, 1992, 1993; Folk & Annett, 1994; Folk & Remington, 1994, 1996; Folk, Remington, & Wright, 1994), or for displaywide features that include in the target display as a whole (Gibson & Kelsey, 1998; Atchley, Kramer, & Hillstrom). In this alternative view, attentional capture by any feature occurs only when the organism’s behavior goal is set to search for that feature; that is, top-down control determines the nature of attentional capture.

For those studies that address the role of attentional control setting, a modified spatial cuing paradigm is usually used in which a cue is presented before the target, and the response time to the target is compared when the target appears at the cuing location with that when different from it. The cue is non-informative in that the chance that the target location will be the same as the cue is no more likely than different from it, and so for the task at hand (e.g., letter discrimination) the best strategy of the participant is to ignore the cue. For this reason, we prefer the use of “distractor” instead of “cue” hereafter. If the response time is faster when the target appears at the same location as the distractor than when at different locations (i.e, a location effect), attentional capture by the distractor is then inferred. The absence of the location effect thus indicates that the appearance of the distractor does not affect the performance of the task (i.e., no attentional capture occurs).

In applying this paradigm and manipulating participants' attentional set by specifying the target with a defining feature unique to the target, Folk et al. (1992) found that a non-informative distractor showed a location effect only when it carried the same feature with the defining feature of the target; that is, capture occurs only when the distractor is contingent on the attentional control settings, a "contingent involuntary orienting hypothesis" as so named. For example, to find a red letter among white ones and to discriminate what it was, only the preceding red distractor, but not the onset distractor, showed the location effect. In this case, the attentional control was set for "color red", so a red distractor could capture attention since it was contingent on the control setting. The onset distractor, on the other hand, was not contingent on the attentional setting, thus leading to no capture effect.

Such attentional setting can be thought of as defined explicitly to a particular feature dimension to distinguish the target from other non-target letters. Folk, Remington, & Wright (1994) further examined the structure of the attentional control and found that attentional settings were limited to a broader distinction of "dynamic discontinuity" and "static discontinuity". They examined features of motion, onset, and color, and found that motion and onset belonged to the dynamic discontinuity, while color belonged to the static discontinuity. That is, a motion distractor paired with an onset target showed the location effect, and vice versa, but not when a motion distractor was paired with a color target. The distinction of these two broad classes of attentioal setting serve to explain the seemingly stimulus-driven capture that is actually contingent on the dynamic or static discontinuity of attentional settings.

Another broadly tuned attentional setting, the setting for displaywide features, has been proposed recently by Gibson & Kelsey (1998). According to this view, the way the target is presented can all be set into the attentional controls and influence the efficiency of the capture effect, not just the target-specific features as in Folk et al. (1992, 1994). Using the display sequence similar to our Figure 6, Gibson and Kelsey (1998) showed that when the target display contained all red onset letters, both the preceding red and onset distractors showed the location effect (Experiment 1). When the letters in the target display were all changed into white, however, the location effect of the red distractor disappeared, but not the onset distractor (Experiment 2). The possibility of participants' strategy to find the color match between the target display and the preceding distractor's location (rather than attentional capture by color singleton) in their Experiment 1 was excluded by using a green distractor instead, and foreknowledge of the nature of the distractor, the target, or both, did not seem to affect such an attentional setting for displaywide features (Johnson, Hutchison, & Neill, 2001).

Note that only the presence (Experiment 1) and the absence (Experiment 2) of attentional setting for displaywide color was tested in Gibson and Kelsey (1998). If the displaywide contingency hypothesis of Gibson and Kelsey is correct and is general enough, it should also apply to the onset property as well. Accordingly, no location effect of the onset distractor should be observed when no onset property is associated with the whole target display. Difficulties arise with issues involved with abrupt visual onsets, however. Theoretically, not the onset property, but the representation of new object the abrupt onset brings about that is critical in capturing attention (Yantis & Hillstrom, 1994; Yantis & Jonides, 1996; Yantis, 1998). This would make the ideal situation for the strong test of the onset-uniqueness hypothesis a target display without any changes other than the presentation of new objects. Technically, this would be very difficult to design, as admitted by Gibson and Kelsey (1998, footnote 3, p. 700). Nevertheless, if we set aside the new object argument, abrupt visual onsets could also be thought of as the most salient stimulus property (Gibson, 1996a, b), in that its luminance change is the largest among all, and that it is associated with dynamic changes in which our visual system is very sensitive to (Todd & Van Gelder, 1979). Therefore, we take the approach in this study by framing the question in terms of whether the most salient property, abrupt onsets, can capture attention when it is not contingent on the attenitonal control settings.

Also, the effect of display size should be considered as well. Although Gibson & Kelsey (1998) used two display sizes, 4 and 8, and found no difference between the two display sizes, we suspect that this may be due to a more robust capture effect of attentional setting for displaywide onsets, but this may not necessarily apply to the setting for color, which may lead to a weaker capture effect than onsets. Todd and Kramer (1994) found that the location effect of irrelevant singletons increased with display size and suggested that the salience of feature singletons increased with display size and served as landmarks to guide the allocation of visual attention. The findings of Todd and Kramer (1994) are important since if stimulus saliency increases with display size and guides attentional allocation as proposed, then showing a location effect in one display size does not guarantee the same effect in another. In addition, searching for a target among different display sizes may yield different interaction patterns of the complex top-down and bottom-up processes.

Eight experiments were reported in this study to address the issue that under what conditions purely stimulus-driven capture occur, given the considerations of attentional setting for displaywide features as proposed by Gibson & Kelsey (1998) and target-specific features by Folk and colleagues (Folk et al, 1992, 1994, 1998, 1999). The first five experiments used the no-onset technique of Yantis & Jonides (1984) developed from Todd & Van Gelder (1979), and the letters in the target displays of the last three experiments were all onsets. The stimulus onset asynchrony (SOA) was manipulated in Experiment 8.

Display size was manipulated in all eight experiments.

EXPERIMNT 1: ONE ONSET BOX

In this experiment, we adopted the method used by Gibson & Kelsey (1998), but examined one aspect that was not tested in their study: When the displaywide visual features include color but not onset. To avoid the displaywide attentional set for onset stimuli, the non-onset technique of Yantis and Jonides (1984) was used in the target display. In such a display, figure 8 patterns were used as placeholders, and the letters to be discriminated in the target display were shown by removing two camouflaging lines from each of the figure 8 patterns. Since results of gradual change and sudden change from figure 8s to each of the letters were the same (Yantis & Jonides, 1984), we used the method of sudden removal of the two lines. To manipulate the displaywdie visual features in the target display including color but not onset, all the non-onset letters in the target display were painted in red. According to the displaywide contingency hypothesis, only the red distractor, but not the onset one, should show the location effect in such a no-onset display.

Method

Participants

Twenty-four undergraduates studying at National Taiwan University participated in this experiment to exchange for course credit. All had normal or corrected-to-normal vision, and were naïve about the purpose of this experiment.

Stimuli and design

Stimulus displays were shown on a 20' SONY monitor and controlled by an IBM 486 personal computer. The refresh rate of the monitor was 70 Hz. Participants sat at a viewing distance of 60 cm in a dimly lighted chamber. Each trial consisted of 3 kinds of display, including the fixation, the distractor, and the target displays (Figure 1).

In the fixation display, a cross ($0.8^o \times 0.8^o$) in gray (CIE (.302, .302), 1.47cd/m^2) was served as the fixation pattern. Around the fixation cross, 4 or 8 red figure 8s (CIE (.610, .345), 5.71cd/m^2) were presented at the circumference of an imagery circle of radius 5.1º. For the display of size 4, the four figure 8s were presented at the locations of 0º, 90º, 180º, and 270º. For the display of size 8, four more figure 8s were presented additionally at 45º, 135º, 225º, and 315º.

Two kinds of distractor displays were used: onset and color. In the display of onset distractor, one of the figure 8s was surrounded by a white box (CIE (.284, .300), 31.7 cd/m^2) with width of 0.22º. In the display of color distractor, seven of the figure 8s were surrounded by the same white box, while one was in color red, with the same specification with the red figure 8s. Letters ($1.3^o \times 0.8^o$) in the target display were all in red, and were constructed by removing two segments from each of the figure 8s in the fixation display. One of the letters was the target (H or U), and the other 3 or 7 letters were P, E, and S, each appeared once for display size 4 and at least twice for size 8. The fixation cross was presented throughout the three displays. The three factors manipulated (distractor-target location, distractor type, and display size) were all with-subject designs. Except for the camouflaging figure 8s patterns added in this experiment, the stimulus sequence followed that of Gibson & Kelsey (1998).

Procedure

Figure 1(left) illustrates the procedure used in this experiment. In each trial, the fixation display was presented for 500 ms, followed by the distractor display for 100 ms, then back to the fixation display for 100 ms, and finally the target display was presented for 200 ms and then back to the fixation display again. Except for the first trial, each trial started immediately after the response to the last trial. The participants' task was to press the left shift key if the target letter H was presented, and to press the right shift key if U was presented. They were asked to respond as quickly and yet accurately as possible.

The two kinds of distractors, color and onset, each comprised half of the trials, and the presentation order of color and onset in the distractor display was randomly assigned within each display size condition. Due to the constraint by the non-onset target display, the two kinds of display size were separated in blocks. There were six blocks (three blocks for size 4 and three blocks for size 8), each consisting of 64 trials (32 trials for color distractor and 32 trials for onset). The presentation order of the 6 blocks was random.

Within each display size, the location that the distractor appeared was not relevant to the target letter. That is, for display size 4 the cuing validity of the distractor was 25%, and the target could appear in any of the 4 locations with equal probability. For display size 8, the cuing validity of the distractor was 12.5%, also the same with the other 7 locations. The participants were informed about this, and were asked to ignore the distractors. Thirty-two practice trials preceded the formal 256 trials, and the participants took short breaks between experimental blocks.

Results

Response times longer than 4 sec or shorter than 200 ms were excluded from further analysis in all 8 experiments, and 0.08%, 0.50%, 0.16%, 0.40%, 0.08 %, 0.13%, 0.09 %, and 0.89 % trials were removed according to these criteria from Experiment 1 to 8 respectively. A 3-way analysis of variance (ANOVA, Chen & Cheng, 1999) with factors of location (same, different), type (color, onset), and size (4, 8) was carried out for both response time and error rate. The results of response time are shown in Figure 1 (right).

ANOVA on the results of response time showed that, main effects of location ($F(1,23)=58.448$, $MSE=377122.261, p<.0001$) and size ($F(1,23)=36.722$, $MSE=311493.887$, $p<.0001$) were found, but not the main effect of type ($F(1,23)=0.867$, $MSE=3637.560$, $p>.30$). Two-way interactions of location x type ($F(1,23) = 21.382$, $MSE = 162897.578$, $p<.0002$) and location x size ($F(1,23) = 16.309$, $MSE = 92734.472$, p<.0006) were significant, but not type x size (F(1,23)=0.234, MSE = 1470.464, p>0.6). The three-way interaction of location x type x size was not significant (F(1,23)=0.159, MSE=637.685, p>0.6).

Further analysis of the interaction of location x type showed that, the mean response time was shorter for same location than for different location when the distractor was an onset (F(1,23) = 73.609, MSE = 517865.327, p < 0.0001), but not when it was a color singleton (F(1,23) = 3.149, MSE = 22154.512, p > 0.08). The response time was shorter for onset distractor than for color at the same location (F(1,23) = 18.217, MSE = 107609.914, p<.0002), but it was longer at different locations (F(1,23) = 9.975, MSE = 58925.225, p < 0.003).

For the interaction effect of location and size, the response time was shorter at the same location than at different locations at size 4 (F(1,23)=7.896, MSE=47919.720, p<.01) and size 8 (F(1,23)=69.521, MSE=421937.013, p<.0001), and the response time was shorter at size 4 than at size 8 when the location was the same (F(1,23)=4.539, MSE=32154.710, p<.04) and when it was different (F(1,23) = 52.521, MSE = 372073.649, p<.0001).

The ANOVA of the error rate showed that the main effects of location (F(1,23)=22.835, MSE=0.282, p<.0002), type (F(1,23)=10.780, MSE=0.106, p<.004), and size (F(1,23)=25.187, MSE=0.288, p<.0001) were all significant, so were the two-way interactions of location x type (F(1,23) = 21.231, MSE = 0.179, p<.0002), location x size (F(1,23)=7.606, MSE=0.048, p<0.02), and type x size (F(1,23)=6.716, MSE=0.022, p<.02). The three-way interaction of location, type, and size was also significant (F(1,23)=14.348, MSE=0.060, p<.001).

Further analysis of the interaction effect of location and type showed that the error rate was lower when the location was same than when it was different only for the onset distractor (F(1,23)=43.812, MSE=0.455, p<.0001), but not for color distractor (F(1,23)=0.554, MSE=0.006, p>.40)；the error rate was lower for the onset distractor than for the color distractor only when the location was the same (F(1,23)=30.694, MSE=0.280, p<.0001), but not when location was different (F(1,23)=0.524, MSE=0.005, p>.40).

The interaction of location and size showed that the error rate was lower at the same location than at different location at size 4 and 8 (F(1,23)=5.237, MSE=0.049, p<.03, and F(1,23)=30.160, MSE= 0.281, p<.0001, respectively); It was lower at size 4 than at size 8 at the same location and at different location (F(1,23) =5 .716, MSE = 0.051, p <. 03, and F(1,23) = 32.198, MSE = 0.285, p <. 0001, respectively). The interaction of type and size indicated that the error rate was lower for onset than for color only at size 8 (F(1,23)=17.129, MSE=0.112,p<.0002), but not at size 4 (F(1,23)=2.406, MSE=0.016, p>0.1); the error rate was lower at size 4 than at size 8 for both color and onset distractors (F(1,23)=31.897, MSE=0.234, p<.0001, and F(1,23)=10.275, MSE=0.076, p<.003, respectively). From these results, there does not seem to show trade-off between response time and accuracy.

Discussion

In this experiment, the target display consisted of non-onset red letters while the preceding distractor could be onset or color. As with Gibson & Kelsey (1998), we will emphasize the response time data and compare the location effect under different conditions.

At size 4, the response time was faster when the target appeared at the same than at a different location only for onset distractor, but not for color distractor. Such a location effect was found for both onset and color distractors at size 8. These results thus seemed to support the onset capture view of Yantis and Jonides (1984). The color distractor, though was contingent on the displaywide attentional setting since all the letters in the target display were red, seemed to show a weaker capture effect than the onset distractor. Only at size 8 was the location effect of color reliable, and the magnitude of the location effect was smaller for color than for onset.

It is possible that the stronger effect of onset distractor obtained from this experiment resulted from the way the onset was presented. We followed that of Folk et al. (1992) by presenting only one onset box in the distractor display, which, when compared to the color distractor which was a unique red box among other 3 gray boxes, might yield a higher signal-to-noise ratio. In fact, Folk et al. (1992) used only one onset in both the distractor and the target displays and found that the onset distractor captured attention only when it was contingent on attentional setting. The absence of onset capture when the target was defined in red, a result different from what we found here, may come from the fact that searching for a target with a defining feature (red in this case) can have one's attentional control relatively quite narrowly tuned only for color red, but nothing else. When attentional control was more broadly tuned for displaywide properties as in this study, onset can then somehow "leaky" from the control setting, and draw one's attention in a stimulus-driven fashion.

Alternatively, the way onset distractor is presented may affect more for the implicit setting of displaywide than the explicit setting for a particular feature. In Gibson & Kelsey (1998), the onset distractor was actually presented as luminance increment of one of the four gray boxes, rather than a unique onset as in this experiment. We took the same approach in the next experiment to see whether the contingent capture proposal of Gibson & Kelsey (1998) holds in such a condition. The difference in one vs. four boxes can also be thought of as the new vs. old object (e.g., Folk & Remington, 1999).

EXPERIMNT 2: FOUR BOXES

In the first experiment, the onset distractor was defined as the only brightening box surrounding one of the figure 8s to allow for a first-step test of involuntariness of attention capture by onset. Having provided evidence that onset-capture does occur even when the distractor was not predictive to the target location and was not contingent on the displaywide attentional set, we were able to move from this extreme condition of onset distractor to a more conservative estimate of onset capture.

In so doing, the appearance of the onset distractor was changed to be more comparable with the appearance of the color distractor. Four or eight boxes, instead of only one, surrounding the figure 8s were shown, and one was brightening and thickening as opposed to the others. By comparing the results from this experiment and the previous one, whether the way the onset distractor was presented would affect the displaywide contingent capture could be examined.

Method

Participants

Another group of 24 participants recruited from the same pool as described in Experiment 1 participated in this experiment.

Stimuli, design, and procedure

The stimulus, design, and procedure were basically the same as in Experiment 1, except that for each of the fixation, distractor, and target displays, thin (0.06°) gray (CIE (.302, .302), 1.47 cd/m^2) boxes surrounding each of the figure 8s and the letters were added. See Figure 2(left) for the display sequence.

Results

ANOVA on response time showed that both the main effects of location and size were significant, (F(1,23) = 21.786, MSE = 423367.305, p <.0002, and F(1,23) = 18.025, MSE = 366437.776, p <.0002, respectively), but not the main effect of type (F(1,23) = 0.070, MSE = 330.450, p > .7). The two-way interaction effects of location x type and location x size were significant (F(1,23) = 23.484, MSE = 210067.054, p <.0002, and F(1,23) = 7.470, MSE = 93367.381, p <.01, respectively), but not that of type x size and the three-way interaction location x size x type (F(1,23) = 0.544, MSE = 4285.718, p >.4 & F(1,23) = 0.112, MSE = 532.814, p >.7)。

Further analysis of the location x type interaction showed that the response time was shorter at the same location than at a different location for onset distractor (F(1,23) = 43.339, MSE = 614937.773. p <.0001)，but not for color distractor (F(1,23) = 1.304, MSE = 18496.586, p >.2); the response time was shorter for onset distractor than for color one at the same and different locations (F(1,23) = 14.155, MSE = 96869.087, p <.001, and F(1,23) = 16.590, MSE = 113530.416, p <.001, respectively). For the location x size interaction, shorter response time was found in at the same location than at a different location at size 8 (F(1,23)=28.635, MSE=457185.594, p<.0001), but not at size 4 (F(1,23)=3.730, MSE=59549.093, p>.5); And shorter response time was found at size 4 than at size 8 at a different location (F(1,23) = 25.275, MSE = 414871.051, p <.0001), but not at the same location (F(1,23) = 2.738, MSE = 44934.107, p >.1)。

ANOVA on error rate indicated that the main effects of location, type, and size were all significant (F(1,23) = 13.511, MSE = 0.071, p <.002, F(1,23) = 22.115, MSE = 0.171, p <.0002, and F(1,23) = 68.797, MSE = 0.326, p <.0001), so were the two-way interaction of location x type and type x size, and the three-way interaction of location, type, and size (F(1,23) = 89.425, MSE = 0.525, p <.0001, F(1,23) = 5.767, MSE = 0.042, p <.03, and F(1,23) = 6.187, MSE = 0.042, p <.03, respectively), but not the interaction of location x size (F(1,23) = 2.549, MSE = 0.014, p >.1).

Further analysis of the location x type interaction showed that the error rate was lower at the same location than at a different location for onset distractor (F(1,23) = 88.323, MSE = 0.491, p <.0001), but the pattern was reversed for color distractor (F(1,23) = 18.916, MSE = 0.105, p <.0002)；and the error rate was lower for onset distractor than for color distractor at the same location and at a different location (F(1,23) = 95.260, MSE = 0.647, p <.0001 & F(1,23) = 7.142, MSE = 0.049, p <.02)。The interaction of type x size indicated that the error rate was lower for onset than for color only for size 8 (F(1,23)=26.331, MSE=0.177, p<.0001), but not for size 4 (F(1,23)=3.999, MSE=0.027, p>.05)；and the error rate was lower at size 4 than at size 8 for both the onset distractor and the color distractor (F(1,23) =14.523, MSE=0.076, p<.0005 & F(1,23)=54.187, MSE=0.283, p<.0001). No response time-accuracy trade off seemed to exist here.

Discussion

Even when the presentation of the onset distractor was as in Gibson & Kelsey (1998) to make the two types of distractor comparable, the same result pattern as in Experiment 1 was still found. Compare Figure 1 and Figure 2 to see the similarity of the two results. Therefore, the onset distractor seemed to capture attention when it signaled a new object (Experiment 1) and when it was a luminance change from an old object (Experiment 2). The onset capture occurred even when the displaywide setting was on color, but not on onset, as indicated by the results that the location effect was found for the onset distractor when the goal was to search for a red letter.

The color distractor, even when it was contingent on the displaywide attentional setting, seemed to yield a weaker capture effect than the onset distractor. Unlike the onset distractor, only at size 8 was the color distractor showed a significant location effect, but not at size 4. Therefore, results from both distractor types did not seem to support for the displaywide attentional setting view of Gibson & Kelsey (1998). Rather, the onset-uniqueness view of Jonides & Yantis (1988) was supported.

EXPERIMNT 3: BASELINE CONDITION

In this experiment, we examined the supposedly baseline condition of Gibson & Kelsey (1998) that had left untested in their study: the target display contained no color and no onset. As mentioned before, in the two experiments of Gibson & Kelsey (1998), all the letters in the target display were presented abruptly, that is, with onset property, and they showed that when the letters were in red, red distractor captured attention, but not when the letters were in white. The onset distractor could capture attention in both cases. Although they explained these results based on the displaywide setting on color and onset in the former case, and on onset alone in the latter case, it is possible that such a displaywide contingent capture applies only to color, but not to onset.

One way to test this conjecture is to examine the two conditions when the target display does not contain the onset property, but one with color and another without. The former condition has been tested in the previous two experiments, and the results showed that even in such a non-onset target presentation the onset distractor could capture attention. This is true when the onset distractor is presented as the only onset (Experiment 1) following the one used in Folk et al. (1992), or when it is presented as broadening and lightening of one of the four boxes, like the one used in Gibson & Kelsey (1998). Therefore, onset seemed to capture attention even under conditions of non-onset red display, a non-contingent condition. If onset is so unique in capturing attention, we should also expect to find onset-capture in another non-contingent condition, the non-onset white target display. This experiment was designed to test this.

Method

Participants

Another group of 21 participants recruited from the same pool as described in Experiment 1 participated in this experiment.

Stimuli, design, and procedure

The stimulus displays were the same as in Experiment 2, except that all the figure 8s, surrounding boxes, and letters were in white, as shown in Figure 3 (left)

Results

ANOVA on the results of response time showed that, main effects of location ($F(1,20)=16.406$, $MSE=122449.214$, $p<.001$) and size ($F(1,20)=43.318$, $MSE=511845.368$, $p<.0001$) were found, but not the main effect of type ($F(1,20)=0.270$, $MSE=2564.342$, $p>.6$). Non of any two-way interactions of location x type, location x size, and type x size were significant, ($F(1,20) = 1.866$, $MSE = 19026.950$, $p > 0.1$, $F(1,20) = 2.701$, $MSE = 113455.960$, $p > .1$, $F(1,20) = 0.018$, $MSE = 160.423$, $p > .8$, respectively), neither was the three-way interaction of location x type x size ($F(1,20)=0.644$, $MSE=6444.744$, $p>0.4$).

The ANOVA of the error rate showed that the main effects of location ($F(1,20)=5.665$, $MSE=0.093$, $p<.03$), type ($F(1,20)=11.810$, $MSE=0.079$, $p<.003$), and size ($F(1,20)=7.777$, $MSE=0.071$, $p<.02$) were all significant, so were the two-way interactions of location x type ($F(1,20)=12.385$, $MSE=0.105$, $p<.003$). The two-way interactions of location x size ($F(1,20)=2.977$, $MSE=0.041$, $p>.09$), and type x size ($F(1,20)=2.215$, $MSE=0.015$, $p>.1$) are not significant, neither was the three-way interaction of location, type, and size($F(1,20)=3.835$, $MSE=0.009$, $p>.06$).

Further analysis of the interaction effect of location and type showed that the error rate was lower when the location was same than when it was different only for the onset distractor ($F(1,20)=15.885$, $MSE=0.197$, $p<.001$), but not for color distractor ($F(1,20)=0.014$, $MSE=0.000$, $p>.9$); the error rate was lower for the onset distractor than for the color distractor only when the location was the same ($F(1,20)=24.144$, $MSE=0.183$, $p<.0001$), but not when the location was different ($F(1,20)=0.118$, $MSE=0.001$, $p>.7$).

Discussion

In this experiment, the target display was designed to contain no color and no onset. According to the contingent capture view, neither onset nor color should show the capture effect. The onset-uniqueness view, however, should expect to find the capture effect of onset, but not that of color.

Neither view was fully supported by the results. The onset distractor captured attention at both size 4 and size 8, inconsistent with the contingent capture view, and seemed to support for the onset-uniqueness view. However, the color distractor, though did not capture attention at size 4, showed the capture effect at size 8. This is also inconsistent with the onset-uniqueness view.

Actually, all the first three experiments showed that both onset and color could capture attention at size 8, and only onset captured attention at size 4, regardless of the manipulations of the display. Therefore, display size may be a more dominant factor than attentional setting in determining the capture effect. Large display size increases the salience of a singleton, be it an onset or a different color, and so increasing the chance of stimulus-driven attentional capture.

Before concluding that the displaywide color setting did not seem to be strong enough at size 4 to lead to capture effect of color for the first two experiments, one more possibility for the absence of the contingent color effect cannot be excluded. Scrutiny of the fixation, distractor, and target displays revealed one thing that may be important for the absence of the color effect in Experiments 1 and 2: all the figure 8s and letters were painted in red. Although in the account of the displaywide setting, Gibson & Kelsey (1998) emphasized the importance of the target display in which all properties accompanied in the target display may all be included in the attentional setting, what really matters, however, may not be the target display alone. The difference between displays (or the change from one display to another in the sequence of a trial) may also be critical for the displaywide settings. This can explain the lack of color effect in the first two experiments. Athough the letters in the target display were all in red, there was no change from the previous display. When viewing a target display with red letters changing from red figure 8s, the constant existence of color red (and thus no change in the color dimension) may prevent the participants from setting their attention on red.

To test this hypothesis, the figure 8s in both the fixation display and the distractor display were changed into white. This would make the letters in the target display the only red stimuli in the sequence. Such a sequential change in color dimension should increase the possibility of the displaywide setting for color red and thus lead to the color capture effect, if the above conjecture is correct.

EXPERIMNT 4: A SEQUENTIAL CHANGE IN COLOR

The purpose of this experiment was to further clarify the notion of displaywide setting to see whether a change between displays was necessary to define the displaywide setting, especially between the target display and its preceding display. If the displaywide setting on the properties of the target had to be specified not only by the target display per se, but also by the difference between the target display and its preceding display, this should then explain the absence of the color capture effect at display size 4 in Experiments 1 and 2 in which the letters in the target display were all in red, but there was no change in the color dimension in the display sequence.

Method

Participants

Another group of 21 participants recruited from the same pool as described in Experiment 1 participated in this experiment.

Stimuli, design, and procedure

The stimulus displays and experimental procedure were the same as in Experiment 3, except that all the letters in the target display were in red, with the same luminance value as the white figure 8s. Since all figure 8s in the fixation display preceded the target were in white, there was a sequential change in the color dimension (but not in the luminance dimension) for the displays in a trial. See Figure 4 (left) for the stimulus displays.

Results

ANOVA on the results of response time showed that, main effects of location ($F(1,30) = 51.510$, MSE = 362010.407, $p < .0001$) and size ($F(1,30)=37.545$, MSE=512271.985, $p<.0001$) were found, but not the main effect of type ($F(1,30)=0.916$, MSE=2377.380, $p>.3$). Two-way interactions of location x type ($F(1,30) = 9.972$, MSE = 20366.151, $p<.01$) and location x size ($F(1,30) = 41.323$, MSE = 156045.232, $p < .0001$) were significant. The two-way interaction of type x size ($F(1,30) = 1.708$, MSE = 4938.334, $p>.2$) and the three-way interaction of location x type x size ($F(1,30) = 0.501$, MSE = 949.654, $p > .4$) were not significant.

Further analysis of the interaction of location x type showed that, the mean response time was shorter for the same location than for different location with onset distractor ($F(1,30) = 23.224$, MSE = 105323.510, $p < 0.001$) and color distractor ($F(1,30)=61.090$, MSE=277053.047, $p<0.0001$). The response time was shorter for onset distractor than for color at the same location ($F(1,30)=7.906$, MSE=18330.076, $p<.01$, but there was not significant at different locations($F(1,30) = 1.904$, MSE=4413.455, $p>.1$).

For the interaction effect of location and size, the response time was shorter at the same location than at different locations at size 8 ($F(1,30) = 91.947$, MSE = 496704.065, $p < .0001$), but no at size 4 ($F(1,30) = 3.952$, MSE = 21351.574, $p > .05$), and the response time was shorter at size 4 than at size 8 when the location was the same ($F(1,30) = 5.904$, MSE = 51426.225, $p <. 02$) and when it was different ($F(1,30) = 70.824$, MSE = 616890.992, $p <.0001$).

The ANOVA of the error rate showed that the main effects of location ($F(1,30)=36.877$, MSE=0.231, $p<.0001$) and size ($F(1,30)=66.408$, MSE=0.479, $p<.0001$) were significant, but not type ($F(1,30)=1.890$, MSE=0.009, $p>.1$). The two-way interactions of location x type ($F(1,30) = 0.673$, MSE = 0.003, $p>.4$) and type x size ($F(1,30) = 0.231$, MSE = 0.001, $p>.6$) were not significant, but the two-way interaction of location x size ($F(1,30) = 30.542$, MSE = 0.129, $p <0.0001$) were significant. The three-way interaction of location, type, and size was not significant ($F(1,23) = 0.231$, MSE = 0.001, $p>.6$).

Further analysis of the interaction effect of location and size showed that the error rate was lower at the same location than at different location at size 8 ($F(1,30)=67.241$, MSE=0.352, $p<.0001$) but not at size 4 ($F(1,30)=1.417$, MSE= 0.007, $p>.2$); the error rate was lower at size 4 than at size 8 at the same location and at different location ($F(1,30)=9.727$, MSE=0.056, $p<.01$, and $F(1,30)=96.640$, MSE=0.552, $p<.0001$, respectively). From these results, there does not seem to show trade-off between response time and accuracy.

Discussion

When the sequence of the display contained a change in the color dimension, compared to when no such change occurred as in Experiments 1 and 2, a striking difference between the results of this experiment and those of the first two experiments was found. At size 4, the color distractor showed the capture effect, but not the onset distractor. These results are consistent with the displaywide contingent capture view of Gibson & Kelsey (1998). This is the first time that the color distractor did show the capture effect when the letters in the target display are all in color. Therefore, the definition of displaywide attentional setting should be elaborated according to the present result. What properties are presented in the target display are the sufficient condition for the displaywide setting, but not the necessary condition. A sequential change in displays, especially the change between the target display and that before it, is necessary for the displaywide setting.

At size 8, however, the results were still the same as the previous three experiments. Both onset and color distractors showed the location effect. Therefore, it seemed that as display size increased, the chance of stimulus-driven capture increased as well. It is possible that to find one of the two target letters among multiple letters, the larger the display size, the harder the task. As the difficulty level of the task increases, the best strategy for the participants may be to use all kinds of cues possibly available, thus making both types of distractors capable of capturing attention.

EXPERIMNT 5: NON-ONSET TARGET WITH A DEFINING FEATURE

Atchley, Kramer, & Hillstrom (2000) manipulated the relationship of the distractor and the target in a two (distractor, onset/offset) by two (target, onset/offset) design. They found that when the target property (onset or offset) was pre-specified, a contingent onset/offset effect was found, but when the target property was not known until the presence of the target, a displaywide set for salient luminance changes was found instead. It thus seemed that the internal control set could be either on onset or offset (i.e., the two are separated) or on a more general category of "transient change".

Our first three experiments showed that onset seemed to capture attention even when the displaywide attentional setting was on color but not on onset. One reason for this kind of results may lie in the non-onset display used in these experiments. To control for the absence of onset when the target display was shown, figure 8s were presented in the positions of the letters preceded the target display and afterwards. In such a sequence of displays, the target display contained two kinds of properties regarding the transient change; the offset of two segments from each the figure 8s, and then the onset of the same segments. It is possible that this change in the target display makes the displaywide setting to be on a more general dynamic discontinuity of transient change, rather than on its sub-dimension such as onset and offset. Therefore, even the letters shown in the target display were offsets, they were still contingent on the displaywide setting of transient change, thus making the onset distractor capable of capturing attention. In this account, the onset-capture is also contingent on the displaywide setting for transient change.

If this is true, it is then interesting to see whether this also applies to the condition of a more narrowly tuned setting, the explicit setting of defining feature of the target. Folk et al. (1992) found that attentional capture occurred only when the distractor was contingent on the attentional control setting; onset is no exception. When the participants were to find a red target and identify what it was, whether the target was presented in the same location as the preceding non-informative onset distractor had no effect on the response time to the red target. In this experiment, we used the same non-onset target display as in the previous experiments, but the target was defined as one of the unique color, similar to that in Folk et al. (1992), to see whether the onset distractor could still capture attention in this condition.

Method

Participants

Another group of 27 participants recruited from the same pool as described in Experiment 1 participated in this experiment.

Stimuli, design, and procedure

The stimulus materials, experimental design, and procedure were the same as in Experiment 4, except that the target letter in the target display was the only letter in red, among other white letters. The participants were told to search for a red letter and discriminate whether it was a U or an H by pressing different response keys. See Figure 5(left) for the display.

Results

ANOVA on the results of response time showed that, the main effect of location was found ($F(1,26) = 57.969$, $MSE=51734.277$, $p<.0001$), but not the main effect of size ($F(1,26)=0.722$, $MSE=676.850$, $p>.4$) and type ($F(1,26) = 0.077$, $MSE = 44.775$, $p > .7$). Two-way interactions of location x type ($F(1,26) =21.373$, $MSE=9439.431$, $p<.0002$) was significant, but not location x size ($F(1,26)=0.718$, $MSE=595.899$, $p>.4$) nor type x size ($F(1,26)=1.145$, $MSE=662.670$, $p>.2$); The three-way interaction of location x type x size was not significant, either ($F(1,26) = 1.568$, $MSE = 546.369$, $p >.2$).

Further analysis of the interaction of location x type showed that, the mean response time was shorter for same location than for different location when the distractor was an onset ($F(1,26) = 12.725$, $MSE = 8488.389$, $p <.001$) and a color singleton ($F(1,26) =78.983$, $MSE=52685.319$, $p<.0001$). The response time was shorter for onset distractor than for color at the same location ($F(1,26)=10.502$, $MSE=5392.220$, $p<.01$), but it was longer at different locations ($F(1,26) = 7.970$, $MSE=4091.986$, $p<0.003$).

The ANOVA of the error rate showed that the main effects of location ($F(1,26)=0.560$, $MSE=0.001$, $p>.4$), type ($F(1,26)=2.692$, $MSE=0.008$, $p>.1$), and size ($F(1,26)=0.098$, $MSE=0.000$, $p>.7$) were all not significant, so were the two-way interactions of location x type ($F(1,26)=0.799$, $MSE=0.002$, $p>.3$), location x size ($F(1,26)=0.086$, $MSE=0.000$, $p>.7$), and type x size ($F(1,26)=0.558$, $MSE=0.001$, $p>.4$). The three-way interaction of location, type, and size was also not significant ($F(1,26)=0.197$, $MSE=0.0001$, $p>.6$).

Discussion

In this experiment, the non-onset target letter was defined uniquely by color red. For such a target-specific visual feature that was previously shown to have contingent capture effect (Folk et al., 1992), only color distractor should be expected to capture attention. However, our results from this experiment indicated that not only color, but also onset, captured attention, at both size 4 and size 8. Therefore, our conjecture seemed to be verified: the camouflaging figure 8 patterns may have caused the onset-capture, even under the condition when the target was associated with a prespecified defining feature.

A definite confirmation to this conjecture, however, should be made only when the following condition was also satisfied: when the figure 8 patterns were removed, so was the onset-capture effect. We tested this in the next experiment.

EXPERIMNT 6: ONSET TARGET WITH A DEFINING FEATURE

In this experiment, the camouflaging figure 8 patterns in the fixation display were removed, leaving only 4 or 8 empty boxes in the display. This is similar to the display used in Folk et al. (1992), but with some minor differences. First, we used the same target display but paired with two kinds of distractors. In Folk et al. (1992), two kinds of target displays were used. The display of color target was similar to what we used here (Figure 6(left)), but the onset target in their study was shown as the only item appeared within one of the four boxes.

Second, our onset distractor was defined by the brightening and thickening of one of the multiple thin boxes in this experiment, whereas in Folk et al. (1992) it was defined by four small circles surrounding one of the four boxes. Third, in our target display, the target was either U or H, and the other non-target items were always different from the target letter. In Folk et al. (1992), only two types of characters were used, X or =, and so for the display of color target, the red target was either X or =, and the other three non-target items were also X or =. The only difference between these non-target items and the target lie in their colors: whiter vs. red. Fourth, two kinds of display size were used in this experiment, wherease in Folk et al. (1992) only display size 4 were tested.

Method

Participants

Another group of 20 participants recruited from the same pool as described in Experiment 1 participated in this experiment.

Stimuli, design, and procedure

All the stimulus materials were the same as in Experiment 5, with the exception that all figure 8s in the fixation display were removed.

Results

ANOVA on the results of response time showed that, main effects of location ($F(1,19) = 41.489$, $MSE = 30677.641$, $p < .0001$) and type ($F(1,19) = 8.680$, $MSE = 6839.749$, $p < .001$) were found, but not the main effect of size ($F(1,19)=0.158$, $MSE=335.539$, $p>.6$). Two-way interactions of location x type ($F(1,19) = 10.490$, $MSE = 5762.282$, $p <.005$) and location x size ($F(1,19) = 5.623$, $MSE = 7053.390$, $p <.03$) were significant, but not type x size ($F(1,19) = 0.034$, $MSE =18.040$, $p>.8$), neither was the three-way interaction of location x type x size ($F(1,19) = 0.499$, $MSE = 266.610$, $p >.4$).

Further analysis of the interaction of location x type showed that, the mean response time was shorter for same location than for different location when the distractor was an onset ($F(1,19) = 7.642$, $MSE = 4924.352$, $p < .01$) and a color singleton ($F(1,19) = 48.910$, $MSE = 31515.572$, $p < .0001$). The response time was shorter for onset distractor than for color at the same location ($F(1,19)=18.812$, $MSE=12578.958$, $p<.0002$), but it was not longer at different locations ($F(1,19)=0.035$, $MSE=23.073$, $p>.8$).

For the interaction effect of location and size, the response time was shorter at the same location than at different locations at size 4 ($F(1,19)=4.168$, $MSE=4155.609$, $p<.05$) and size 8 ($F(1,19)=33.680$, $MSE=33575.423$, $p<.0001$), and the response time was not shorter at size 4 than at size 8 when the location was the same ($F(1,19) = 3.094$, $MSE = 5232.869$, $p>.08$) nor when it was different ($F(1,19) =1.275$, $MSE=2156.060$, $p>.2$).

The ANOVA of the error rate showed that the main effects of location ($F(1,23)=22.978$, $MSE=0.283$, $p<.0005$), type ($F(1,23)=10.714$, $MSE=0.105$, $p<.005$), and size ($F(1,23)=25.505$, $MSE=0.290$, $p<.0001$) were all significant, so were the two-way interactions of location x type ($F(1,23) = 21.304$, $MSE = 0.181$, $p <.0005$), location x size ($F(1,23)=7.675$, $MSE=0.048$, $p<0.05$), and type x size ($F(1,23)=6.513$, $MSE=0.021$, $p<.05$). The three-way interaction of location, type, and size was also significant ($F(1,23) = 14.746$, $MSE =0.061$, $p<.001$).

Further analysis of the interaction effect of location and type showed that the error rate was lower when the location was same than when it was different only for the onset distractor ($F(1,23)=44.038$, $MSE =0.458$, $p<.0001$), but not for color distractor ($F(1,23)=0.553$, $MSE=0.006$, $p>.40$)；the error rate was lower for the onset distractor than for the color distractor only when the location was the same ($F(1,23)=30.700$, $MSE=0.280$, $p<.0001$), but not when the location was different ($F(1,23)=0.561$, $MSE=0.005$, $p>.40$).

The interaction of location and size showed that the error rate was lower at the same location than at different location at size 4 and 8 ($F(1,23)=5.224$, $MSE=0.049$, $p<.05$, and $F(1,23)=30.364$, $MSE= 0.283$, $p<.0001$, respectively); the error rate was lower at size 4 than at size 8 at the same location and at different location ($F(1,23)=5.725$, $MSE=0.051$, $p<.05$, and $F(1,23)=32.543$, $MSE=0.288$, $p<.0001$, respectively). The interaction of type and size indicated that the error rate was lower for onset than for color only at size 8 ($F(1,23)=16.905$, $MSE=0.111$, $p<.0003$), but not at size 4 ($F(1,23)=2.409$, $MSE=0.016$, $p>0.1$); the error rate was lower at size 4 than at size 8 for both color and onset distractors ($F(1,23)=31.997$, $MSE=0.234$, $p<.0001$, and $F(1,23)=10.490$, $MSE=0.077$, $p<.005$, respectively). From these results, there does not seem to show trade-off between response time and accuracy.

Discussion

The major difference in the designs between this experiment and the previous five experiments was the absence of the camouflaging figure 8 patterns in the fixation display. By removing the figure 8 patterns in this experiment, all the letters were presented abruptly in the target display. At display size 4, only color distractor captured attention, but not onset. These results are consistent with the contingent capture view of Folk et al. (1992, 1994, 1998), despite of the differences between this experiment and that of Folk et al. (1992).

At size 8, however, the results did not support for such contingent capture view, in that both onset and color distractors were shown to capture attention. Display size larger than 4 was never examined in Folk et al. (1992, 1994, 1998), thus conclusions drawn from one display size may render the danger of over-generalization by assuming that contingent capture should occur across different display size conditions. As we consistently found both onset and color distractors captured attention at display size 8 regardless of the conditions manipulated, it is possible that a purely stimulus-driven capture can indeed occur under conditions of large display size, whereas displays of small set size are more constrained by the internal control of attentional setting.

One possibility for the onset-capture at display size 8 cannot be excluded yet still before the conclusion of purely stimulus-driven capture can be drawn firmly. Bacon & Egeth (1994) have demonstrated that task-irrelevant singletons could also capture attention when participants adopted a "singleton search mode". According to this view, the seemingly stimulus-driven effect of onset distractors should not be interpreted as such. Rather, it should be seen also as the effect of contingent capture; that is, attentional priority is set for salient singletons in the displays. The possibility of adopting such singleton search strategy may increase with display size, as the salience of the singletons increases with display size (Todd & Kramer, 1994). This can explain why we obtained the location effect for onset distractors at size 8 but not at size 4.

One way to test this hypothesis is to exclude the possibility of participants' using the singleton detection mode. If the onset-capture disappears at display size 8 under this condition, then the onset-capture shown in this experiment was due to the singleton search strategy adopted. These result patterns should thus provide evidence supporting for the contingent capture view. If, however, the same result pattern is found even when the participants cannot adopt a singleton search mode, a purely stimulus-driven attentional capture should thus hold. The next experiment was designed to differentiate these two possibilities.

EXPERIMNT 7: SINGLETON SEARCH MODE EXCLUDED

In this experiment, the singleton search mode was excluded by adding one more color in the target display: green. This would make the target display with two colors, red and green. When the target display contained only one unique color as in the previous experiment, the participants may adopt two kinds of strategies in searching for the red target: a feature detection mode and a singleton detection mode. The findings of absence of onset-capture at display size 4 and existence of such effect at display size 8 may then reflect the different modes adopted by the participants: feature detection mode at size 4 and singleton detection mode at size 8. When the target display contained more than one color as designed in this experiment, no color singleton existed in the target display so that only one detection mode could be adopted by the participants: the feature search mode. Whether onset distractors could capture attention at size 8 under this condition provides a critical test for the differentiation between the possibilities of purely stimulus-driven capture and contingent capture.

Method

Participants

Another group of 24 participants recruited from the same pool as described in Experiment 1 participated in this experiment.

Stimuli and procedure

All the experimental details were the same as in Experiment 6, with the only exception that one of the non-target letters in the target display was in green, with the same luminance value as the red target (Figure 7). The chance of which letter would be in green was equally distributed among the non-target letters. Therefore, two colored letters were shown in the target display, one in red and one in green. The participants were asked to search for a red letter and to discriminate whether it was a U or an H.

Results

ANOVA on the results of response time showed that main effects of location ($F(1,23) = 58.220$, $MSE=378673.923$, $p<.0001$) and size ($F(1,23) =37.163$, $MSE=312904.233$, $p<.0001$) were found, but not the main effect of type ($F(1,23)=0.830$, $MSE=3486.918$, $p>.30$). Two-way interactions of location x type ($F(1,23)=21.599$, $MSE=163917.921$, $p<.0002$) and location x size ($F(1,23)=16.504$, $MSE=93504.719$, $p<.0006$) were significant, but not type x size ($F(1,23)=0.220$, $MSE=1375.265$, $p>0.6$). The three-way interaction of location x type x size was not significant ($F(1,23)=0.175$, $MSE=703.018$, $p>0.6$).

Further analysis of the interaction of location x type showed that, the mean response time was shorter for same location than for different location when the distractor was on onset ($F(1,23) = 73.856$, $MSE =520437.332$, $p < 0.0001$), but not when it was a color singleton ($F(1,23) = 3.144$, $MSE=22154.512$, $p>0.08$). The response time was shorter for onset distractor than for color at the same location ($F(1,23)=18.257$, $MSE=107609.914$, $p<.0002$), but it was longer at different locations ($F(1,23)=10.145$, $MSE=59794.925$, $p<0.003$).

For the interaction effect of location and size, the response time was shorter at the same location than at different locations at size 4 ($F(1,23)=7.875$, $MSE=47919.720$, $p<.01$) and size 8 ($F(1,23)=69.724$, $MSE=424258.922$, $p<.0001$), and the response time was shorter at size 4 than at size 8 when the location was the same ($F(1,23)=4.566$, $MSE=32154.710$, $p<.05$) and when it was different ($F(1,23)=53.141$, $MSE=374254.242$, $p<.0001$).

The ANOVA of the error rate showed that the main effects of location ($F(1,23)=22.978$, $MSE=0.283$, p<.0005), type (F(1,23)=10.714, MSE=0.105, p<.005), and size (F(1,23)=25.505, MSE=0.290, p<.0001) were all significant, so were the two-way interactions of location x type (F(1,23)=21.304, MSE=0.181, p<.0005), location x size (F(1,23)=7.675, MSE=0.048, p<0.05), and type x size (F(1,23)=6.513, MSE=0.021, p<.05). The three-way interaction of location, type, and size was also significant (F(1,23)=14.746, MSE=0.061, p<.001).

Further analysis of the interaction effect of location and type showed that the error rate was lower when the location was same than when it was different only for the onset distractor (F(1,23)=44.038, MSE =0.458, p<.0001), but not for color distractor (F(1,23)=0.553, MSE=0.006, p>.40)；the error rate was lower for the onset distractor than for the color distractor only when the location was the same (F(1,23)=30.700, MSE=0.280, p<.0001), but not when location was different (F(1,23)=0.561, MSE = 0.005, p>.40).

The interaction of location and size showed that the error rate was lower at the same location than at different location at size 4 and 8 (F(1,23)=5.224, MSE=0.049, p<.05, and F(1,23)=30.364, MSE= 0.283, p<.0001, respectively); the error rate was lower at size 4 than at size 8 at the same location and at different location (F(1,23)=5.725, MSE=0.051, p<.05, and F(1,23)=32.543, MSE=0.288, p<.0001, respectively). The interaction of type and size indicated that the error rate was lower for onset than for color only at size 8 (F(1,23)=16.905, MSE=0.111,p<.0003), but not at size 4 (F(1,23)=2.409, MSE=0.016, p>0.1); the error rate was lower at size 4 than at size 8 for both color and onset distractors (F(1,23)=31.997, MSE = 0.234, p<.0001, and F(1,23)=10.490, MSE=0.077, p<.005, respectively). From these results, there does not seem to show trade-off between response time and accuracy.

Discussion

When the singleton detection mode was excluded in this experiment, the pattern of results was still the same as the previous experiment. At size 4, only color showed the capture effect, whereas at size 8, both color and onset could capture attention. These results thus provide evidence for a purely stimulus-driven capture at large display size. Since no singleton search mode could be adopted when no singleton existed in the target display, the onset-capture at size 8 in the previous and the current experiments cannot be explained by the singleton search mode the participants used. That is, these results did not support the contingent capture hypothesis.

EXPERIMNT 8: EFFECT OF SOA

In this experiment, an effort was made to investigate the time course of the capture effect, particularly, its interaction with display size. Many studies have addressed the issue of the time courses of exogenous orienting and endogenous orienting of attention. How the involuntary capture of attention by task-irrelevant salient stimuli varied with time were investigated by manipulating the stimulus onset asynchrony (SOA) between distractor and target in the spatial cueing paradigm as adopted here (e.g., Muller & Rabbit, 1989; Remington, Johnston, &Yantis 1992; Theeuwes, 1994). In this experiment, the same design as in Experiment 6 was used, and the SOA was varied at 50, 150, and 250 ms. In Experiment 6, the distractor-target SOA was 200 ms.

Method

Participants

Another group of 40 participants recruited from the same pool as described in Experiment 1 participated in this experiment.

Stimuli and procedure

All the stimulus materials were the same as those used in Experiment 6, with the following exceptions. All factors, including distractor type, location, size, and (100ms, 150ms, and 250 ms) were within-subject factors. Under each SOA condition, there were 32 trials for each of the four distractor types (onset vs. color) crossed with display size (size 4 vs. size 8) conditions. In the size-4 condition, there were 8 same-location trials and 24 different-location trials. In the size-8 condition, there were 4 same-location trials and 28 different-location trials. In total, there were 384 trials (32 trials x 4 conditions x 3 SOAs). Trials of different SOAs were mixed and presented in a random order within separate blocks of display size.

Twenty-four trials preceded the formal experiment. There were 12 trials of display size 8 and another 12 trials of display size 4.

Results

ANOVA on response time showed that both the main effects of location and size were significant, (F(1,23) = 26.193, MSE = 591259.526, p<.0001, and F(1,23) = 27.426, MSE = 523810.274, p<.0001, respectively), but not the main effect of type (F(1,23)=0.001, MSE=2.294, p>1). The two-way interaction effects of location x type and location x size were significant (F(1,23)=35.383, MSE = 287225.412, p<.0001, and F(1,23)=7.945, MSE = 113696.663, p<.01, respectively), but not that of type x size and the three-way interaction location, size, and type (F(1,23)=0.212, MSE=1577.750, p>.6 & F(1,23) =0.443, MSE=2803.881, p>.5).

Further analysis of the location x type interaction showed that the response time was shorter at the same location than at a different location for onset distractor (F(1,23)=55.479, MSE=851340.468. p<.0001), but not for color distractor (F(1,23)=1.769, MSE = 27144.470, p>.1); the response time was shorter for onset distractor than for color one at the same and different locations (F(1,23) = 23.127, MSE = 142802.207, p <.0001, and F(1,23) = 23.389, MSE = 144425.498, p< .0001, respectively). For the location x size interaction, shorter response time was found at the same location than at a different location at size 4 and size 8 (F(1,23)=5.054, MSE=93201.726, p<.05, and F(1,23)=33.173, MSE=611754.463, p<.0001, respectively); And shorter response time was found at size 4 than at size 8 at the same location and at a different location (F(1,23) = 4.473, MSE = 74713.553, p <.05, and F(1,23) = 33.691, MSE = 562793.384, p <.0001).

ANOVA on error rate indicated that the main effects of location, type, and size were all significant (F(1,23)=14.060, MSE=0.067, p<.005, F(1,23) =17.624, MSE=0.156, p<.0005, and F(1,23)=66.718, MSE = 0.324, p<.0001), so were the two-way interaction of location x type and type x size, and the three-way interaction of location, type, and size (F(1,23) = 79.590, MSE=0.467, p<.0001, F(1,23) =6.833, MSE=0.044, p<.05, and F(1,23)=6.475, MSE=0.046, p<.05, respectively), but not the interaction of location x size (F(1,23)=2.606, MSE =0.017, p>.1)。

Further analysis of the location x type interaction showed that the error rate was lower at the same location than at a different location for onset distractor (F(1,23)=83.582, MSE=0.443, p<.0001), but the pattern was reversed for color distractor (F(1,23) =17.060, MSE=0.090, p<.0005); and the error rate was lower for onset distractor than for color distractor at the same location and at a different location (F(1,23)=79.061, MSE=0.581, p<.0001 & F(1,23) =5.687, MSE=0.042, p<.05). The interaction of type x size indicated that the error rate was lower at the same location than at a different location only for size 8 (F(1,23)=23.928, MSE=0.182, p<.0001), but not for size 4 (F(1,23)=2.267, MSE=0.017, p>.1); and the error rate was lower at size 4 than at size 8 for both the onset distractor and the color distractor (F(1,23)=11.553, MSE=0.065, p<.002 & F(1,23) = 53.858, MSE = 0.302, p < .0001). No response time-accuracy trade off seemed to exist here.

Discussion

As can be seen from Figure 8, the interaction effect of distractor type, display size, and SOA was quite intriguing. When the property of the distractor was the same as the target, that is, a red distractor that is contingent on the attentional control setting for the red target, the location effect (invalid RT – valid RT) increases with SOA for both size 4 (net effect of 31 ms, 63 ms, and 75 ms for the three levels of SOA) and size 8 (net effect of 52 ms, 45 ms, and 77 ms). As is well documented in the literature that the altering effect increases with cue-target SOA (Posner, 1980; Shulman, Remington, & McLean, 1979), the increasing location effect with SOA found here can be explained as the accumulation of the information from the top-down control and that sent from the stimulus. Such accumulation does not seem to change with display size.

A quite different pattern was found for the non-contingent property, however. For the location effect of the onset distractor on the color target, an opposite pattern was observed at size 4 as opposed to at size 8. The location effect decreases with SOA at size 4, being 37 ms, 22 ms, and 6 ms, for SOA of 50 ms, 150 ms, and 250 ms; while the location effect increases with SOA at size 8, being 12 ms, 33 ms, and 31 ms for the three levels of SOA, respectively. It is possible that as information accumulates over time, top-down control gradually takes over and can then override the stimulus-driven effect. This interaction of top-down and bottom-up processes may well be affected by the amount of information in the stimulus display. The larger the display size, the more information is present and so the strength of the bottom-up process may be increased, as compared to a smaller display size. However, as this accumulation of information from the stimulus display also takes time, only after certain amount of time (between 50 ms and 150 ms) can the stimulus-driven process exerts its effect.

GENERAL DISCUSSION

Whether attention can be captured involuntarily by salient stimuli or capture occurs only under contingent attentional control set has been debated over the past 15 years. One of the difficulties in differentiating these two views lies in the definition and the scope of attentional setting. One's attention can be set narrowly such as searching for a red target among white ones for its identification, or set widely such as looking for any unspecified singletons or transient changes. Gibson & Kelsey (1998) showed that both onset and red distractors could capture attention when the target display contained multiple onset items all painted in red (i.e., the target was not uniquely defined), while only onset distractor captured attention when the target display contained onset items all painted in white. They postulated that all properties involved in the target display, not only those task relevant ones, would be set into search goals and they called such as "attentional set for displaywide visual features". This displaywide setting, however, applies to color but not necessarily to onset since onset property was not manipulated in their study, and yet onset has been considered as the most unique property in stimulus-driven attentional capture (Yantis & Jonides, 1984; Jonides & Yantis, 1988; Yantis & Hillstorm, 1994).

When we took the approach of the intentionally unexamined aspects left by Gibson and Kelsey (1998) and contrasted the displaywide contingency hypothesis with the onset uniqueness hypothesis, the results do not seem to support completely for either hypothesis. Most importantly, interesting interaction effect of distractor-target location, display size, and distractor-target SOA calls for modifications of both hypotheses. These results also demand an integrated view concerning the conditions under which a purely stimulus-driven attentional capture occurs, as well as the extent to which attentional control setting constrains the stimulus-driven capture effect.

Defining the conditions of stimulus-driven attentional capture

Table 1 summaries the location effect obtained in this study. As is clear from this table, a purely stimulus-driven attentional capture can be inferred from the conditions of large display size. For example, both onset and color showed the location effect at display size 8 regardless of the manipulations across different experimental conditions. What are particularly informative are the conditions when the properties of the distractor were not the same as the one defined the target as a whole (i.e., a displaywide visual features), or defined the target uniquely (i.e., a target-specific defining features). As the purpose of this study was to test the capture effect of onset by manipulating properties associated with the target in the color dimension, any location effects triggered by onset distractors would tend to violate the displaywide contingency hypothesis. For all eight experiments conducted in this study, except for the 100 ms SOA condition in Experiment 8, onset distractors indeed indicated such a violation. For the only condition under which the target is not associated with color (Experiment 3, all white letters in the target display), even color distractors showed the location effect in the size-8 condition as well.

The stimulus-driven attentional capture did not seem to exert its effect within a very short time interval, as reflected by the absence of the onset-capture effect under the 100 ms SOA condition in Experiment 8. The accumulation of information from external stimulus may demand more time at large display sizes than at small ones, and there may be a threshold level above which the location of the distractor can be signaled. If the target display comes about before the accumulation of the information from the distractor reaches its threshold level, the accumulated and yet below threshold information about the distractor location may be disrupted by the incoming target display. As we obtained the location effect of the onset distractors at 150 ms, 250 ms (Experiment 8), and 200 ms SOA (Experiments 1 to 7), it seems that the time for information accumulation under the size-8 conditions is around 100 to 150 ms. This estimation of the time window for stimulus-driven capture to occur, of course, should also be varied with the stimulus configurations in the distractor display and the target display.

Once the location of the distractor is signaled, it should be withheld for a while, until the target display comes and interacts with the target display. At least for size-8 conditions, the stimulus-driven effect stays within the interval of 150 ms to 250 ms (Figure 8, bottom panel). Whether after a longer interval or for a simpler target display within the same interval will the stimulus-driven effect be taken over by attentional control setting is not known here and cannot be answered by this study. The focus here, nevertheless, is on the existence and range of occurrence for the involuntary attentional shift in a purely stimulus-driven fashion under the large size conditions.

In the small size conditions, however, the attentional control settings seemed to exert its effect earlier than in the large size conditions. Therefore, unlike the size-8 conditions, the non-contingent onset distractors were not able to capture attention under all the size-4 conditions. Interestingly, the absence of onset-capture effect occurred when the letters in the target display were each presented abruptly, and the target was defined by a particular color value. Under these conditions, around 200-250 ms interval (Experiment 6, 7, and 8), the appearance of the target display overrides the stimulus-driven effects so that no onset capture was possible.

Capture effect contingent on attentional control

When the distractors shared the same property with the target (i.e., color distractor and color target), capture effects shown by these color distractors are contingent on attentional control settings (Experiment 4, 5, 6, 7, 8). Therefore, one should not be surprised to find a much larger location effect under these conditions, compared with that in the onset distractor conditions. When the behavior goal is to search for a red target, more weight may be placed on the dimension of red by attentional control, thus increasing its salience value compared to other dimensions. Accordingly, compared to other non-contingent dimensions, this should lead to stronger information signals and so to approach the threshold level at earlier times.

As to the time course of these contingent signals, the capture effect occurred as early as 100 ms SOA (Figure 8) and stayed until 250 ms. Folk et al. (1992) manipulated the SOA and found the capture effect of green distractors on red targets from 50 ms to 200 ms, but no capture occurred when they were presented simultaneously. From these, it is estimated that the contingent distractor can reach the threshold for signaling its location by about 50 ms, and withhold its effect until 250 ms.

Attentional set for displaywide visual features

Our results from Experiments 1 to 4 helped in clarifying the notion of attentional set for displaywide visual features proposed by Gibson and Kelsey (1998). In their original term, "features that signal the appearance of the task-relevant target display as a whole" are displaywide visual features and "that attentional capture is contingent on these displaywide visual features, at least within the color dimension." (pp. 705). Two elaborations can be made from our results.

First, displaywide visual features are not necessarily included into the attentional control settings, unless there exist changes in these visual features over time. Take our Experiments 1, 2, and 4 for example. Although the letters in the target displays in Experiments 1 and 2 were all in red, the distractor that matched this displaywide feature, i.e., the red distractor, was not able to capture attention. Only when the display sequence consisted of changes in color did the color distractor showed capture effect, as demonstrated in our Experiment 4. Therefore, the features presented in the target display as a whole are not sufficient to have attention set for these displaywide features, they also need to have enough signaling values for the observer's internal control to be turned into. Constant existence of any features would lose their signaling value and thus would not be included into attentional control settings. In this sense, the notion of attentioal set for displaywide visual features needs to be clarified so that not only the features in the target display *per se,* but also the dynamic properties of these features that define the displaywide visual features that would be set into the search goals.

Second, the attentional set for displaywide features may apply to the color dimension, but not to abrupt onset. In our Experiments 1 to 5, the non-onset technique of Yantis and Jonides (1984) was adopted by presenting the camouflaging figure 8 patterns before the presentation of the target display. In these non-onset target displays, there should be no displaywide onset property associated with the target. However, the onset distractors could still capture attention even at size 4, except for Experiment 4. It may be argued that since only in Experiment 4 is the attentional set for displaywide color effective, so as to make the onset-capture disappear at size 4. When attentional control settings were not on any particular features, be they the target-specific or the displaywide features in Experiments 1 to 3, the attentioal control may then be set for any salient features, and abrupt onset is very likely to be the most salient features amongst all, given its significant role ecologically. This does not apply to the results of Experiment 5, however. When the target was uniquely defined by red, onset still captured attention at size 4.

The critical factor, therefore, may lie in the non-onset technique adopted here. This is evident when comparing the first 5 experiments with the last 3. The former group of experiments all used the non-onset technique, while the latter group did not, and the onset-capture effect is more consistently found in the former group. It seems odd that stimulus-driven onset capture occurs only under conditions of non-onset target presentation, but not under conditions of onset target display. At a first glance, this certainly seems inconsistent with the notion of contingent capture hypothesis of the displaywide-feature kind.

Alternatively, it may be that the structure of the attentional control setting is between the broader distinction of dynamic discontinuity and static discontinuity (Folk et al., 1992, 1994), and onsets and offsets may both be included into the set for transient luminance change (Atchley et al., 2000; Folk et al., 1994). If this is true, then the onset-capture found in the first 5 experiments can all be said to be consistent with the contingent capture hypothesis. The offset property in the target display made the attentional control set for transient luminance changes, and so the onset distractor could capture attention because it matched the property of the attentional setting: displaywide transient luminance change.

Although this account may sound reasonable, it still cannot explain the results that no onset-capture effect was found in Experiments 6 and 7 under the size-4 conditions. All the letters in the target display were presented abruptly, and so the displaywide visual features should also include the property of onset or transient luminance change. Therefore, according to the displaywide contingency hypothesis, onset should be able to capture attention. The fact that it cannot thus argues against the displaywide contingency hypothesis.

In fact, Gibson and Kelsey (1998) have noted such inconsistency when they discussed the absence of onset-capture effect under the condition when the target was uniquely defined by color in Folk et al. (1992). They proposed that attentional set for displaywide features might be weakened when the feature that uniquely defined the target as in Folk et al. was available. This conjecture, however, cannot explain our results of Experiment 5, either. The target was also associated with the defining feature red, and yet onset could still capture attention. Even such onset-capture effect can be explained by the attentional setting for luminance change, it is still a displaywide change. Why in this case the displaywide property is not diminished even when the target comes with a defining feature calls for reconsideration of the original explanation. In any case, the complex interaction of the goal-directed control settings and the stimulus-driven processes, as well as the structure of the attentional settings, certainly demands further investigations along this line.

Conclusions

Three main conclusions can be made in this study. First, purely stimulus-driven attentional capture that is independent of the defining features of the target and independent of the target display as a whole is possible, given the two criteria set by Folk et al. (1992) and Gibson & Kelsey (1998). Second, the larger the display size, the higher the chance for stimulus-driven attentional capture. Third, attentional set for displaywide visual features occurs only under conditions of sequential changes between displays in the feature dimensions. The results from this study clarified the notion of attentional set for displaywide features and helped in solving the discrepancy between stimulus-driven and contingent attentional capture.

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Table 1
A summary table of the location effect in each experiment

	Display size 4		***Display size 8***	
Experiment	***onset***	***color***	***onset***	***color***
1	✓		✓	✓
2	✓		✓	✓
3	✓		✓	✓
4		✓	✓	✓
5	✓	✓	✓	✓
6		✓	✓	✓
7		✓	✓	✓
8 100ms**SOA**	✓	✓		✓
8 150ms**SOA**	✓	✓	✓	✓
8 250ms**SOA**		✓	✓	✓

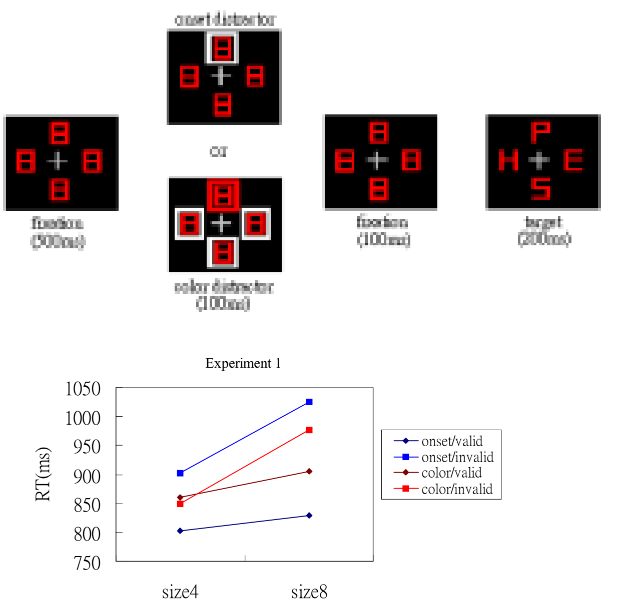

Figure 1. The stimulus display (top) and the results (bottom) of Experiment 1.

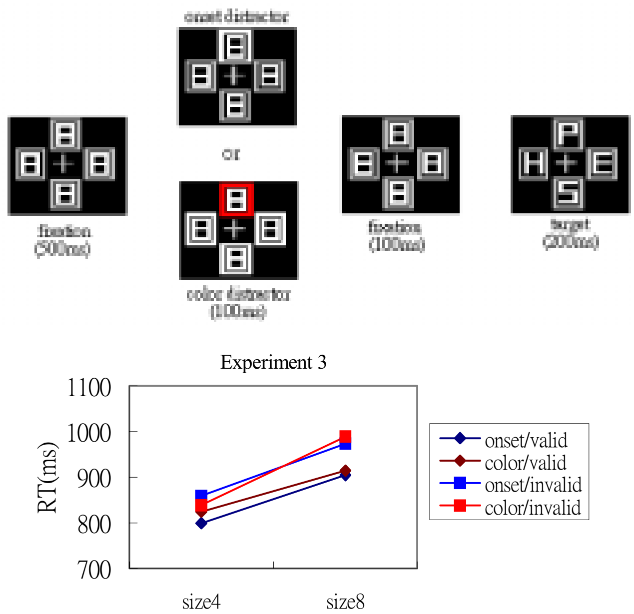

Figure 3. The stimulus display and the results of Experiment 3.

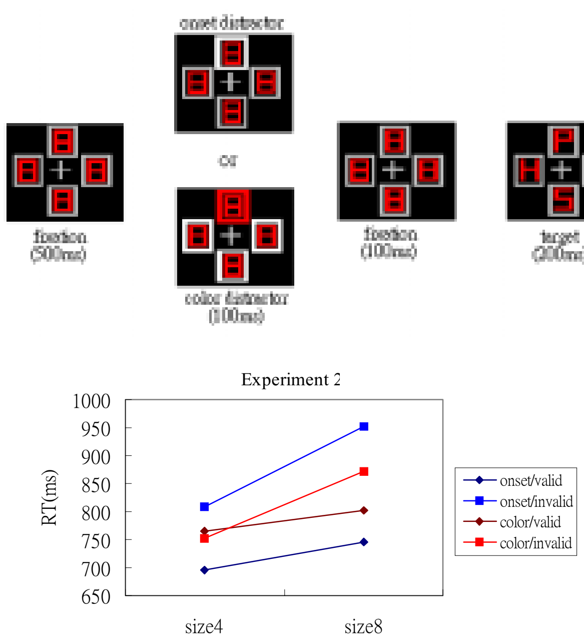

Figure 2. The stimulus display and the results of Experiment 2.

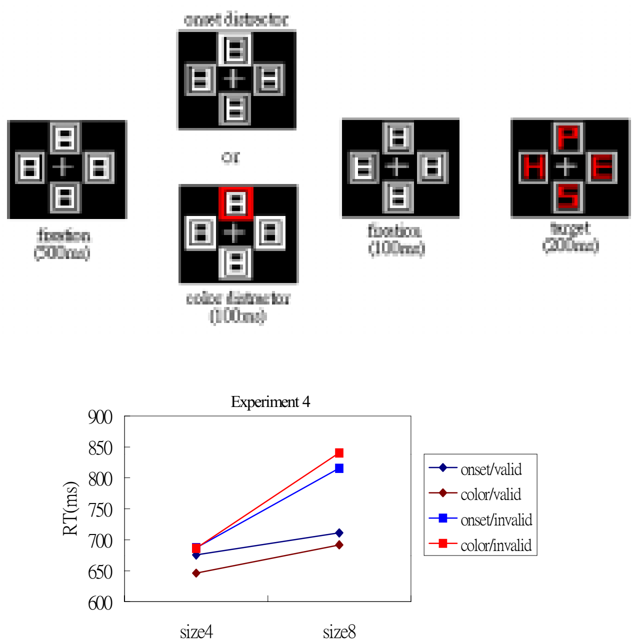

Figure 4. The stimulus display and the results of Experiment 4.

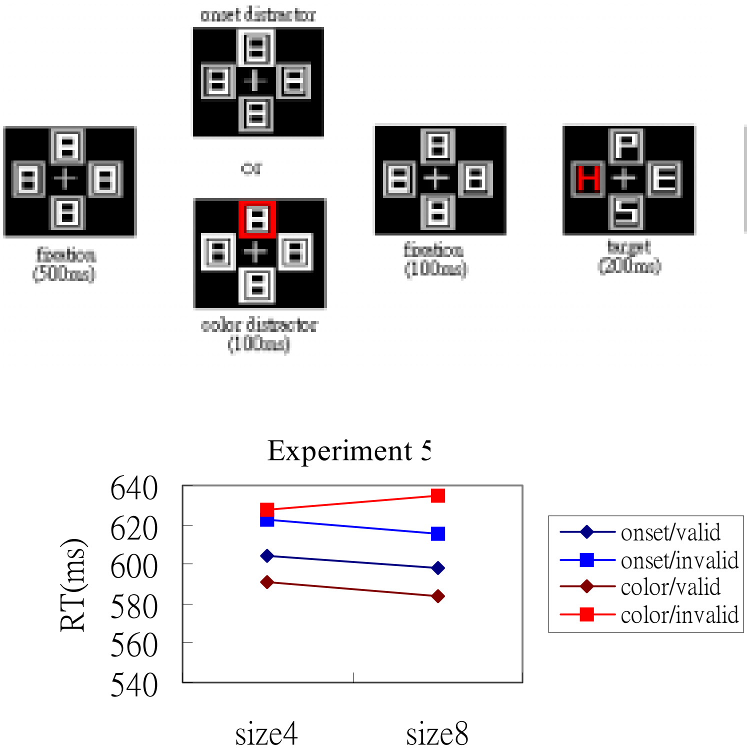

Figure 5. The stimulus display and the results of Experiment 5.

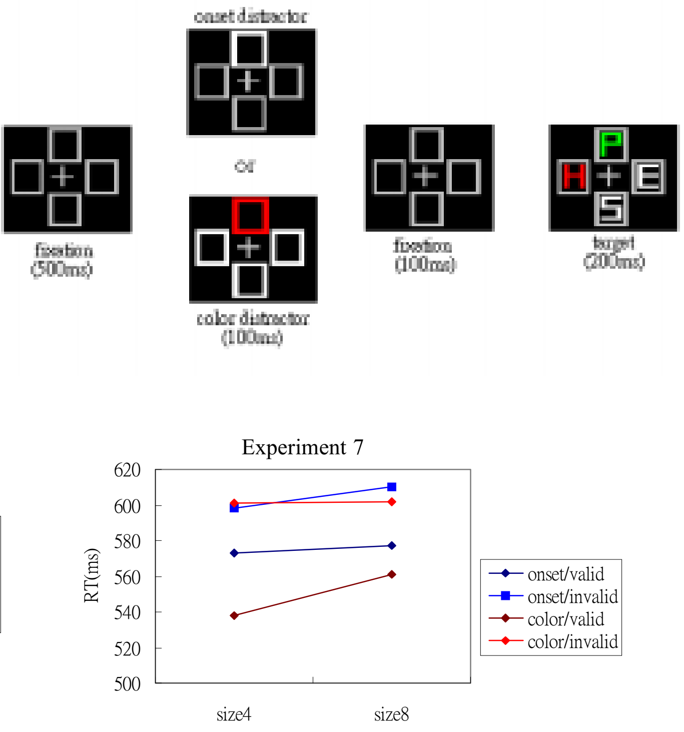

Figure 7. The stimulus display and the results of Experiment 7.

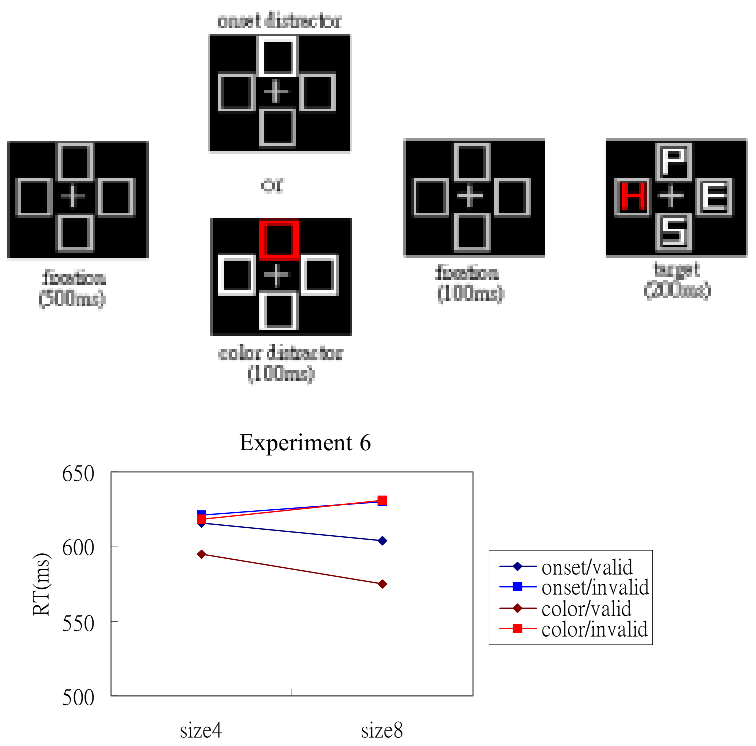

Figure 6. The stimulus display and the results of Experiment 6.

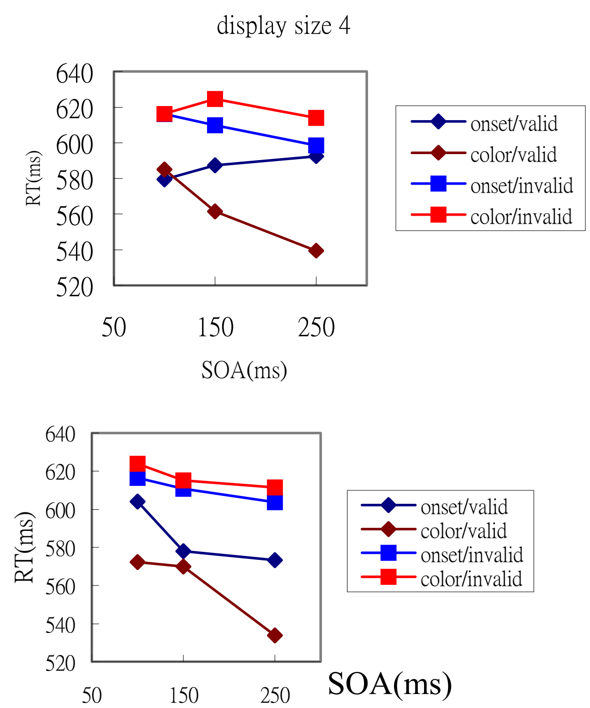

Figure 8. The results of display size 4 and display size 8 in Experiment 8.