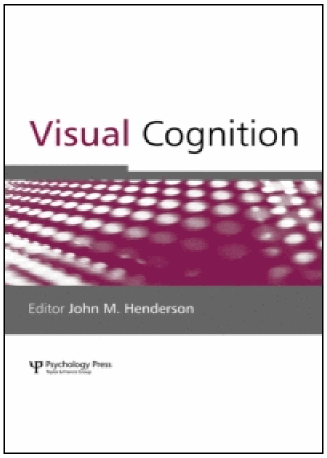

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The role of cueing in attentional capture

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The role of cueing in attentional capture

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In the present study, participants searched for an odd-man-out target within the shape dimension (either a diamond or a circle) while a colour distractor singleton could be present. In some conditions, the identity of the target singleton for the upcoming trial was cued in advance by either a word cue (e.g., a word saying "diamond") or a symbolic cue (e.g., a cue showing the shape of a diamond). The results indicate that cueing the upcoming target singleton reduced but did not eliminate attentional capture by the irrelevant colour distractor. Furthermore, cueing benefits were especially large when a colour distractor was present, suggesting that top-down processing plays a large role after attention has been captured to the location of the irrelevant colour distractor. Finally, when no distractor is present, top-down processing plays no role; in those circumstances, only priming can facilitate singleton search.

Since the early 1990s, a lot of research has been devoted to the question of whether we are able to exert control over what we select from the visual environment. Overt or covert selection may either be controlled by the properties of the stimulus field or by the intentions, goals, and beliefs of the observer (see reviews, e.g., Burnham, 2007; Rauschenberger, 2003; Ruz & Lupiañez, 2002; Theeuwes & Godijn, 2002). When we select only those objects and events needed for our current tasks, selection is said to occur in a voluntary, goal-directed manner. When, irrespective of our goals and beliefs, specific properties present in the visual field determine what we select, this selection is said to occur in an involuntary, stimulus-driven manner. When objects or events receive priority independent of the observer's goals and beliefs, one refers to *attentional capture* when such an event or object only captures attention (e.g., Theeuwes & Godijn, 2002), and one refers to *oculomotor capture* when such an event triggers an exogenous saccade to the location of the object or event (Theeuwes, Kramer, Hahn, & Irwin, 1998).

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To study the properties of attentional capture, stimuli are typically used that are highly salient and "pop out" from the display (such as a red element surrounded by green elements). The question is whether these so-called *feature singletons* capture attention even when you are not looking for them. In the early 1990s, Theeuwes (1991, 1992, 1994) developed a paradigm, referred to as the "irrelevant singleton" paradigm, that addressed this question. In this task, there was always one highly salient singleton (the so-called distractor) that was completely irrelevant for task performance. The logic underlying the additional singleton task is simple: Participants perform a visual search task, and one item in the search display is a unique salient feature singleton that is completely irrelevant to the search task. This condition is compared to a condition in which such an irrelevant featural singleton is not present. For example, in one experiment, participants were presented with circular displays consisting either of six circles and a single diamond or six diamonds and a single circle (Theeuwes, 1991). The task was to discriminate the orientation of a line segment contained within the uniquely shaped stimulus. In addition to the shape singleton, an irrelevant colour singleton was presented on half of the trials. For example, one of the nontarget items was red while the others were green. Critically, the presence of the irrelevant colour singleton increased the time required to respond to the relevant shape singleton. This reaction time (RT) cost led Theeuwes (1991, 1992) to argue that the colour singleton captured attention automatically because of its high level of saliency. Attention was first oriented to the task-relevant shape singleton only after an initial shift of attention to the colour distractor was completed and this more salient stimulus was determined irrelevant. On the basis of these findings, Theeuwes (1991, 1992, 1994, 2004; Hickey, MacDonald, & Theeuwes, 2006; Theeuwes, Kramer, & Kingstone, 2004) argued that attentional capture is basically bottom-up and not subject to top-down control. According to this view, processing in early vision is driven exclusively by bottom-up factors such as salience, and only later in processing may top-down factors play a role (see also Itti & Koch, 2000; Kim & Cave, 1999; Theeuwes, Atchley, & Kramer, 2000; Theeuwes & Chen, 2005).

The notion that attentional capture is bottom-up and automatic has been challenged in various ways. According to the contingent capture account as proposed by Folk and colleagues (e.g., Folk, Remington, & Johnston, 1992), attentional capture by singletons is completely under top-down control. The ability of a stimulus to capture attention is contingent on whether an attentional-capturing stimulus is consistent with the top-down settings, which are established "off-line" on the basis of current attentional goals. According to the contingent capture model, only stimuli that match the top-down control settings will capture attention; stimuli that do not match the top-down settings will be ignored. Folk et al. used a spatial cueing paradigm in which participants have to ignore a "cue" that appeared 150 ms prior to the presentation of the target display (see, e.g., Folk et al., 1992). Only when the search display was preceded by a to-be-ignored featural singleton (the "cue") that matched the singleton for which observers were searching did the cue captured attention. Thus, when searching for a red target singleton, an irrelevant red cue that preceded the search display captured attention while an irrelevant onset had no effect on performance.

On the basis of a series of experiments, Bacon and Egeth (1994) came to another conclusion. They suggested that participants can enter into either a *feature* detection or a *singleton* detection mode. When participants engage in a singleton detection mode, they choose to direct attention to the location having the largest feature contrast. When engaged in this mode, the most salient singleton will capture attention regardless of whether it is the target or not. However, when participants engage in a feature detection mode, they choose to direct their attention to a particular feature (e.g., a green circle), and when choosing this mode, there will be no attentional capture. Bacon and Egeth argued that "goal directed selection of a specific known featural singleton identity may override stimulus-driven capture by salient singletons" (p. 493). These results suggest that when observers "choose" a feature search mode, attentional capture by irrelevant singletons is eliminated. The notion that choosing a search strategy allows attentional control suggests that attentional capture is under top-down control.

The present study examined the role of top-down control on attentional capture. More specifically, it looked at the effect of cueing on attentional capture. In general terms, it is related to the concept of feature and singleton detection modes. Participants had to search for an odd-one-out singleton within the shape dimension (they searched for a circle between diamonds, or for a diamond between circles). On each trial, before the presentation of the search array, a word cue was presented in the centre of the display indicating the identity of the target singleton for the upcoming trial. Cueing should induce a feature search mode because it provides information about the upcoming feature defining the target. We compared this condition to a condition in which participants did not know which of the two targets would be presented. In this condition, participants had to choose a singleton detection mode, since they only knew it was a shape singleton but not which exact feature singleton it was.

Even though the notion of feature versus singleton detection mode is the generally accepted way to account for top-down control in feature search (see recent reviews, Burnham, 2007; Rauschenberger, 2003; Ruz & Lupiañez, 2002), it should be realized that recently Theeuwes (2004) criticized the concept of feature versus singleton detection mode. Theeuwes showed that singleton detection may be nothing other than a condition that allows parallel search, and that a feature search may represent a condition that requires serial or partly serial search.

Regardless of these concepts of feature and singleton search, the present study makes it possible to examine whether preknowledge regarding the target singleton induces enough top-down control to eliminate attentional capture by the distractor. Knowing the identify of the target may allow so much top-down control that the irrelevant colour singleton no longer interferes.

EXPERIMENT 1

The task employed in Experiment 1 was basically the "irrelevant singleton" paradigm of Theeuwes (1991, 1992, 1994). Participants had to search for an odd-one-out singleton within the shape dimension (they searched for a circle between diamonds or for a diamond between circles). On each trial, participants were cued as to whether the target was a diamond or a circle (the word "diamond" or "circle" were presented as a cue). The cue was 100% valid. We compared this condition to a condition in which no cue was provided. The question was whether this type of cueing would eliminate the distractor effect.

Method

Eleven students (seven male; mean age = 20.8; range from 17 to 35 years) participated in the experiment as paid volunteers. Each participant received €7 an hour. All participants were naïve as to the purpose of the experiment. One participant was excluded from further analysis (overall mean response time [RT] > 950 ms).

Apparatus. A Dell computer with a 17-inch SVGA colour monitor using E-prime controlled the timing of the events, generated stimuli, and recorded responses.

Stimuli. Figure 1 shows an example of an experimental trial. A trial started with a presentation of a light-grey fixation cross (0.35° height and 0.35° width; luminance 29.3 cd/m^2) in the middle of the screen for a fixed period of 900 ms. The luminance of the dark-grey background was kept constant at 0.56 cd/m^2 during the experiment. A cue was immediately presented after the presentation of the fixation-cross for a period of 500 ms at the centre of the screen. In the cue condition, the cue consisted of the word "circle" (in Dutch "cirkel") or the word "diamond" (in Dutch "ruit") to indicate with 100% validity the target singleton of the upcoming trial.

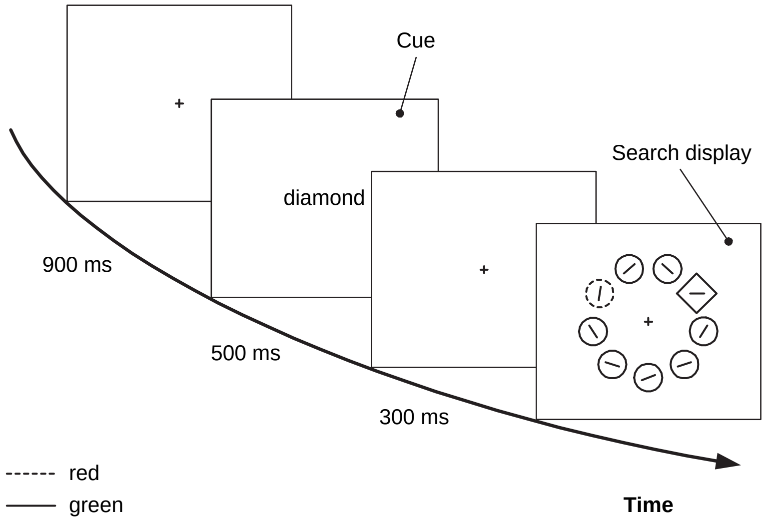

Figure 1. Example of a trial. The cue was 100% valid and indicated the target singleton for the upcoming trial. Participants made a speeded response to the line segment in the target singleton, which was oriented either horizontally or vertically.

In the no cue condition, the word "neutral" (in Dutch "neutraal") was presented, indicating that the target singleton could either be a circle or a diamond. Following the cue, a display with the central fixation cross was presented for 300 ms and was followed by the search display, which stayed on until the response with a maximum of 2000 ms. The words were presented in 18 point Courier New font and had a luminance of 29.3 cd/m^2.

The search display consisted of nine equally spaced items around the fixation cross on an imaginary circle with a radius of 5.3°. When the target was a diamond, the nontarget elements were circles. When the target was a circle, the nontarget elements were diamonds. The elements were outline circles (a radius of 1.1°) or diamonds (each side was 2.0°), having a luminance of 11.65 cd/m^2.

Inside each display element, a grey line segment was placed (luminance 29.3 cd/m^2). In the distractor elements, the line segment was tilted 22.5° to either side of the horizontal or vertical plane (see Theeuwes, 1991, 1992). In the singleton, the target line segment (1.1°) was oriented either vertically or horizontally. Note that a vertical or horizontal line segment does not pop out among slightly tilted line segments (see Theeuwes, 1991), which makes it unlikely that participants searched directly for the target line segment instead of for the singleton that contained the target line segment. All line segments were equiluminant at 29.3 cd/m^2.

Procedure. Participants responded to the orientation of target line segment (either horizontal or vertical), which was always located in the shape singleton (either the unique diamond or the unique circle). Participants were required to direct their attention to the singleton and make a speeded response to the orientation of line segment inside the target singleton. They were instructed to keep their eyes fixated at the fixation point. Participants pressed the "z" key or "m" key when the target bar's orientation was horizontal or vertical, respectively. When participants committed an error, a tone sounded.

Experimental design. The independent variables were distractor presence (present or absent) and cue (informative or noninformative). The nine target positions were randomized with the constraint that the distance between the target and distractor was balanced. On each trial, there was an equal probability of a circle singleton or a diamond singleton. The orientation of the line segment inside the target singleton, horizontal or vertical, was balanced and randomized. In half of the trials (144 trials), the cue was noninformative (neutral cue condition); in the other 144 trials, the cue provided information about the target singleton. These conditions were randomized within blocks. The presence or absence of the colour distractor singleton was varied between blocks of trials. Half of the participants started with a distractor block, the other half with a no-distractor block. Before each block, participants received 48 practice trials.

Results

Trials in which participants responded slower than 1400 ms were excluded from further analysis. This led to a loss of 1.8% of the trials. Figure 2 presents mean correct RT as a function of distractor presence and cue. We conducted an analysis of variance (ANOVA) on the correct mean RT and mean percentage errors with distractor presence and cue as within-subjects variables.

RT data. The main effect of distractor presence was significant, $F(1, 9) = 14.4$, $MSE = 1678.8$, $p < .005$, indicating that participants were faster when the distractor was absent (704 ms) than when the distractor was present (753 ms). The main effect of cue failed to reach significance, $F(1, 9) = 2.8$, $MSE = 2784.2$, $p = .131$. Furthermore, there was an (almost) significant two-way interaction between distractor presence and cue, $F(1, 9) = 5.0$, $MSE = 377.4$, $p = .053$. This two-way interaction between distractor presence and cue was further examined by a two-tailed paired-samples t-test for each distractor condition. The t-test revealed a significant

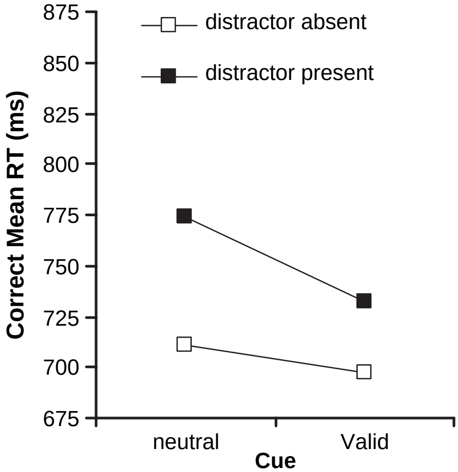

Figure 2. Results of Experiment 1. Correct mean reaction time (RT) as a function of distractor presence and cue.

effect of cue when the distractor was present, $t(9) = 2.6$, $p < .05$, as responses were faster when the cue was valid (733 ms) than when the cue was neutral (774 ms). In contrast, the effect of cue was far from significant when the distractor was absent, $t(9) = 0.7$, $p = .485$. In addition, there was a significant effect of distractor when the cue did not provide any information about the upcoming target singleton, $t(9) = 3.9$, $p < .005$, but also when the cue provided 100% valid information about the identity of the target singleton, $t(9) = 2.8$, $p < .05$.

Error data. Overall mean error rate was at 5.5%. The ANOVA revealed no significant effects.

Discussion

The present findings show that even in the condition in which participants had full knowledge about the identity of the upcoming target singleton, the distractor still captured attention. The conditions in which participants have full knowledge about the target singleton do seem to reduce the distractor effect but do not eliminate it. In fact, the size of the distractor effect (about 35 ms) is similar to the effect reported by Theeuwes (1992), in which participants searched during the whole experiment for the same singleton (i.e., a red circle). These findings suggest that full knowledge about the target singleton does not induce a search mode that allows full top-down control over attentional capture.

The present findings indicate that in the condition in which the distractor was present, the cue was effective. Indeed, when a distractor was present, participants were faster in finding the target singleton than when no information was provided about the upcoming target singleton. Note however, that the cue was not effective in the no-distractor condition. When only a target singleton was present and not the distractor singleton, advance knowledge about the identity regarding the target singleton could not facilitate visual search.

This latter finding that top-down knowledge cannot affect visual search for a target singleton is consistent with recent findings of Theeuwes, Reimann, and Mortier (2006; see also Theeuwes & van der Burg, 2007). In a paradigm investigating the role of cueing in singleton search, the dimension of the upcoming singleton was cued with 80% validity. Theeuwes et al. (2006) showed that advance knowledge about the dimension of the upcoming target singleton did not affect search time. In other words, the validity of a cue indicating the dimension of the upcoming singleton (e.g., the word "colour" when a colour singleton would be presented) had no effect on search times. Note that, in these previous experiments, we did not include a condition in which a singleton distractor was present. The no-distractor condition of the current experiment is similar to the conditions tested in these previous experiments. The findings from our no-distractor condition corroborates and extends these previous findings demonstrating that in singleton search top-down knowledge cannot affect visual search. The findings are inconsistent with theories such as the dimensional weighting account (e.g., Müller, Reimann, & Krummenacher, 2003) or guided search (e.g., Wolfe, Butcher, Lee, & Hyle, 2003), which assume that participants can actively set themselves for the upcoming target by allocating differential weights to the likely target dimension or feature.

EXPERIMENT 2

As noted, previous results showed no effect of the validity of a word cue on search time (Theeuwes et al., 2006) or on *d*-prime (Theeuwes & van der Burg, 2007), indicating that preknowledge regarding the upcoming target singleton cannot be used to speed up responding. The no-distractor condition of Experiment 1 confirms this finding. Note, however, that in these previous studies, Theeuwes and colleagues did show that it is possible to generate cueing effects in singleton search. Instead of using a word cue, in some experiments, the actual singleton that participants had to search for was presented as a cue in the centre of the screen. The cue consisted either of a red circle or a green diamond and was identical to the target singleton participants had to search for. Using this set-up, the results showed small but reliable cueing benefits both in terms of RT (Theeuwes et al., 2006) and *d*-prime (Theeuwes & van der Burg, 2007).

In Experiment 2, we used the same cueing procedure as in Theeuwes et al. (2006). Instead of using a word cue (i.e., the word "diamond" or "circle"), we used a symbolic cue that was identical to the target singleton of the search display. The question is whether this type of cueing, which has proven to be effective in singleton search, would eliminate the distractor effect.

Method

Participants. Eleven students (seven male; mean age = 18.6; range from 17 to 21 years) participated in the experiment as paid volunteers. Each participant received €7 an hour. All participants were naïve as to the purpose of the experiment. One participant was excluded from further analysis (overall mean RT > 950 ms).

Design, stimuli, and procedure. The experiment was exactly the same as Experiment 1 except that instead of using a verbal cue, a symbolic (direct) cue was used. The symbolic cue was presented in the centre of the display and was identical to the singleton in the search display. In other words, the cue was either a diamond or a circle and had exactly the same measurements as the target singleton in the search display. As in Experiment 1 an "X" was presented in the neutral cue condition.

Results

Trials in which participants respond slower than 1400 ms were excluded from further analysis. This led to a loss of 1.5% of the trials. Figure 3 presents mean correct RT as a function of distractor presence and cue.

RT data. The main effect of distractor presence was significant, $F(1, 9) = 5.6$, $MSE = 7267.7$, $p < .05$, indicating that participants were faster when the distractor was absent (720 ms) than when the distractor was present (784 ms). Also, the main effect of cue was significant, $F(1, 9) = 9.5$, $MSE = 2740.0$, $p < .05$, indicating that participants were faster when the cue was valid (726 ms) than when the cue was neutral (777 ms). Furthermore, there was a significant two-way interaction between distractor presence and cue, $F(1, 9) = 13.6$, $MSE = 269.0$, $p = .005$. This two-way interaction between distractor presence and cue was further examined by a paired-samples *t*-test for each condition. The analysis indicated that when a distractor was

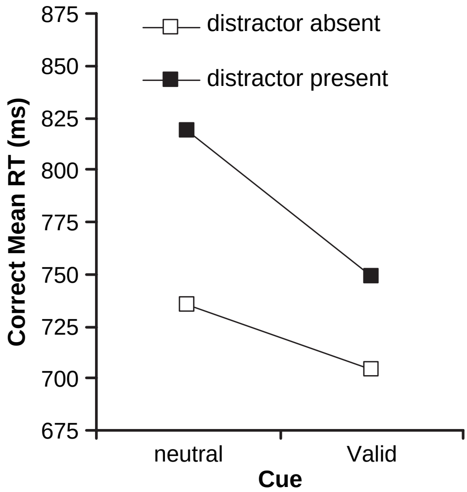

Figure 3. Results of Experiment 2. Correct mean reaction time (RT), as a function of distractor presence and cue.

present, the cue significantly speeded up search relative to the no-cue condition (748 ms vs. 818 ms), $t(9) = 3.4$, $p < .01$. More importantly, when the distractor was absent, the cue also had a beneficial effect on RT: When a cue was present, RTs were faster (702 ms) than when no cue was present (733 ms), $t(9) = 2.3$, $p < .05$. When no cue was present, the distractor caused a large distractor effect, $t(9) = 3.4$, $p < .05$. However, when the cue was present, the distractor effect was smaller but still reliable, $t(9) = 1.9$, $p < .05$, one-sided.

Error data. Overall mean error rate was at 4.6%. The ANOVA revealed no significant effects.

Discussion

The present findings show that it is possible to affect singleton search. Search was speeded by presenting the actual target singleton as a symbolic cue. Contrary to Experiment 1, the symbolic cue also had an effect in the condition in which no distractor was present. This finding is consistent with Theeuwes et al. (2006) and Theeuwes and van der Burg (2007), who showed similar effects for cross-dimensional cueing (colour and shape cueing). In both Experiment 1 and 2, the cueing effects were much larger in case a distractor singleton was present.

GENERAL DISCUSSION

The present study shows that a verbal word cue (Experiment 1) and a symbolic cue (Experiment 2) cannot eliminate capture by an irrelevant colour singleton. In both experiments, cueing reduced the capture effect, but in neither experiment did the cue eliminate capture. In fact, in both experiments, the size of the distractor effect was about 40 ms, an effect size that is about the same as in previous experiments using the additional singleton task (Theeuwes, 1992, 1994). It is important to note that the cue was effective in reducing RT, indicating that participants actively used the cue. However, at the same time, this top-down "knowledge" could not eliminate the distracting effect of the irrelevant colour singleton.

The present data are related to the idea that that participants can choose to adopt what is called a *feature* or *singleton detection* search mode as suggested by Bacon and Egeth (1994). According to this view, when participants engage in a singleton detection mode, they choose to direct attention to the location having the largest feature contrast (highest salience). When engaged in this mode, the most salient singleton will capture attention regardless of whether it is the target or not. When participants engage in the feature search mode, they choose to direct their attention to a particular feature and, when choosing this mode, there should be no attentional capture by a salient singleton. This view is a part of the contingent capture hypothesis (Folk et al., 1992), which states that only salient features that are relevant to the attentional set of the observer (i.e., onset, colour) capture attention. In the present study, participants have to engage in a singleton detection mode in case the cue is uninformative. Indeed, participants only know that they are searching for an odd-one-out in the shape dimension (a diamond or a circle) but not which one. However, when an informative cue was provided, participants could have used the feature search mode because they knew exactly which singleton to expect (i.e., the cue was 100% valid). Moreover, participants did use this information, because cueing had an effect in both experiments. However, even though the cue was used, the capture effect of the colour distractor was still present. In fact, it was just as large as in typical additional singleton paradigm studies. The current findings add to a growing literature that suggests that the distinction between these search modes may not be as useful as previously assumed (see also Belopolsky, Zwaan, Theeuwes, & Kramer, in press; Theeuwes, 2004).

The current finding that in the no-distractor condition, word cueing had no effect, while symbolic cueing did significantly reduce search time, is consistent with earlier findings (Theeuwes et al., 2006; Theeuwes & van der Burg, 2007). In those previous studies, it shown that the validity of the symbolic cue had no effect on the effectiveness of the cue. Indeed, for example, in Theeuwes et al. (2006), the cueing effect of the symbolic cue remained basically the same regardless of whether the cue had a high (83%) or a low validity (17%). On the basis of these findings, Theeuwes and colleagues (Theeuwes et al., 2006; Theeuwes & van der Burg, 2007) concluded that in singleton search, the cueing effects with symbolic cues are not the result of some top-down processing but are the result of bottom-up priming (see also Kristjansson, Wang, & Nakayama, 2002; Maljkovic & Nakayama, 1994). Looking at the symbolic cue that has exactly the same measurements and colour as the target singleton (i.e., the square or the diamond) facilitates search for that target singleton. The fact that only symbolic cues are effective and that the effect occurs independently of the cue's validity (see Theeuwes et al., 2006) indicates that this effect is the result of passive bottom-up priming. These effects are basically the same as so-called intertrial effects in feature search. For example, Maljkovic and Nakayama (1994) showed that even when a target on a given trial was 100% predictable (e.g., target definition changed in AABBAABBAA ... -manner), knowledge-based expectations could not modulate feature-specific intertrial effects. Maljkovic and Nakayama conclude that their intertrial effects reflect passive priming that are not top-down penetrable. In line with this notion, we conclude that the cueing benefits with symbolic cues in the condition in which there is no distractor are the result of bottom-up priming.

Another aspect of the current data that is important is the finding that the effect of the cue is much larger when a distractor singleton was present. In fact, when a distractor was present, not only with a symbolic (Experiment 2) but also with a word cue (Experiment 1), search times were substantially reduced. In Experiment 1, a word cue reduced search time to 41 ms; in Experiment 2, a symbolic cue reduced search time to 70 ms. The fact that the word cue was also effective indicates that this effect cannot solely be attributed to bottom-up priming. When a word cue is presented, participants have to set themselves in a top-down way for either a diamond or a circle singleton. If we assume that the benefit of the cue in Experiment 1 is due to top-down processing, and in Experiment 2 due to a combination of top-down and bottom-up processing, then it is feasible that the 41 ms benefit in Experiment 1 represents benefits due to top-down processing, and the 70 ms benefit in Experiment 2 a combination of top-down processing (41 ms) and bottom-up priming (32 ms). Obviously this is appealing yet very speculative.

It is intriguing that when a distractor is present, top-down processing plays a role in finding the target singleton while there is no role for top-down processing in feature search when no distractor is present. There appears to be a fitting explanation for this finding. In line with Theeuwes' notions (1991, 1992, 2004), it is possible that early spatially parallel processing cannot be modulated by intentional, top-down processes. When no distractor singleton is present, the only salient element in the display is the target singleton. We claim that this target singleton pops-out from the background and deliberate top-down operations do not have any influence on these processes. However, when a distractor singleton is present, attention will be captured by the distractor singleton. Because attention is then focused on the location of the distractor singleton, it is quite feasible that the target needs to be found by effortful processing, implying that search will no longer be parallel and "preattentive" but serial and "attentive". When search become serial or partly serial, it is known that top-down processes play a large role. For example, Kaptein, Theeuwes, and van der Heijden (1995) showed that participants can restrict search for a colour-orientation conjunction target to a colour-defined subset in a top-down fashion. This notion also fits with the earlier ideas of Theeuwes (2004; Belopolsky et al., in press), attempting to explain the original Bacon and Egeth (1994) studies that postulated the existence of differential search modes referred to as "feature and singleton detection". In the original experiments of Bacon and Egeth, more shape singletons (a diamond, a square, and a triangle) were added to the display, ensuring that observers could not use a singleton detection mode anymore (i.e., participants had to look for a specific feature). However, by adding more and more different shape singletons, the display became less and less homogenous. The consequence is that it may become impossible to detect the target singleton by parallel, preattentive search. Because observers must engage in serial (or partly serial) search to find the target singleton, top-down processing may start playing a larger role. Indeed, even though in Bacon and Egeth, slopes were relatively flat (up to 11.5 ms/item), they always differed significantly from zero, suggesting that search may have been partly serial. If our conjecture is correct, this would imply that when preattentive parallel search is no longer possible (for example, because the display is too heterogenous as in Bacon & Egeth, 1994), or because attention is captured erroneously to the location of the distractor (as in the current experiments), search has to become serial or partly serial. In that case, knowing what you are looking for facilitates search.

This interpretation is also consistent with data from Theeuwes (2004). He took the original rather heterogenous displays of Bacon and Egeth (1994) and added more identical nontarget elements. The addition of these nontarget elements made the display more homogenous. The result was that search was performed in parallel and top-down control was lost. Indeed, a large interference effect of the colour distractor was found, while no distractor effect was found with heterogeneous displays when search was partly serial (12 ms/item).

A recent study by Belopolsky et al. (in press) addressed this issue from a somewhat different perspective. They showed that focusing attention to a location in space prevents attentional capture by salient singletons. On the other hand, spreading attention over the visual field caused attention to be captured on a subset of trials. They claimed that the size of the attentional window plays a role in the extent to which salient singletons can capture attention. If the attentional window is wide, preattentive processing is possible, allowing no top-down control within the attended window. However, when the window is focused on a location, it enables serial attentive processing, which is slow but does allow top-down processing.

Note that in a recent study, Leber and Egeth (2006) found an interference effect of the irrelevant singleton of only 6 ms, which turned out to be statistically not reliable ($p = .21$). At same time, the search slopes were basically flat, suggesting that it is possible to search in parallel across the visual field while involuntary capture by the salient singleton is overridden. Even though this study provides direct evidence against Theeuwes's (2004) notion that during parallel search there is no top-down control, the evidence that this study provides may not be that convincing. First, there was an interference effect of 6 ms, which was not reliable even though a clear trend was present (especially at display size 9). Also, this effect could only be obtained after an extensive training phase of 480 trials, in which participants were trained to use the feature search mode. Finally, the feature search group was much slower (at least nominally) than the singleton search mode. As suggested by Leber and Egeth, it is likely that by slowing down, participants were able to avoid capture, a result that fits with the view that bottom-up effects are especially present when participants respond as quickly as possible (see Theeuwes et al., 1998; van Zoest, Donk, & Theeuwes, 2004).

The current results show that in singleton search ("pop-out tasks") in which the only salient element in the display is the target singleton, advance knowledge about the identity of the target does not facilitate search. This suggests that preattentive parallel search cannot be influenced by top-down processing (see Theeuwes, 1991, 1992). However, in those circumstances priming – which is assumed to be bottom-up—(see Theeuwes et al., 2006), can facilitate target singleton detection. Furthermore, we show that even though cueing is effective, it cannot eliminate attentional capture by the irrelevant distractor. Even when participants know what they are looking for (a diamond or a circle), the presence of an irrelevant colour distractor causes interference, providing evidence against the notion of feature and detection search modes (e.g., Bacon & Egeth, 1994). Finally, when a salient distractor singleton is present, top-down processing allows a faster and more effective detection of the target singleton.

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