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No capture outside the attentional window

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ABSTRACT

A recent study has proposed that attentional window determines when the color singletons capture visual attention (Belopolsky, Zwaan, Theeuwes, & Kramer, 2007). The present study used the additional singleton paradigm of Theeuwes (1992) and showed that capture was abolished when the size of the attentional window was reduced by focusing on RSVP stream in the center of the screen. Narrowing of attentional window also resulted in increase in search slope even in such a simple task as the pop-out detection. These findings suggest that attentional window plays a crucial role in visual selection and in the occurrence of attentional capture.

1. Introduction

When driving along a city road, the sudden appearance of a child from behind a parked car may grab our attention. Did this event grab your attention because you were set for it (watching the road looking out for unexpected events) or was your attention captured in a bottom-up automatic fashion? This example illustrates one of the most debated issues in the study of visual attention: can visual stimuli capture attention automatically independent of the observer's goals, beliefs or intentions? (for recent reviews see Burnham, 2007; Theeuwes (in press); Theeuwes, Olivers, and Belopolsky (in press); Van der Stigchel, Belopolsky, Peters, Wijnen, Meeter, and Theeuwes (2009)). Goal-directed or top-down control of selection refers to the ability to select those areas, objects, feature attributes and events that are needed for our current tasks. Stimulus-driven or bottom-up selection refers to the capacity of certain stimulus attributes to attract our attention, irrespective of our goals and beliefs.

In the early nineties Theeuwes (Theeuwes, 1991, 1992, 1994b) developed the so-called additional singleton task which has been instrumental in the debate regarding top-down and bottom-up control of selection. In this visual search task two salient singletons were simultaneously present, and participants were required to search for the target singleton, while ignoring the distractor singleton. The target shape that participants searched for was a singleton because it was the only green diamond presented among a variable number of green circles. In the distractor condition, an irrelevant color singleton was also present in the display (i.e., one of the circles was red). Time to find the shape singleton increased when such irrelevant color singleton was present, even though participants knew they had to search for the shape singleton (the single green diamond). It was shown that selectivity depended on the relative salience of the stimulus attributes: when the color singleton was made less salient (by reducing the color difference between the target and the non-target elements), the color singleton no longer interfered with search for the shape singleton. It was concluded that attention was captured automatically and involuntarily by the most salient singleton in the display regardless of top-down control settings.

Even though the basic finding of Theeuwes has been replicated many times in different labs (Bacon & Egeth, 1994; Belopolsky, Kramer, & Godijn, 2008; Geyer, Müller, & Krummenacher, 2008; Kim & Cave, 1999; Kumada, 1999), with different dependent measures (d-prime): (Theeuwes & Chen, 2005; Theeuwes, Kramer, & Kingstone, 2004), saccadic eye movements: (Belopolsky, Kramer, & Theeuwes, 2008; Theeuwes, Kramer, Hahn, & Irwin, 1998; Theeuwes, Kramer, Hahn, Irwin, & Zelinsky, 1999), the results are not consistent with experimental paradigms that show that static singletons are not prioritized over non-singletons. Studies of Yantis and colleagues (Jonides & Yantis, 1988; Yantis & Egeth, 1999; Yantis & Jonides, 1984) have shown that unlike abrupt onsets, static singletons do not have the ability to capture attention in an automatic fashion.

In a recent study, Belopolsky et al. (2007) provided a solution for this apparent inconsistency in the literature. Based on the idea first proposed by Theeuwes (Theeuwes, 1994a, p. 436) that "top-down control over visual selection can be accomplished by endogenously varying the spatial *attentional window*" (see also Theeuwes, 2004), they suggested that such attentional window adopted by observers could be one of the factors explaining why salient color singletons fail to capture attention in some studies

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(as in Jonides & Yantis, 1988) while in other studies they do capture attention (as in Theeuwes, 1992). Belopolsky et al. (2007) adopted the original Jonides and Yantis (1988) paradigm, in which participants had to serially search for a target letter, which could have had a unique color at chance level. The size of the attentional window was manipulated by asking participants to detect either a global (diffuse attention) or a local shape (focused attention) before starting the search for a non-singleton target. The results showed that when attention was initially focused in the center (focused attention condition) the salient color singleton was examined just as frequently as the other elements in the display. This result was similar to the "classic" finding of Jonides and Yantis (1988); (see also Folk and Annett (1994); Franconeri and Simons (2003)). However, when attention was initially diffused over the global stimulus arrangement (diffuse attention condition), attention more frequently went to the location of the color singleton, which was evidenced by faster responses and a significantly reduced search slope when the colored element happened to be the target. It was concluded that the size of the attentional window plays a crucial role in attentional capture: when the window is wide salient stimuli capture attention, but when it is small salient stimuli falling outside of the window can be ignored (see also Hernández, Costa, and Humphreys (2010)).

Up till now it has been demonstrated that increasing the size of attentional window leads to attentional capture during difficult search. However, if the window plays a crucial role, the reverse should also be true and focusing attention during parallel search should preclude attentional capture. In addition, if focusing attention affects computation of salience outside of attentional window then it should also render visual search for a pop-out target less efficient. Although the necessity of attentional involvement in pop-out search remains highly controversial (Braun & Sagi, 1990; Luck & Ford, 1998; Müller, Reimann, & Krummenacher, 2003; Reddy, Moradi, & Koch, 2007; Treisman, 1988), several studies have suggested that attention is necessary for pop-out detection (Ghorashi, Smilek, & Di Lollo, 2007; Joseph, Chun, & Nakayama, 1997; Nothdurft, 1999; Theeuwes, 1992; Theeuwes, Kramer, & Atchley, 1999; Theeuwes, Van Der Burg, & Belopolsky, 2008). If attention is required for pop-out detection, one could expect that narrowing of attentional window should lead to a less efficient search even for a pop-out target.

These two questions were investigated in the present study by using the classic additional singleton paradigm of Theeuwes (1992). This search task was combined with a task that required either the focusing or spreading of attention. Based on the attentional window hypothesis (Belopolsky et al., 2007; Theeuwes, 1994a, 2004) we expected attention to be captured only during the diffuse, but not during focused attention (Experiments 1 and 2). In addition, in Experiment 2 we varied the number of elements in the display and expected narrowing of attentional window to result in increased search slope.

2. Experiment 1

To force the observers into spreading their attention in the so-called diffuse attention condition, they had to start searching only when the elements that made up the search display were arranged in a circle. This manipulation was similar to the one used in Belopolsky et al. (2007) which was effective in spreading attention. In the focused attention condition, observers had to attend to a centrally presented RSVP stream and had to start searching for the singleton target as soon as they detected the letter "K" in the central stream. This manipulation ensured that attention was focused in the center of the display (see Joseph et al., 1997; Santangelo & Belardinelli, 2007). We expected to find the classic attentional capture effect in the diffuse, but not in the focused condition.

2.1. Method

2.1.1. Participants

Ten volunteers (six females) from the Vrije Universiteit Amsterdam were paid to participate in a 30 min session. Their age varied between 17 and 23, with a mean age of 20. They all had normal or corrected to normal visual acuity and normal color vision.

2.1.2. Stimuli

The stimuli were presented against a black background and consisted of a central RSVP stream and a search display presented around it. The RSVP stream consisted of 15 letters (sampled randomly from the pool of 18 letters, all letters of the alphabet except for I, O, W, Z, G, M, Q, R). Each letter was gray (6.5 cd/m^2) and subtended $1.4° \times 1.9°$, and was presented for 80 ms, followed by another 80 ms blank interval. The search display was positioned around the RSVP stream and consisted of 8 display elements (3 pixels wide) that were equally spaced around it in a layout of either of an imaginary circle (radius of 6.7°) or square ($9.5° \times 9.5°$). Each search display contained a diamond element (3.8° in diagonal) presented among circles (2.8° in diameter). The diamond, which served as the target contained a gray line segment (1.4°) that was oriented either horizontally or vertically, which determined the response ("z" key for vertical and "/" key for horizontal). Each circle contained a gray line segment that was tilted 22.5° to either side of horizontal or vertical plane. The orientations of the line segments inside the circles were chosen randomly. All search elements were green (CIE:0.3/0.6; 9.3 cd/m^2), except for the trials in the distractor present condition on which one of the circles had a red color (CIE:0.6/0.3; 10 cd/m^2).

2.1.3. Design

The experiment consisted of two main conditions: the diffuse attention condition and the focused attention condition, which were manipulated within-subjects (see Fig. 1). Both conditions had similar displays, but had different instructions. In the diffuse attention condition participants had to start searching only when the display elements made up a circle (Go trials) and to withhold their response when the display elements made up a rectangle (No-Go trials). They had to ignore the RSVP stream in the center of the screen. In the focused attention condition participants had to start searching only when they detected a letter "K" in the RSVP stream (Go trials) and to withhold their response when the letter "K" was absent (No-Go trials). The letter "K" could occur equally likely either at the 4th or 8th position in the RSVP stream. In both conditions the No-Go trials occurred on 1/3 of all trials.

The appearance of the search display was always synchronized with the letter occurring at the 4th or 8th position in the RSVP stream. To minimize the confusion between instructions in the two conditions, in the diffuse attention condition the letter "K" was always absent from the RSVP stream. Similarly, in the focused attention condition only the circular layout of the display elements was used.

On half of the trials, a salient distractor was present in the display. Its location was chosen randomly, with a constraint that the salient distractor could never be directly adjacent to the target element. The order of attention conditions was counterbalanced across participants with half of the participants completing the diffuse attention condition first and the other half completing the focused attention condition first. Within each attention condition all types of trials were mixed. Both diffuse and focused attention condition contained 96 trials (divided in two blocks of 48 trials), 192 trials in total.

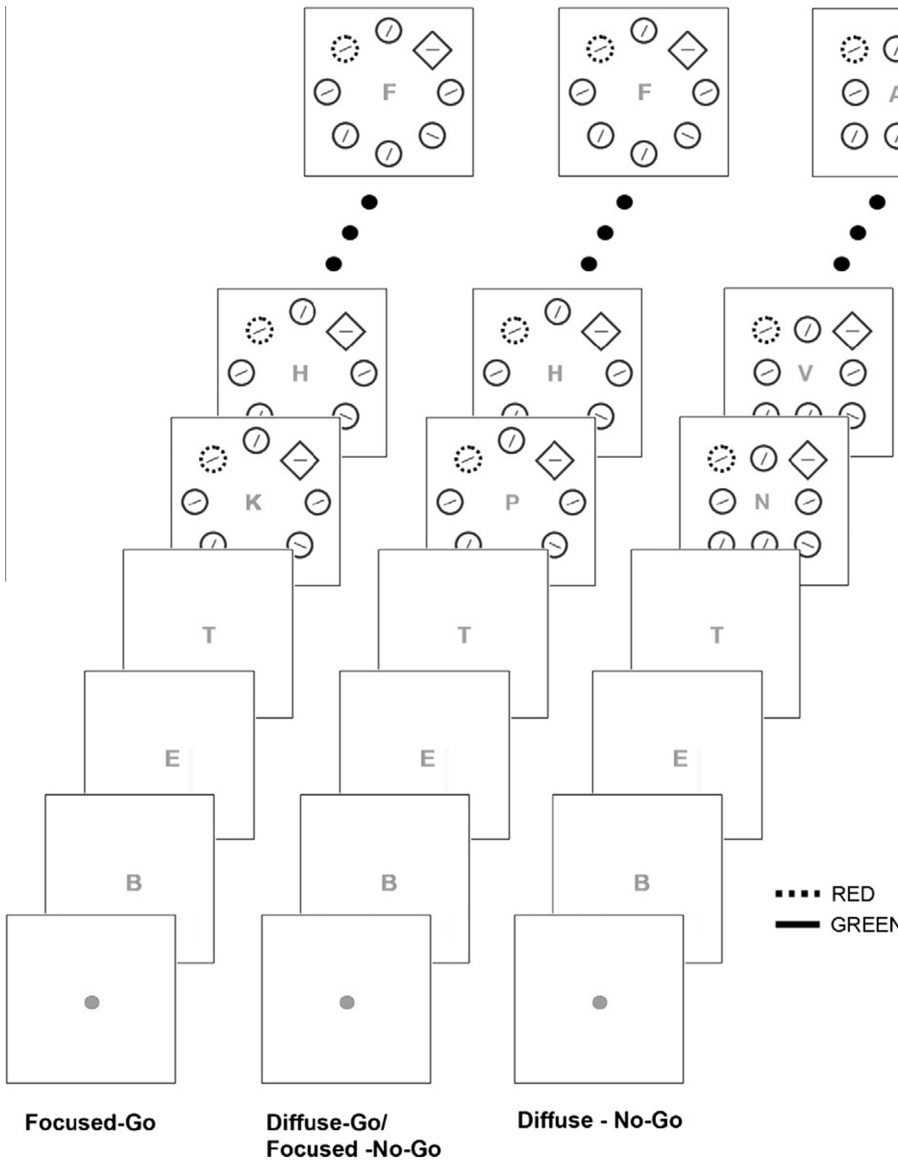

Fig. 1. Examples of the stimulus displays used in the Experiment 1. In the focused condition participants had to start searching for a shape singleton only once they have detected the letter "K" in the RSVP stream in the center of the screen. In the diffuse condition participants had to start searching for a shape singleton only when the global shape was a circle.

2.1.4. Procedure

Participants were seated approximately 75 cm from the screen. They were instructed to search for a diamond element and to determine the orientation of the line segment inside it. They could start searching only when a Go signal (which was different for the diffuse and focused attention condition) was present. They were also told that one of the circles in the display could be uniquely colored, but is irrelevant to the task and therefore should be ignored. The trial started with a fixation cross, which stayed on the screen for 500 ms. It was followed by an onset of the RSVP stream. At either 4th or 8th letter position a search display appeared, and depending on the Go signal participants either had to start searching or to withhold their response. The search display stayed on until a response was detected, otherwise it disappeared simultaneously with the last letter in the RSVP stream. Error trials were followed by an appropriate visual feedback (text saying: "Incorrect response", "No response detected" or "No response required") presented for 1500 ms. Participants also received feedback about their accuracy and reaction time after every block of 48 trials. They were motivated to respond quickly and accurately. Before the start of each condition the participants received a sample block of 48 practice trials.

2.2. Results

Trials in which participants responded faster than 150 ms or slower than 1200 ms were excluded from the analysis. This led to a loss of 2.3% of the trials.

The reaction times (RTs) for the diffuse and focused conditions are presented in Fig. 2. A within-subject ANOVA with condition (diffuse or focused) and distractor (present, absent) showed a main effect of condition ($F(1,9) = 18.85$, $p < .005$) and of distractor ($F(1,9) = 10.29$, $p < .05$). More importantly the interaction between condition and distractor was significant ($F(1,9) = 8.43$, $p < .05$), suggesting that the distractor had a different effect in the diffuse versus the focused condition. Planned comparisons showed that in the diffuse attention condition the presence of the distractor had a marked effect on performance: participants were 33 ms slower when the distractor was present relative to when it was absent ($t(9) = 3.73$, $p < 0.005$). However in the focused condition,

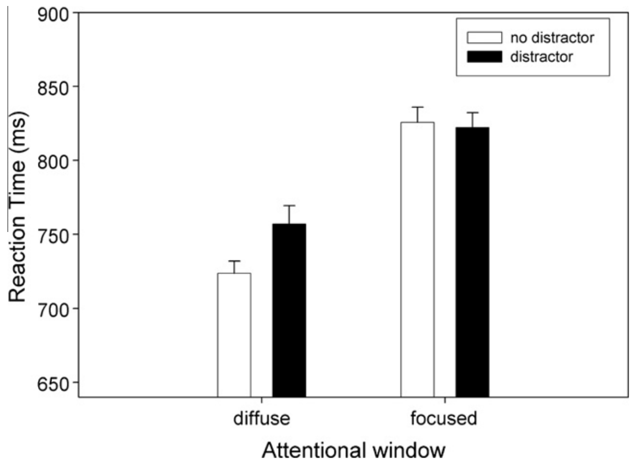

Fig. 2. Mean correct reaction times as a function of attentional window size and the presence of a color singleton distractor in Experiment 1. Error bars represent standard error of the mean for within-subject designs normalized for estimating the effect of distractor presence in each condition.

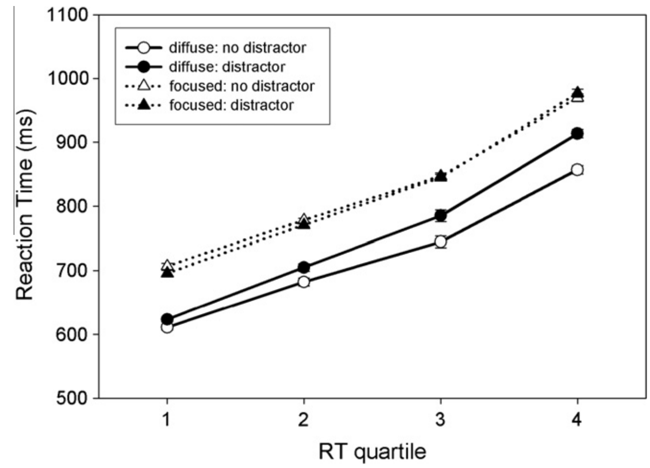

Fig. 3. Mean correct RT in focused and in diffuse attention condition as the function of RT quartile and the presence of a color singleton distractor in Experiment 1. Error bars represent standard error of the mean for within-subject designs normalized for estimating the effect of distractor presence within each quartile and condition.

there was no effect of the distractor whatsoever ($t(9) = 0.52$, $p = .62$).

As is clear from Fig. 2, participants were significantly slower in the focused condition than in the diffuse attention condition. This is to be expected because focusing brings attention in a state in which search is relatively inefficient (as in Jonides & Yantis, 1988). However, this data pattern provides a potential problem for our interpretation because it may suggest that it is not necessarily the size of the attentional window that is crucial for the color singleton to capture attention, but simply the general speed of responding. Previous research have shown that bottom-up capture by salient stimuli is short-lived (Hickey, van Zoest, & Theeuwes, 2010; Theeuwes, Atchley, & Kramer, 2000; van Zoest, Donk, & Theeuwes, 2004) and the salience information could have dissipated by the time the participants started searching in the focused attention condition. Alternatively, the absence of capture in the focused attention condition could also be explained by higher perceptual load in that condition, since on average it took participants longer to complete it than the diffuse attention condition (Lavie, 1995). According to the perceptual load theory, when processing demands are high there is no capacity left for processing of irrelevant information. Both the salience dissipation and the perceptual load accounts predict that attentional capture would depend on the overall processing time and not on the size of the attentional window. To address these alternative explanations we divided the RTs in each condition into the four quartiles and examined attentional capture in each condition as the function of quartile. If the capture by the irrelevant color singleton was simply a function of the speed of responding, we would expect that the distracting effect of the singleton would appear in the focused attention condition as the RT becomes shorter.

Fig. 3 illustrates the results of this analysis. For the diffuse attention condition an ANOVA with distractor (present, absent) and quartile as factors showed that there was a main effect of distractor ($F(1, 9) = 13.88$, $p < .01$), indicating that the distractor captured attention. The effect of the quartile was also significant ($F(3, 27) = 120.08$, $p < .001$). The interaction between the distractor and the bin was marginally significant ($F(3, 27) = 2.86$, $p = .06$), demonstrating a trend for capture to be larger in the slower bins. Such a result has been previously reported in a typical additional singleton paradigm (Hickey et al., 2010) and might seem counterintuitive at first. However, the reason that capture effects increase with RT is that in this paradigm the selection of distractor is measured indirectly, i.e. based on the delayed manual responses to the target. Therefore, the slower bins tend to contain more trials on which selection of the distractor has taken place.

For the focused attention condition the same ANOVA showed only a main effect of the quartile ($F(3, 27) = 161.31$, $p < .001$). There was neither main effect of distractor ($F(1, 9) = 0.27$, $p = .62$) nor the interaction between the distractor and the quartile ($F(3, 27) = 1.03$, $p = .39$), indicating that the distractor did not capture attention in any of the quartiles. Altogether, the RT distribution analysis shows that whether salient distractor captured attention was not determined by the speed of responding per se, but by whether attention was in a diffuse or focused state.

To further illustrate that in the focused condition attentional capture was not determined by the overall speed of responding we took 50% of the slowest RTs in the diffuse attention condition and compared them to the 50% fastest RTs in the focused condition. Fig. 4 illustrates the results of this analysis. An ANOVA with condition (diffuse or focused) and distractor (present, absent) showed that for the chosen subsets of RTs there was a main effect of condition, but now participants were slower in the diffused attention condition than the focused attention condition (825 vs. 738 ms;

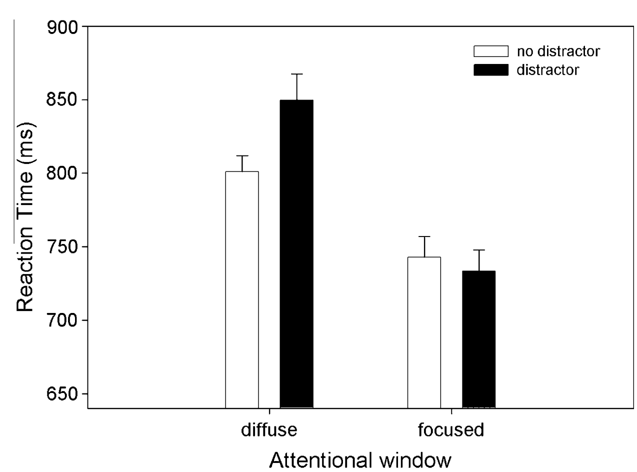

Fig. 4. Mean 50% fastest correct RT in focused condition and 50% slowest RT in diffuse condition as the function of the presence of a color singleton distractor. Error bars represent standard error of the mean for within-subject designs normalized for estimating the effect of distractor presence within each condition.

$F(1,9) = 9.87$, $p < .05$). The main effect of the distractor was also significant ($F(1,9) = 9.82$, $p < .05$), indicating that the distractor captured attention. Moreover, the interaction was also significant ($F(1,9) = 18.24$, $p < .005$), demonstrating that the distractor captured attention only in the diffuse attention condition (49 ms ; $p < 0.005$), but not in the focused condition (−9 ms ; $p = .2$). This analysis shows that even on trials when the overall RT in the diffuse condition was slower than in the focused condition, salient distractor captured attention only in the diffuse, but not in the focused condition. Taken together, the additional analyses argue against the general speed of responding or perceptual load as the explanations of the present results.

Overall, participants were quite accurate. They made only 3% of false alarms in No-Go condition and 0.3% misses in Go-trials. Furthermore, they made only 3% of errors in orientation judgment in Go-trials. For the Go-trials the mean percentage of errors in orientation judgment for each condition are presented in Table 1. ANOVA on percentages of errors in orientation judgment showed no significant effects or interactions.

2.3. Discussion

Experiment 1 showed that only when attention was spread across the search display, the presence of a color singleton interfered with the search and captured attention. However, when right before the search started attention was focused in the center by means of attending to the RSVP, no attentional capture by the color singleton was observed. Additional analysis of RT distribution showed that this effect was due to the size of the attentional window and not to a simple increase in reaction time during the focused attention condition. Specifically, the attentional capture was observed for both fast and slow responses in the diffuse attention condition, but was never observed in the focused attention condition.

3. Experiment 2

Although the results of Experiment 1 were quite straightforward, one might wonder if they were due to the difference between the diffuse and focused tasks that were unrelated to the manipulation of the size of the attentional window. For example, the focused attention task required selection of a target letter from a stream of rapidly presented distractors, while the diffuse attention task had to do with discrimination between a circle and a square. In Experiment 2 we controlled for such differences by using essentially the same tasks, but presented in different modalities.

In the focused attention condition the task was basically the same as in Experiment 1: participants had to detect the target letter in RSVP at the fixation. However, simultaneously with the visual stream a rapid serial auditory presentation letter stream (RSAP) was presented, which participants were asked to ignore. In the diffuse attention condition, participants had to do the opposite: they had to ignore the RSVP and to detect the target letter in the auditory letter stream. Although we did not explicitly ask participants to spread their attention, we assumed that attention would be diffuse just as it is assumed to be diffuse in the typical additional singleton search task (Theeuwes, 1992).

Table 1
Errors in orientation judgment (percent) by condition and distractor presence in Go-trials in Experiment 1.

	Diffuse	Focused
Distractor present	3.1	2.8
Distractor absent	2.2	4.7

To provide further evidence that the size of the attentional window was affected by the task instruction, we manipulated the number of elements in the search display. According to the attentional window hypothesis (Belopolsky et al., 2007; Theeuwes, 1994a, 2004) reducing the size of the attentional window should result in more serial processing of the visual display. Therefore, if our manipulation of the size of the attentional window is successful, we expect to find less efficient search in the focused attention condition than in the diffuse attention condition.

3.1. Method

3.1.1. Participants

Sixteen volunteers (eight females) from the Vrije Universiteit Amsterdam participated for monetary pay or in exchange for credit in 1,5 h session. Two participants were replaced due to a large error rate (>10%). The age of the participants varied between 17 and 23, with a mean age of 21. They all had normal or corrected to normal visual acuity, normal color vision and Dutch was their first language.

3.1.2. Stimuli, design and procedure

The experiment was very similar to Experiment 1. The RSVP stream again consisted of 15 letters, but was now sampled randomly from the pool of 22 letters (all letters of the alphabet except for I, O, W, Z) and the letters were made slightly smaller ($1° \times 1.2°$). The search display was positioned around the RSVP stream and consisted of either 6 or 9 display elements that were equally spaced around it in layout of an imaginary circle. Another important difference from Experiment 1 was the diffuse attention manipulation. Instead of processing the overall stimulus layout the participants were asked to attend to the rapid serial auditory presentation stream (RSAP), presented synchronously to the visual stream (sounds were presented into headphones). The RSAP consisted of 15 letters sampled from the same pool of 22 letters as the RSVP. Note that the letters for the RSAP were sampled independently from the letters sampled for the RSVP, therefore the identities of the spoken and visual letters very seldom coincided. The letters were spoken in Dutch and the duration of each spoken letter was 90 ms. The onset of the each spoken letter in the RSAP was synchronized with the onset of each visual letter in RSVP.

Both RSVP and RSAP streams were presented in both diffuse and focused attention conditions. In the diffuse condition participants were instructed to attend to the auditory stream and to ignore the visual stream of letters. They were instructed to start searching only when they detected the letter "K" in the RSAP stream (Go trials) and to withhold their response when the letter "K" was absent (No-Go trials). In the focused condition participants were instructed to attend to the visual stream and to ignore the auditory stream of letters. As in Experiment 1 they were instructed to start searching only when they detected the letter "K" in the RSVP stream (Go trials) and to withhold their response when the letter "K" was absent (No-Go trials). In both conditions the letter "K" could occur equally likely either at the 4th or 8th position in the streams. To minimize the confusion between instructions in the two conditions, in the diffuse attention condition the letter "K" was always absent from the RSVP stream. Similarly, in the focused attention condition the letter "K" was always absent from the RSAP stream. In both diffuse and focused conditions the No-Go trials occurred on half of all trials.

Half of the participants performed the diffuse attention condition first and the other half performed the focused attention condition first. For each condition all types of trials were mixed. Both diffuse and focused attention condition contained 320 trials (divided in ten blocks of 32 trials), 640 trials in total. Before the start of each condition the participants received five blocks of 32 practice trials.

3.2. Results

Trials in which participants responded faster than 150 ms or slower than 1350 ms were excluded from the analysis. This led to a loss of 1.5% of the trials.

The reaction times (RTs) for the diffuse and focused conditions are presented in Fig. 5. A within-subject ANOVA with condition (diffuse or focused) and distractor (present, absent) and number of elements in the display (6 or 9) showed a main effect of condition ($F(1, 15) = 40.39$, $p < .001$) and no main effect of distractor ($F(1, 15) = 0.99$, $p = .34$). Importantly, the interaction between condition and distractor was significant ($F(1, 15) = 4.99$, $p < .05$), suggesting that the distractor had a different effect in the diffuse versus focused condition. Moreover, there was a significant interaction between condition and the number of elements in the display ($F(1, 15) = 4.87$, $p < .05$), indicating that the reaction times increased more as the number of elements increased in the focused attention condition (2.7 ms/item) than in the diffuse attention condition (−3.7 ms/item). No other main effects or interactions were significant.

Planned comparisons showed that in the diffuse attention condition the presence of the distractor marginally slowed the responses to the target ($F(1, 15) = 3.93$, $p = 0.07$). However in the focused condition, there was again no effect of the distractor ($F(1, 15) = 0.17$, $p = 0.69$).

Since the presence of capture by the distractor can cloud the estimation of the search slopes, we further compared the slopes between the focused and diffuse conditions when the distractor was absent. The results showed that search was less efficient in the focused attention condition than in the diffuse attention condition (5.5 ms/item vs. −3.0 ms/item, respectively; $t(15) = 2.36$, $p < .05$). Furthermore, the search slope in the focused condition was also significantly different from zero ($t(15) = 2.43$, $p < .05$, two-tailed), but it was not in the diffuse condition ($t(15) = 1.22$, $p = .24$, two-tailed).

Overall, participants were quite accurate. They made only 1.5% of false alarms in No-Go condition and 1.4% misses in Go-trials. Furthermore, they made only 6.5% of errors in orientation judgment in Go-trials. For the Go-trials the mean percentage of errors in orientation judgment for each condition are presented in Table 2. ANOVA on percentages of errors in orientation judgment showed no significant effects or interactions.

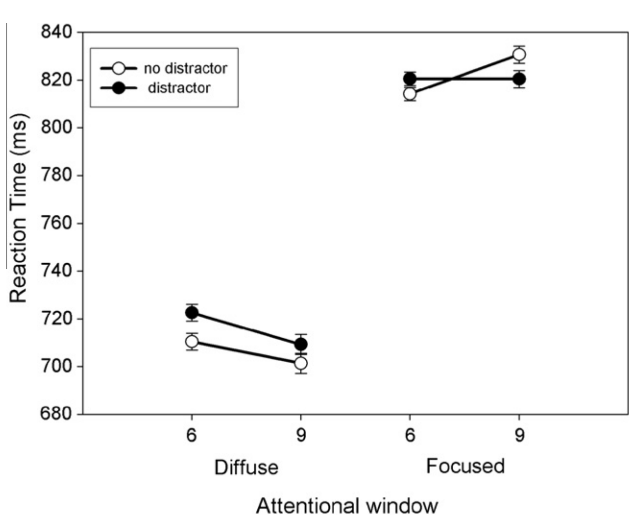

Fig. 5. Mean correct reaction times as a function of attentional window size, number of elements in the display and the presence of a color singleton distractor in Experiment 2. Error bars represent standard error of the mean for within-subject designs normalized for estimating the effect of distractor presence within each condition and the number of elements in the display.

Table 2
Errors in orientation judgment (percent) by condition, number of elements in the display and distractor presence in Go-trials in Experiment 2.

	Diffuse		Focused	
	6 elements	9 elements	6 elements	9 elements
Distractor present	5.5	6.7	5.9	7.7
Distractor absent	6.1	6.3	7.3	6.9

3.3. Discussion

Experiment 2 clearly showed that even when the tasks used to manipulate the size of the attention window were made similar there was still capture by the color singleton only in the diffuse, but not in focused attention condition. Importantly, consistent with the assumptions of the attentional window hypothesis even in the classic pop-out search task the search became less efficient when attention was focused, suggesting that fewer elements in the visual field were processed in parallel.

4. General discussion

The present study shows that in a diffuse attentional state, we obtain the classic attentional capture effect as reported by Theeuwes (1992): the presence of an irrelevant color singleton slows search for a shape singleton. When attention was spread over the display the most salient singleton captures attention, causing an increase in time to find the target singleton. This effect was demonstrated when participants were explicitly asked to spread their attention by detecting the overall layout of the stimuli (Experiment 1) and was slightly smaller when no such explicit instruction was given (Experiment 2). However, this very same capture effect was abolished when just before the presentation of the display attention was in a focused state (Experiments 1 and 2). If attention is not spread over the display, but focused in the center, the presence of an irrelevant singleton no longer captures attention. Furthermore, we provide direct evidence that when attention is brought into a focused state before the search begins, the search becomes less efficient, just as proposed by the attentional window hypothesis (Belopolsky et al., 2007; Theeuwes, 1994a, 2004). This clearly illustrates why attentional capture by the color singleton is reduced: when the color singleton falls out of the narrow attentional window it fails to compete for selection with the singleton target.

The results are consistent with those of Belopolsky et al. (2007) who showed the opposite of what we show here: in the classic Jonides and Yantis (1988) paradigm in which there is usually no capture, capture was reinstated when participants spread their attention across the visual field. Together with these findings, the present findings show that the extent to which spatial attention is divided across the visual field plays a crucial role in attentional capture. The notion of the attentional window as a determining factor in the occurrence of attentional capture provides a framework for understanding previous findings on capture.

The current findings are consistent with a study by (Proulx and Egeth (2006)). They showed that the distraction caused by an irrelevant feature (a bright singleton) was modulated by target-non-target similarity. With increasing target-non-target similarity search became more difficult, and with increasing search difficulty, the effect of the presence of the irrelevant bright singleton was reduced. These findings are fully consistent with the idea that when search becomes more difficult, the attentional window needs to be smaller, causing a reduced effect of the irrelevant distractor on search (see also Lu and Han (2009)). The same reasoning holds for the findings reported by Bacon and Egeth (1994). After replicating Theeuwes (1992) original capture effect, they added different shapes to the display such as triangles and squares. Since the display was no longer homogenous, the task to find the shape singleton became more difficult, which abolished the distracting effect of the singleton. When the target salience was increased by adding several non-target circles (Theeuwes, 2004), search became fully parallel again, rendering flat search times of near zero ms/item. Importantly because observers were now dividing their attention across the visual display in order to find the target, the irrelevant color singleton captured attention and caused a large RT interference effect.

Even though the results of Proulx and Egeth (2006) and Bacon and Egeth (1994) can be explained in terms of search difficulty and the assumed decrease in the size of the attentional window, it should be noted that typically the absence of a capture effect have been explained in terms of *feature* and *singleton detection* search mode (Bacon & Egeth, 1994; Leber & Egeth, 2006). These search modes are thought to be under top-down control, and allow participants to either engage in a singleton detection mode in which they choose to direct attention to the location having the largest feature contrast (highest salience) or in a feature search mode, in which they choose to direct their attention to a particular feature. If participants adopt a singleton detection mode, all irrelevant singletons capture attention. However, if participants choose a feature search mode, irrelevant singletons no longer capture attention. As we have suggested before (Belopolsky et al., 2007; Theeuwes, 2004) the size of the attentional window provides a way to reconcile different views on the extent of top-down control, without assuming different unintentional search modes.

Specifically, we suggest that top-down control over attentional capture is restricted solely to the spatial domain (see Theeuwes and Van der Burg (2007)). When attention is spread, visual search may be conducted in parallel across all items in the visual field (as in the additional singleton task of Theeuwes, 1991, 1992, 2004), at the expense that an irrelevant salient singleton would also be selected automatically. However when the attentional window is set to a smaller size, irrelevant singletons that fall outside of the attentional window will not capture attention. We propose that salience computations that are performed during the first sweep of information are restricted to the attentional window of the observer. Our claim is that while the size of the attentional window is under top-down control, within the attentional window top-down control cannot preclude attention from being captured by the most salient feature.

Leber and Egeth (2006) challenged the attentional window hypothesis in a study employing heterogenous displays forcing participants to use a feature search mode. After an extensive training phase with such displays and the instruction to search for a specific feature (a circle), participants were able to avoid capture by the salient singleton even though search slopes were basically flat. On the surface this finding seems problematic for the window hypothesis because it represents a case of non-serial search without capture by the salient distractor singleton. In that same study, Leber and Egeth (2006) also had a group of observers trained in singleton search. These data showed the classic interference by the salient distractor. Importantly, observers in this group responded faster in the distractor absent condition than observers in that very same condition that had learned to search for a feature. In footnote 3, Leber and Egeth (2006) speculate that the distractor interference effect in the feature search group may be have been concealed by slower responding of observers that have learned to use the feature search mode. Consistent with our claims, by slowing down search (possibly by setting a smaller attentional window) the effect of the distractor should disappear. Also, note that in Leber and Egeth (2006) the search slopes were compared between groups of participants, which makes a small increase in the search slope difficult to detect. In our Experiment 2 we were able to show a small increase in the search slope when the size of the attentional window was manipulated within-subjects.

The finding of less efficient search during a classic pop-out task has also important implications for the current theories of visual attention. The distinction between preattentive and attentive stages of processing is a fundamental question of visual selection and has a long history in cognitive psychology. While many researchers suggested that attention is not needed for detection of pop-out of simple features (Braun & Sagi, 1990; Luck & Ford, 1998; Müller et al., 2003; Reddy et al., 2007; Treisman, 1988), other researchers argued that all visual information has to pass through a limited-capacity stage before being detected (Ghorashi et al., 2007; Joseph et al., 1997; Nothdurft, 1999; Theeuwes, 1992, 1999, 2008).

For example, Joseph et al. (1997) measured the accuracy of orientation pop-out detection while participants were engaged in a RSVP task in the center of the screen. They showed that pop-out detection was severely impaired when it was presented within the attentional blink and was recovered when it was presented outside of the attentional blink. It was proposed that performance in all tasks, even the tasks requiring detection of simple featural differences is contingent upon availability of attentional resources. This argues against the classic preattentive/attentive dichotomy. Ghorashi and colleagues (2007) have replicated the findings of Joseph et al. (1997) using RTs, but they failed to show increase in the search slope when the search task was placed inside the attentional blink. Note, however, that the impairment of pop-out detection within the attentional blink has also been interpreted as a result of a post-selection processes, having nothing to do with attention needed for selection of the pop-out (see Luck & Ford, 1998).

The present study extends the previous results by showing an increase in search slope in a pop-out task during focused attention. This suggests that decrease in the size of the attentional window directly affects selection, with search even for the simple feature becoming more serial. Note that since a very small amount of attention is needed for pop-out detection (Joseph et al., 1997) only a modest search slope was expected and observed in the focused attention condition of our study (5.5 ms/item). Typically, the slope of 5.5 ms/item would have been considered to represent preattentive search, since it is smaller than the commonly used but arbitrary chosen criterion of 10 ms/item. However, such absolute measure might be inaccurate, since in a pop-out task search slopes tend to decrease as the number of search elements increases because the salience of the target increases as more homogenous distractors are added to the display (Bravo & Nakayama, 1992; Ghorashi et al., 2007; Wolfe, Butcher, Lee, & Hyle, 2003). Therefore, including the diffuse attention condition as a baseline allowed us to demonstrate a significant relative increase in the search slope (from −3.0 ms/item to 5.5 ms/item, total of 8.5 ms/item) when attention was focused.

To summarize, our results showed that the size of the attentional window plays an important role in visual selection and in attentional capture. When attentional window is wide all items are processed in parallel across the visual field and all salient elements capture attention irrespective of a top-down goal. However, when attentional window is small search becomes less efficient, even in a classic pop-out search task. Such narrowing of the attentional window excludes processing of irrelevant singletons and precludes attentional capture. Therefore, attentional capture occurs only within attentional window, but there is no capture outside the attentional window.

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