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Top-down control settings and the attentional blink: Evidence for nonspatial contingent capture

Charles L. Folk
Villanova University, Villanova, PA, USA

Andrew B. Leber and Howard E. Egeth
Johns Hopkins University, Baltimore, MD, USA

Previous studies have shown that spatial attention can be "captured" by irrelevant events, but only if the eliciting stimulus matches top-down attentional control settings. Here we explore whether similar principles hold for *nonspatial* attentional selection. Subjects searched for a coloured target letter embedded in an RSVP stream of letters inside a box centred on fixation. On critical trials, a distractor, consisting of a brief change in the colour of the box, occurred at various temporal lags prior to the target. In Experiment 1, the distractor produced a decrement in target detection, but only when it matched the target colour. Experiments 2 and 3 provide evidence that this effect does not reflect masking or the dispersion of spatial attention. The results establish that (1) nonspatial selection is subject to "capture", (2) such capture is contingent on top-down attentional control settings, and (3) control settings for nonspatial capture can vary in specificity.

It is now well-established that the involuntary allocation of spatial attention to irrelevant, salient stimuli (e.g., abrupt onset, movement, discontinuities in colour, etc.) can be significantly modulated by top-down attentional set (e.g., Bacon & Egeth, 1994; Folk & Remington, 1998; Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994; Gibson & Kelsey, 1998; Yantis & Jonides, 1990). For example, in an early demonstration of top-down modulation, Folk et al. (1992) found that in a spatial cueing task, the

Please address all correspondence to C. L. Folk, Department of Psychology, Villanova University, Villanova, PA 19085, USA. E-mail: charles.folk@villanova.edu

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ability of irrelevant abrupt-onset precues to capture spatial attention was contingent on the attentional "set" of the observer. Specifically, spatial cueing effects associated with abrupt onset cues paired with abrupt onset targets (Remington, Johnston, & Yantis, 1992) were eliminated when the very same cues were paired with targets defined by a colour discontinuity. Similarly, precues defined by a colour discontinuity produced no spatial cueing effects when paired with onset targets, but large effects when paired with colour targets. These results led Folk and colleagues to propose the *contingent involuntary orienting hypothesis*, according to which a given stimulus property will capture attention only if it matches top-down attentional control settings induced by task demands.

Subsequent studies have explored the nature and specificity of attentional control settings. For example, Folk and Remington (1998) found that colour-singleton precues paired with colour targets produced evidence of attentional capture, but only when the target was a singleton of the same colour, suggesting that attentional control settings can be established for particular feature values (e.g., "red"). Similar results have been reported for properties such as luminance change (offset vs onset; Atchley, Kramer, & Hillstrom, 2000) and motion (rotational vs translational; Folk, Hackman, & Brady, 2002). However, studies suggest that the specificity of attentional control settings in any given task is highly sensitive to the task demands. In the context of a visual search task, Bacon and Egeth (1994) found that when subjects were asked to search for a singleton target of a particular shape (e.g., a diamond among circles), the presence of an irrelevant colour singleton produced a cost in performance suggestive of attentional capture. This effect disappeared, however, when, on some trials, the heterogeneity of the shapes was increased, which encouraged subjects to adopt a set for the particular shape. Bacon and Egeth proposed that subjects tend to adopt an attentional control setting referred to as *singleton search mode* unless forced by task demands to adopt the more specific *feature search mode* (see also Lamy & Egeth, 2003; Pashler, 1988). Although some have challenged this conceptualization (Theeuwes, 2004), recent work by Leber and Egeth (2006) provides confirmation of the role of top-down search mode in attentional control.

In addition to attentional control settings for feature properties such as colour, shape, and motion, there is also evidence that attentional capture can be modulated by a top-down set for location. Yantis and Jonides (1990) found that when the location of a target letter in a visual search task was uncertain, the presence of an irrelevant abrupt onset letter produced evidence of attentional capture. However, when subjects were given a 100% valid precue regarding the subsequent location of a target, capture effects were eliminated. Similar results were reported by Theeuwes (1991), who systematically varied the stimulus-onset asynchrony (SOA) between the presentation of a precue (a 100% valid, centrally presented arrow) and target, as well as the SOA between an irrelevant onset (and offset) and target. When the location precue preceded the target by 300 or 600 ms, irrelevant onsets (and offsets) appearing at nontarget locations had no effect on responses to the target, regardless of whether the irrelevant onset (offset) appeared before, simultaneous with, or after target presentation.

Folk, Leber, and Egeth (2002) explored the interaction between attentional control settings for feature properties and control settings for location using a variant of the rapid serial visual presentation (RSVP) paradigm that has been used to study a phenomenon known as the attentional blink (AB). In the typical AB task, a rapid series of stimuli is presented at fixation, and either one or two targets can appear within the stream (e.g., Broadbent & Broadbent, 1987; Chun & Potter, 1995; Raymond, Shapiro, & Arnell, 1992). The AB refers to a decrement in the detection or identification of the second target (T2) when it occurs soon after the presentation of a first target (T1), to which a response is required. Although the precise mechanism is still under debate (see, for example, Olivers, van der Stigchel, & Hullemann, in press), the decrement in T2 processing is generally assumed to be a consequence of attentional selection of T1. In the study by Folk et al., subjects were required to monitor a centrally presented stream of coloured letters for a target letter of a particular colour, and to report the identity of that letter. However, instead of an additional target in the stream, a task-irrelevant, peripheral distractor that either matched or did not match the target colour was presented at different temporal positions relative to the target. Distractors that matched the target colour produced a decrement in target identification when they appeared 200 ms prior to the target. These results suggest that the attentional control setting for colour needed to select the target from the temporal stream at fixation resulted in contingent spatial capture by irrelevant peripheral stimuli, thereby overriding an attentional set for the spatial location of the target (i.e., fixation). The spatial nature of this capture effect was confirmed in subsequent experiments showing that a peripheral prime appearing at the location of a target-coloured distractor interfered more than one appearing at another peripheral distractor location. Moreover, consistent with the work of Bacon and Egeth (1994), when the coloured target appeared among homogeneous grey distractors in the central stream, irrelevant peripheral colour singletons captured attention regardless of whether they matched the target colour or not, suggesting that subjects had adopted singleton search mode.

Similar results have been reported by Jolicoeur, Sessa, Dell'Aqua, and Robitaille, (2006), who presented subjects with a central stream of letters followed by a target letter that could appear to the left or right of fixation. They found that a distractor letter in the central stream produced an attentional blink when it matched the colour of the subsequent peripheral target. Moreover, event-related-potential (ERP) measures showed that the N2pc component, which is associated with shifts of spatial attention, was sharply attenuated for the peripheral target when the central distractor matched its colour. These data provide additional support for the contingent capture of spatial attention in the AB paradigm (see also Serences et al., 2005, for evidence from fMRI).

The results of Folk et al. (2002) and Jolicoeur et al. (2006) demonstrate the importance of top-down attentional control settings in modulating the allocation of spatial attention. Additionally, the results suggest that irrelevant stimuli at one location can produce a shift in spatial attention that results in a transient decline in perceptual processing of target stimuli at other locations, similar to that produced by T1 in a traditional AB paradigm. This is an interesting result, in that, traditionally, the AB is only evident when T1 is task relevant (i.e., must be reported). Indeed, the presence and magnitude of the AB is typically indexed in terms of performance when T1 is reported relative to when it is ignored. Given that the traditional AB is assumed to reflect the nonspatial, voluntary selection of T1, the results of Folk et al. and Jolicoeur et al. suggest that if one were to insert the distractor into the central stream itself, it may be possible to produce *nonspatial* attentional capture, as long as the capturing event matches attentional control settings for the target event.

There are, in fact, several existing studies providing at least some evidence for nonspatial contingent attentional capture. Chun (1997) presented subjects with an RSVP stream of white letters appearing inside a box frame at fixation, and required them to report the identity of two targets in the stream, separated by various temporal lags. The target letters to be reported were indicated by turning the box frame a different colour. For example, for T1 the frame might turn red, and for T2 the frame might turn green. A typical AB was obtained; T2 report declined at short lags when T1 was reported relative to when T1 was ignored. However, even in the ignore T1 condition, there was a significant effect of lag, with T2 reports averaging around 55% at short lags compared to approximately 75% at longer lags. In other words, even when T1 was ignored, it affected T2 report at early lags, suggesting that attentional resources had been "captured" by T1 in the absence of any shifts of spatial attention. The author suggested that this nonspatial capture effect may be due to the fact that the defining features of T1 and T2 were similar (i.e., a colour change to the box frame).

Several other studies have found that the similarity between targets and the intervening distractor letters significantly influences the magnitude of the attentional blink. For example, Maki, Bussard, Lopez, and Digby (2003) found that the magnitude of the AB for letter targets was significantly reduced when the distractors were presented in a "false font" or mathematical symbols (see also Maki, Couture, Frigen, & Lien, 1997). Similar results were reported by Visser, Bishof, and DiLollo (2004) using a variant of the two-target version of the AB paradigm, in which T1 and T2 are presented at different spatial locations, at varying temporal lags, each followed by a trailing mask. In addition to the targets, which were presented peripherally, Visser et al. presented an irrelevant RSVP stream of distractors at fixation, and varied the similarity between the RSVP characters and the targets. They found that target identification was impaired by the presence of the irrelevant RSVP stream, but only when the targets and distractors were similar (for example, both letters). Ghorashi, Zuvic, Visser, and DiLollo (2003) reported similar results with response time to a single target as the dependent measure. Response times were longer when the irrelevant RSVP stream contained distractors that were from the same stimulus set as the targets (e.g., both letters) than when they were from different stimulus sets (e.g., letter targets and dot pattern distractors). Moreover, this was true even when the distractors and target appeared at the same location, suggesting that the distractor effects were not due to shifts of spatial attention.

These studies of target-distractor similarity indicate that the presence of irrelevant stimuli intervening between T1 and T2 can influence the magnitude of the AB depending on the degree of similarity to the targets, which suggests a degree of unintentional or involuntary attentional selection of distractors contingent on top-down control settings. However, it seems possible that the observed target-distractor similarity effects might reflect the ease with which targets are segregated from distractors rather than the involuntary selection of those distractors. That is, perhaps it's simply more difficult to *detect* the target when it appears in the context of similar distractors. Moreover, these studies do not establish whether a specific event in the temporal sequence can produce involuntary selection, in the same way a spatial cue might draw attention to a specific location in space.

Four recent studies, however, do provide evidence for the involuntary selection of a specific event in a temporal sequence. The studies suggest that such effects are not contingent on top-down control settings, but as we shall see, that conclusion is dubious. Dalton and Lavie (in press) had subjects view a short sequence of presentations of a single letter, and required them to identify a change in size of the letter during one frame of the sequence. In addition, on half the trials, the letter presented prior to, or directly after, the target was different in colour (i.e., a colour singleton) than the rest of the sequence. This colour singleton produced a significant cost in RT, suggesting that nonspatial attention was captured by the irrelevant colour singleton, and that this effect was independent of top-down contingencies because the colour singleton produced interference even when subjects were set to respond to a change in size. It is unclear however, whether the effects reflect involuntary attention allocation, because the temporal position of the target was relatively certain (i.e., it always appeared in positions 4 or 5 in the sequence) and the distractor always appeared in close temporal proximity to the target (i.e., immediately before or after). Thus, the apparent selection of the distractor may simply reflect the *voluntary* allocation of attention to stimuli in the same general temporal location as the target. Moreover, it is possible that the apparent noncontingent nature of the effect may be the result of subjects setting themselves for singletons in general (i.e., singleton detection mode) rather than size changes in particular.

Spalek, Falcon, and DiLollo (in press) have also recently reported results suggesting the existence of nonspatial capture that is not contingent on top-down control settings. One-third of the subjects viewed an RSVP stream of white characters, with the exception of the target letter, which was a red letter. For another third of the subjects, a green distractor letter appeared in the stream at various lags prior to the target, whereas for the final third the green letter was replaced by green dots. Both green distractors produced a decrement in target report, with the green letter producing the largest decrement. These results suggest that the distractor captured attention even though it did not share the defining features of the target. However, given that the remainder of the stream contained white characters, it is once again possible that subjects in this experiment adopted singleton-detection mode.

A potentially more convincing case for noncontingent capture of nonspatial attention can be found in a study by Maki and Mebane (2006). Subjects were presented with a black target word among a sequence of black, four-character strings. At various lags prior to the target, an irrelevant red letter string consisting of either a word, consonants, digits, or "false font" characters appeared. Compared to trials on which no red distractor string appeared, the presence of an irrelevant red string produced a decrement in target report consistent with an AB. Importantly, however, this was only true for strings consisting of letters (i.e., a word or a string of consonants); red strings made up of false font characters or digits had no influence on target report. The authors concluded that the irrelevant red string produced the capture of nonspatial attention, after which the similarity of the characters to the target modulated the magnitude of interference. Moreover, the fact that an irrelevant red distractor produced capture when searching for black target suggests that the effect was driven by the salience of the red string, rather than the compatibility with a top-down attentional set. However, the fact that red digits and red false font distractors had virtually no effect on target report suggests that the effect of the distractor had nothing to do with its status as a salient colour singleton, but instead was driven entirely by the featural similarity between the distractor and the target, consistent with a contingent capture account.

Finally, Wee and Chua (2004) presented subjects with a traditional RSVP task in which subjects were required to identify two targets (defined by colour) embedded within the stream. However, on some trials, a square singleton frame, enclosing a distractor letter, was introduced into the stream between the two targets. The temporal position of this singleton was varied with respect to T1 such that it occurred equally often within (e.g., lags 2–3) or outside of (e.g., lags 4 or greater) the traditional blink period. The presence of the distractor prolonged the AB regardless of whether it appeared within or outside the blink period. Moreover, this effect occurred even though the distractor singleton did not share the defining feature of the target (i.e., colour). Thus, an intervening distractor affected the characteristics of the AB even when it was dissimilar to the target. However, it is unclear whether prolonging an existing AB can necessarily be taken as evidence that the distractor produced involuntary selection of the distractor.

In summary, there are a number of studies that suggest irrelevant, nominally ignored distractors can produce an AB-like phenomenon indicative of the capture of nonspatial attention. However, the evidence is not decisive with respect to whether such effects are contingent on top-down control settings. Moreover, in each case there are aspects of the design that limit the ability to conclusively tie the effects to involuntary, nonspatial, selection. The present studies were designed to critically assess the ability of irrelevant stimuli to produce nonspatial capture as well as to determine the degree to which such capture is contingent on top-down control settings. There are several key aspects of the present design. First, rather than indexing nonspatial capture in terms of the degree to which target-distractor similarity affects the *magnitude* of the AB, we explore whether a specific, irrelevant (i.e., ignored), event in time can produce an AB. Second, to be certain that any attentional selection is truly involuntary, we use distractors that are clearly discriminable from the target. Third, to determine the influence of attentional control settings, we systematically manipulate the relationship between the defining features of the target and those of the distractor.

Stimuli were based on those used by Chun (1997) and Folk et al. (2002). Each trial consisted of the presentation of an RSVP stream of letters appearing inside a box frame at fixation. One target, defined by a specific colour (e.g., red), appeared on every trial, and subjects were to report the identity of the target. On critical trials, an irrelevant, distracting event, consisting of a brief change in the colour of the box frame occurred at various temporal lags relative to the target. Given that all events occurred at fixation (i.e., stimulus location was held constant), it was assumed that any distractor effects would reflect nonspatial attentional selection. In addition, given that the distractor consisted of an irrelevant change in the colour of the surrounding box (rather than a change in the colour of one of the stream letters), any decrement in target identification as a function of the presence of the distracting event, was assumed to index involuntary selection. Moreover, it was expected that any such decrements in target identification should be time-locked to the presentation of the distractor, such that the largest decrements should occur at short lags after the distractor. In other words, it was expected that if ignored distractors result in involuntary attentional selection, they should produce a typical AB pattern. Finally, it was expected that if nonspatial capture is contingent on top-down attentional control settings, then only distractors that match the defining property of the target should produce this pattern.

EXPERIMENT 1

Method

Subjects. Thirty-eight undergraduate students from Villanova University participated in a single, 50-minute experimental session for credit towards fulfilment of a class research requirement. All had self-reported normal or corrected-to-normal visual acuity and colour vision.

Apparatus and stimuli. Stimuli were presented on a Sony Trinitron Multiscan 500 PS 21-inch monitor, driven by a Hewlett Packard Vectra VL computer. Subjects viewed the monitor in a dimly lit room at a distance of approximately 50 cm.

Stimuli consisted of a series of single letters centred within a square outline box in the centre of the computer screen. Letters measured 1.9° in height and 1.8° in width with a stroke width of 0.4°, and the box measured 3.0° per side with a stroke width of 0.5°. One letter in the sequence (i.e., the target) was red or green (varied across subjects), and the colour of each nontarget letter was chosen randomly from a set of four possible colours. For subjects searching for red targets, the sampled colours were grey, blue, purple, and green. For subjects searching for green targets, the sampled colours were grey, blue, purple, and red. The box within which the letters appeared was grey, but at critical points in stimulus presentation, changed for 100 ms to either red or green.

Design and procedure. Each trial of the experiment began with a 500 ms presentation of an empty grey box at fixation followed after 200 ms by the sequential presentation of 20 letters inside the box. Each letter in the sequence was presented for 50 ms, followed by a 50 ms blank period during which only the box was present, yielding a letter-to-letter SOA of 100 ms (see Figure 1). With this procedure, the outline box remained on the screen continuously. The letters on each trial were selected randomly without replacement from the English alphabet, with the exception of I, O, W, and Z. For half the subjects, one of the letters in the sequence (i.e., the target) was red,

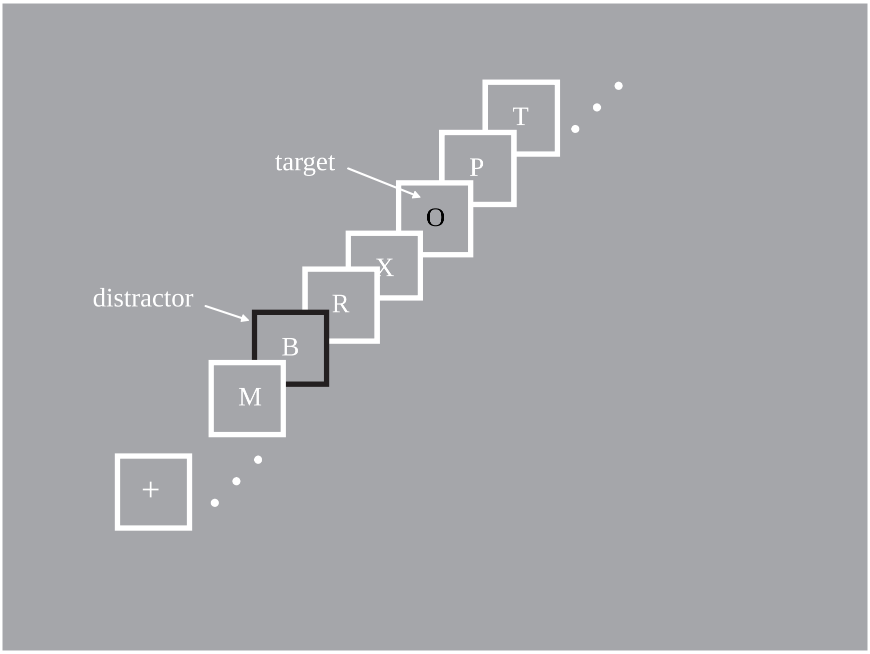

Figure 1. Representation of stimuli and sequence of events on a trial with a distractor-target lag of 3. The characters and lines printed in black were actually red or green. Note also that in Experiment 1, nontarget letters varied randomly in colour (see text for details).

and for the other half it was green. Across trials, the target could appear in positions 11–16 of the letter sequence, chosen randomly on each trial.

Each subject was presented with three different distractor conditions, mixed randomly within blocks. In the no-distractor condition, the outline box remained grey throughout the trial sequence. In the same-colour distractor condition, the outline box turned the same colour as the target simultaneously with one of the letters in the sequence, and remained that colour for 100 ms, returning to grey with the presentation of the next letter in the sequence The different-colour distractor condition was similar, except that the box turned red for subjects searching for a green target, and green for subjects searching for a red target. The grey box was removed 100 ms after the onset of the last stream letter.

The three distractor conditions were crossed with eight temporal lags between the presentation of the distractor and the presentation of the target. Specifically, the distractor appeared equally often 8, 7, 6, 5, 4, 3, 2, and 1 letter frame(s) prior to target presentation. For analysis purposes, trials in the no-distractor condition were randomly assigned lag values, but the distractor was omitted from the sequence. Across trials, each distractor type appeared equally often at each possible lag.

The experiment consisted of 24 practice trials followed by 10 blocks of 48 trials. Subjects received written and oral instructions regarding the nature of the stimuli and task. They were fully informed with respect to the various distractor conditions, and were explicitly encouraged to ignore the distractor if possible. Each trial was initiated by a press of the spacebar. After the trial sequence, subjects identified the target by typing in their response on the computer keyboard. They were instructed to guess if they were unsure of the identity of the target. A 250 ms, 500 Hz feedback tone was generated on error trials.

Results

Mean proportions of correct target identifications as a function of distractor condition and distractor-target lag, collapsed across target colour, are presented in Figure 2. These data were subjected to a mixed analysis of variance (ANOVA) with target colour (red and green) as the single between-subjects variable, and distractor condition (no-, same-colour, and different-colour) and distractor-target lag (1–8) as the within-subjects variables. Neither the main effect of target colour nor any of its interactions with other variables was significant. The analysis yielded significant main effects of distractor condition, $F(2, 72) = 66.10$, $MSE = 0.033$, $p < .0001$, and distractor-target lag, $F(7, 252) = 12.30$, $MSE = 0.097$, $p < .0001$, and a significant distractor condition by distractor-target lag interaction, $F(14, 504) = 8.27$, $MSE = 0.061$, $p < .0001$. Simple effects analyses yielded significant effects of distractor condition for lags 1–7, $p < .001$ for lags 1–6; $p < .05$ for lag 7. Tukey tests (alpha = .05) revealed a significant difference between same-colour distractor condition and both the no-distractor and different-colour distractor conditions at each lag. The latter two conditions did not differ from one another at any lag.

Discussion

As is quite evident in Figure 2, a brief, irrelevant change in the outline box to the colour of the target produced a significant decrement in target identification relative to the no-distractor control condition. Moreover, the magnitude of this effect varied systematically with the distractor-target lag. Together, these results indicate that a to-be-ignored, irrelevant event can produce an AB, and thus provide strong evidence for the capture of nonspatial attention by a specific event. In addition, the fact that distractors different in colour from the target had virtually no effect on performance

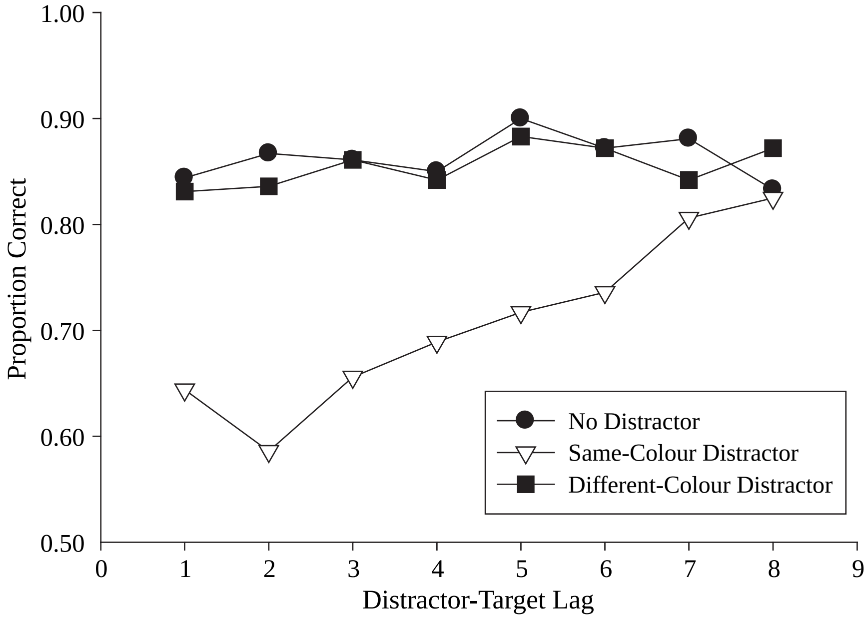

Figure 2. Mean proportion of correct target identification as a function of distractor condition and distractor-target lag in Experiment 1.

relative to the no-distractor control condition provides evidence that contingent attentional capture extends to the temporal, as well as spatial, domain. Note also that the lack of an effect in the different-colour distractor condition argues against the possibility that the effect observed in the same-colour condition might reflect the voluntary allocation of attention to any salient, unexpected event.

Although the decrement in performance in the same-colour distractor condition is consistent with the contingent capture of nonspatial attention, there are at least two alternative interpretations that must be ruled out. One possibility is that given the rapid presentation of stimuli, illusory conjunctions occurred, such that the colour of the distractor frame was miscombined with the identity of a nontarget letter in the stream to produce an "illusory target". Subjects may then have voluntarily selected this illusory target, which, in turn, would produce a traditional AB, rather than an involuntary, capture-based blink.[1] There are several reasons why this interpretation is highly unlikely. First, illusory conjunctions typically require that attention is diverted from the contributing stimuli (Treisman & Schmidt, 1982). In the present experiments, spatial attention was fully

[1] This possibility was suggested to us by Tom Spalek.

focused on the characters appearing at fixation. Thus, one might a priori expect the illusory conjunction rate to be low. Second, and more importantly, if subjects were perceiving illusory targets, then performance should be affected not only at short distractor-target lags (due to an AB), but also at long lags. Consider the case where the lag is long enough that the AB is no longer affecting performance. Under these circumstances, subjects would perceive both the illusory target associated with the distractor, as well as the "true" target, because the true target appears after the AB is over. Thus, with two targets, one would expect the illusory target to be reported on at least some subset of trials, producing a significant drop in performance relative to no-distractor conditions (where there is no possibility of an illusory target). As is evident in Figure 2, as well as the statistical analyses, there is no hint of such an effect in the data. Finally, if, at long lags, subjects functionally perceive two targets in the stream, and are confused about which one to report, one might expect at least some of the subjects to request clarification from the experimenter about whether to report the "first" target or the "second" target. None of the subjects in this experiment or subsequent experiments spontaneously mentioned anything about perceiving two targets.

A second alternative interpretation concerns the possibility that the distractor effects in the present experiment reflect a form of forward masking in which presenting a surrounding frame of the same colour as the target might render the target less perceptually discriminable, especially when the frame and the target appear in close temporal proximity.

In order to distinguish between a masking account and a contingent capture account, and to further test the influence of top-down set, in Experiment 2 we took advantage of the distinction, discussed above, between *feature* and *singleton* search modes (Bacon & Egeth, 1994). Whereas in the first experiment subjects were encouraged to adopt feature search mode by virtue of the fact that the nontarget letters varied randomly in colour, in the second experiment we encouraged subjects to use singleton search mode by (1) presenting all nontarget colours in grey (so that the coloured target was a singleton over time), and (2) varying the target colour unpredictably between red and green across trials. Given that subjects could not predict with any certainty the particular colour of the target on a given trial, it was assumed that attentional control settings would likely be set generally for the "coloured letter" (i.e., a colour singleton) rather than a letter of a particular colour.

The logic of this design is as follows. If the distractor effects observed in Experiment 1 reflect same-colour forward masking of the target by the distractor, then in Experiment 2, target identification should only be affected on those trials in which the distractor and target are the same colour. If, on the other hand, the distractor effects observed in Experiment 1 reflect the capture of nonspatial attention by virtue of a match between the distractor property and top-down attentional control settings, then target identification should be affected regardless whether of the specific colours of distractor and target match. This latter prediction is based on the fact that because subjects are forced into singleton detection mode, any colour singleton distractor should capture attention.

EXPERIMENT 2

Method

Subjects. Twenty-three undergraduate students from Villanova University participated in a single, 50-min experimental session for credit towards fulfilment of a class research requirement. All had self-reported normal or corrected-to-normal visual acuity and colour vision. None of the subjects had participated in Experiment 1.

Apparatus and stimuli. The apparatus and stimuli were identical to those used in Experiment 1.

Design and procedure. The design and procedure were similar to Experiment 1 with two exceptions. First, in contrast to Experiment 1 where the colour of nontarget letters varied randomly, the colour of each nontarget letter in the present experiment was held constant at grey. Second, instead of varying target colour across subjects, target colour was mixed within blocks such that half the trials in each block contained a red target and half contained a green target.

Results

Mean proportion of correct target identifications as a function of distractor condition and distractor-target lag, collapsed across target colour, are presented in Figure 3. The data were subjected to a mixed analysis of variance (ANOVA) with target colour (red and green) as the single between-subjects variable, and distractor condition (no-, same-colour, and different-colour) and distractor-target lag (1–8) as the within-subjects variables. Neither the main effect of target colour nor any of its interactions with other variables was significant. The main effects of distractor condition and lag were both significant, $F(2, 44) = 5.23$, $MSE = 0.047$, $p < .01$ for distractor condition, and $F(7, 154) = 8.22$, $MSE = 0.012$, $p < .0001$ for lag. The interaction was also significant, $F(14, 308) = 3.23$, $MSE = 0.009$, $p < .001$.

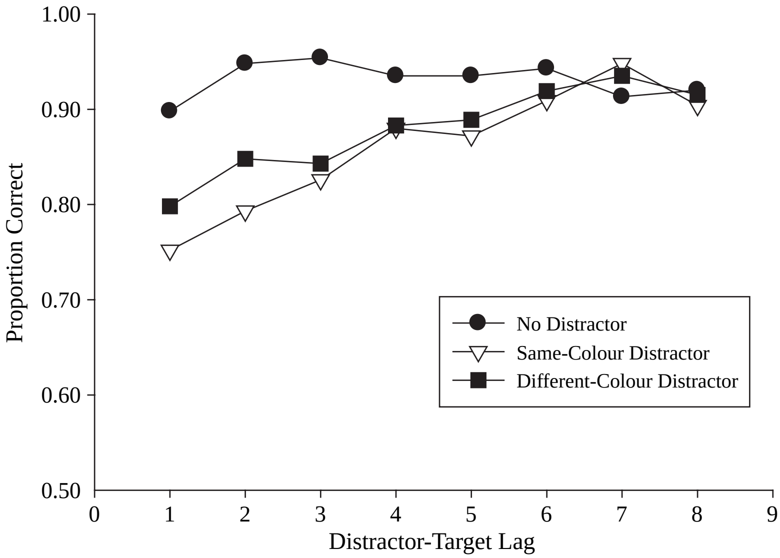

Figure 3. Mean proportion of correct target identification as a function of distractor condition and distractor-target lag in Experiment 2.

Simple effects analyses yielded significant effects of distractor type at lags 1–3 only ($p < .01$). Tukey tests (alpha = .05) on the means at these three lags yielded a consistent pattern, with significant differences between the no-distractor condition and same- and different-colour distractor conditions, but no significant difference between the means of the latter two. The only exception was the different-colour condition at lag 2 which just barely missed the Tukey critical difference criterion when compared to the mean for the no-distractor condition.

Discussion

In contrast to the results of Experiment 1, the present experiment yielded significant distractor effects for both same- and different-colour distractors. This pattern rules out the possibility that the distractor effects observed in Experiment 1 reflect same-colour forward masking. If same-colour masking were the mechanism, then only the same colour distractor condition should have produced a decrement in target report. However, the obtained pattern is precisely what is predicted by the contingent capture account. Specifically, when subjects are encouraged to adopt into singleton detection mode, then any colour singleton distractor should produce evidence of capture, regardless of whether the specific colours match or not.

There are several other aspects of the results of Experiment 2 that are worth noting. First, overall performance was higher than in Experiment 1. This is not surprising given that the targets in Experiment 2 were colour singletons in a stream of grey letters rather than a specific colour among randomly coloured letters as in Experiment 1. Second, both the magnitude and the time course of the AB were reduced relative to Experiment 1. Same-colour distractors in Experiment 1 produced an average 15.7% drop in performance and yielded significant effects out to lag 7, whereas same-colour distractors in Experiment 2 produced an average 7.4% drop in performance, and failed to produce significant effects beyond lag 3. This variation in the magnitude of the AB with task difficulty is consistent with much previous work on the AB (e.g., Grandison, Ghirardelli, & Egeth, 1997; Ouimet & Jolicoeur, in press; Seiffert & Di Lollo, 1997; Ward, Duncan, & Shapiro, 1997). Interestingly, these previous studies are based on variations in T1 difficulty, whereas the current studies vary with respect to the difficulty of detecting what would be T2 in the traditional paradigm. However, McLaughlin, Shore, and Klein (2001) found that T1 difficulty affects the magnitude of the AB only when difficulty is varied across blocks, suggesting that it is the *expectation* of difficulty that is crucial. Thus, it may have been a similar expectation regarding the detectability of the target that is driving the difference in the magnitude of the distractor effect in the present experiments.

EXPERIMENT 3

The first two experiments show that an irrelevant central distractor that matches the top-down attentional control setting for the target produces a decrement in target report that is time-locked to the presentation of the distractor. We have interpreted this effect as the involuntary attentional selection of the stimulus appearing simultaneous with the distractor, which then produces an AB for the target. In other words, we suggest that the data support contingent, nonspatial attentional capture. However, one might argue that although the frame in which the RSVP stream appears is centred at fixation, it nonetheless is slightly larger than the letters, and therefore appears more peripherally than the letters. Thus, perhaps instead of producing nonspatial selection, the distractor's appearance may cause the involuntary "dispersion" of spatial attention. Previous research suggests that under some circumstances, spatial attention is analogous to a "zoom lens" that can contract and expand, producing concomitant increases and decreases in "resolving power" (e.g., Eriksen & Yeh, 1985). It is therefore possible that in the first two experiments, the abrupt change in the colour of the distractor resulted in an involuntary expansion of the spatial attention spotlight, thereby decreasing resolving power needed to identify the subsequent target.

To address this issue, Experiment 2 was replicated with one critical addition. On critical trials in each distractor condition, a grey "prime" letter, consisting of the same letter as the subsequent target, appeared in the letter stream simultaneously with the presentation of the distractor (or at the dummy-coded lag in the no-distractor condition). We reasoned that if the distractor produces the involuntary selection of the character appearing simultaneous with the distractor, a larger priming effect (i.e., prime trials minus no-prime trials) should emerge relative to the prime manipulation on no-distractor trials. If, however, the distractor simply results in the expansion of spatial attention, then the prime letter should not be "selected" and any priming effects should therefore be no larger than that observed in the no-distractor condition. In fact, one might predict that any obtained priming effects should be *smaller* than those in the no-distractor condition if the presence of a distractor withdraws spatial attentional resources from the stream.

Method

Subjects. Twenty-four undergraduate students from Villanova University participated in this experiment. None had participated in the previous experiments. All had self-reported normal or corrected-to-normal visual acuity and colour vision.

Apparatus and stimuli. The apparatus and stimuli were identical to those used in Experiment 2.

Design and procedure. The design and procedure were identical to Experiment 2 except that on three-quarters of the trials in each distractor condition, a grey prime letter, consisting of the same letter as the subsequent target, appeared simultaneously with the distractor (or at the dummy coded lag in the no-distractor condition).

Results

Mean proportion of correct target identifications as a function of distractor condition and distractor-target lag, collapsed across target colour, are presented in Figure 4a for no-prime trials and in 4b for prime trials. The data were subjected to a mixed ANOVA with target colour as the between subjects variable, and distractor condition (no distractor, same colour distractor, different colour distractor), distractor-target lag (1–8), and prime status (prime, no prime) as the within-subjects variables. Neither the main effect of target colour nor any of its interactions with other variables

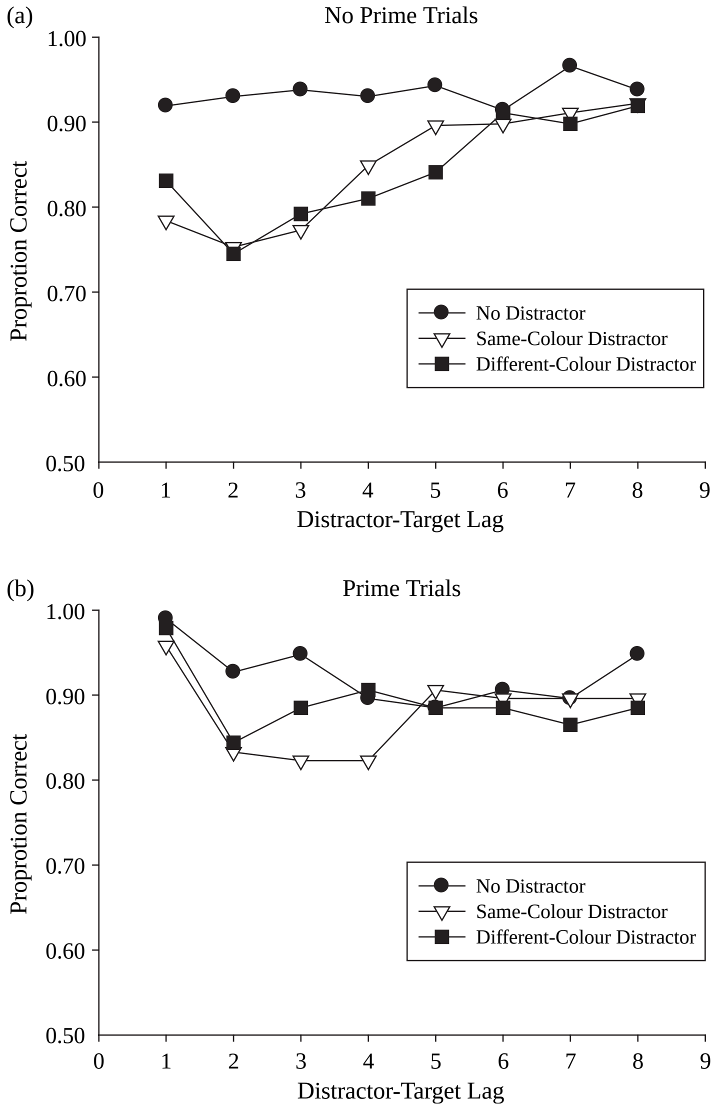

Figure 4. Mean proportion of correct target identification as a function of distractor condition and distractor-target lag for no prime trials (a) and prime trials (b) in Experiment 3.

was significant. The main effect of distractor condition was significant, $F(2, 46) = 14.00$, $MSE = 0.524$, $p < .001$. The main effect of lag was also significant, $F(7, 161) = 5.62$, $MSE = 0.113$, $p < .001$, as was the interaction of distractor condition and lag, $F(14, 322) = 2.837$, $MSE = 0.040$, $p < .001$. These effects are generally consistent with the results of Experiment 2.

Turning to the effects of the prime manipulation, the main effect of prime status was significant, $F(1, 23) = 9.73$, $MSE = 0.152$, $p < .01$, with significantly higher performance on prime trials versus no-prime trials. Prime status also interacted significantly with distractor-target lag, $F(7, 161) = 7.69$, $MSE = 0.109$, $p < .001$. As is evident in Figure 4, this interaction reflects the fact that the lag functions in the prime conditions are generally "flatter" than those in the no-prime conditions. This is especially true for the same- and different-colour distractor conditions, suggesting that primes appearing simultaneously with the distractors mitigated the effects of those distractors on target report. However, the three-way interaction between prime status, distractor condition, and lag failed to reach significance.

Most importantly for the present purposes, the priming effect also varied as a function of distractor condition, as indicated by a significant interaction between prime status and distractor condition, $F(2, 46) = 9.03$, $MSE = 0.087$, $p < .001$. Simple effects analyses confirmed what is evident in Figure 5; the presence of a prime had no significant effect on performance in the no-distractor condition, but significantly improved performance in both the same-and different-colour distractor conditions, $F(1, 23) = 7.23$, $MSE = 0.011$, $p < .05$, and $F(1, 23) = 17.53$, $MSE = 0.028$, $p < .001$.

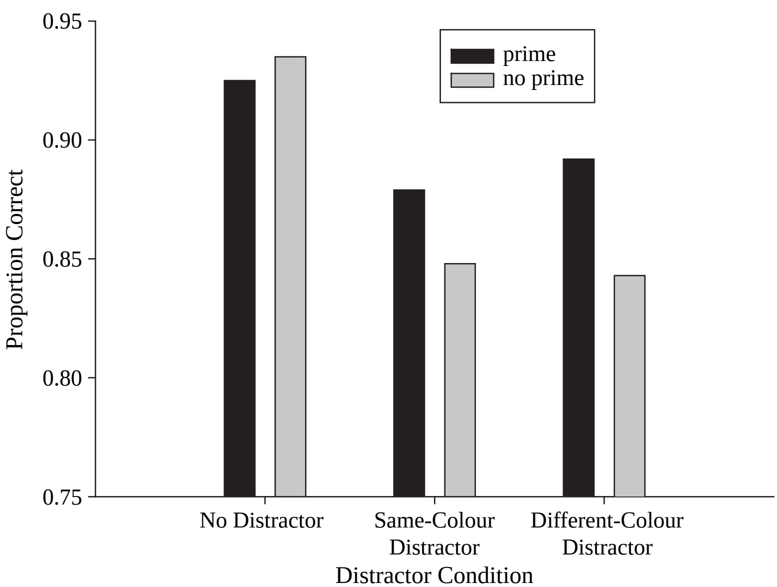

Figure 5. Mean proportion of correct target identification as a function of distractor condition and prime status in Experiment 3.

Discussion

In addition to replicating the results of Experiment 2, the present experiment provides strong evidence that the decrement in target identification produced by distractors in these experiments reflects the selection of the letter accompanying the distractor rather than a dispersion of spatial attention. If attention were simply dispersed by the distractor, then the prime should necessarily receive less spatial attention than when no distractor is present. Thus, priming effects on distractor trials should have been, at best, no larger than in the no-distractor condition. Indeed, if attention were dispersed, one might have expected priming effects to be *smaller* than those in the no-distractor condition because fewer resources would have been available to process the prime. This was clearly not the case. In fact, there is no evidence of any priming at all in the no-distractor condition (if anything, the trend is in the wrong direction—see Figure 4). Thus, given that there is no priming on trials in which attention is focused throughout the trial (i.e., when there is no distractor), it is difficult to attribute the priming observed on distractor trials to anything other than a nonspatial selection process induced by the distractor.

GENERAL DISCUSSION

It is now well established that the ability of a given stimulus to capture spatial attention is contingent on the degree to which the defining properties of the distracting stimulus match top-down attentional control settings related to behavioural goals (e.g., Folk et al., 1992). The primary objective of the present experiments was to explore whether similar principles apply to nonspatial attentional selection. Specifically, the studies were designed to provide evidence for the existence of nonspatial attentional capture, and to determine if any such capture is contingent on top-down control settings. Although several studies have explored these issues in the context of the AB paradigm, the results have been generally mixed. Some studies have shown that the degree of similarity between target and nontarget characters in an RSVP stream modulates the magnitude of the AB, suggesting that such distractors produce nonspatial capture that is contingent on the attentional set of the observer (Ghorashi et al., 2003; Maki et al., 2003; Visser et al., 2004). However, it is unclear whether these results reflect the actual capture of attention by distractors or simply a decrease in the perceptual salience of the target among similar distractors. Other studies have shown that a specific, irrelevant event in the RSVP stream can affect the AB regardless of its similarity to the defining features of the target (Dalton & Lavie, in press; Maki & Mebane, 2006; Wee & Chua, 2004). However, in each of these cases, there is some question as to whether the effects might be contaminated by voluntary attention allocation (Dalton & Lavie, in press), or truly reflect capture that is independent of top-down set (Maki & Mebane, 2006; Wee & Chua, 2004).

Nonspatial capture

The present studies were designed to critically test whether irrelevant (i.e., to-be-ignored) distractors can produce nonspatial capture, as well as to test the degree to which any such capture is contingent on the match between the defining features of the distractor, and those of the target. The results of the experiments support three general conclusions. First, the experiments provide the first clear evidence for the existence of nonspatial attentional capture. In all three experiments, irrelevant distractors appearing at the same location as the RSVP letter stream produced a significant decrement in target report that varied systematically with the temporal lag between the distractor and target. This effect bears all the hallmarks of an AB, which is widely believed to reflect the influence of the attentional selection of one stimulus on the processing of other stimuli presented close time. Given that this AB was elicited by a stimulus that was both task irrelevant (i.e., that was to be explicitly ignored), and that was highly discriminable from the actual target (i.e., a colour change of a surrounding box), the results suggest that attentional allocation to the distractor was indeed involuntary. Moreover, Experiments 2 and 3 provide converging evidence that the effects of the distractor are associated with the allocation of attention rather than perceptual masking of the target by a distractor of the same colour appearing in close temporal proximity. Specifically, when subjects were set to respond to a target defined as a colour singleton, even different-colour distractor singletons produced a decrement in target report. Thus, the effect of the distractor is tied to the attentional set of the observer rather than to specific perceptual features. Finally, the priming effects of the letter presented at the distractor position in Experiment 3 confirmed that the distractor produces nonspatial attentional selection rather than simply a dispersion of the spatial attention.

Contingencies in nonspatial capture

The second general conclusion to be drawn from these experiments is that, as in the spatial domain, involuntary, nonspatial attentional selection is contingent on top-down attentional control settings. In Experiment 1, where subjects were forced to establish a top-down control setting for a particular colour, only distractors that shared the target colour produced evidence of attentional capture. When, in Experiment 2, subjects were forced to establish a more general set for colour singletons, the same distractors that produced no evidence of capture in Experiment 1, now produced a significant decrement in target report. The fact that, across experiments, the effects of the very same distractor stimulus depended on what the subjects were looking for (i.e., a particular colour or a colour singleton) confirms that the involuntary AB observed in the present experiments is contingent on top-down attentional set. Although previous studies (e.g., Maki et al., 2003; Maki & Mebane, 2006; Visser et al., 2004) have shown that the similarity between targets and nontargets can produce variations in the *magnitude* of the attentional blink, the present studies are the first to unequivocally show that a specific, irrelevant (i.e., ignored) event in time can produce an AB that is contingent on the similarity between the defining properties of the target and the eliciting event.

The contingencies in nonspatial capture observed in the present experiments seem to be at odds with Dalton and Lavie (in press), Maki & Mebane (2006), and Wee and Chua (2004), all of whom showed that an irrelevant distractor produced a decrement in target report even when it was defined on a different dimension from the target. However, as argued above, careful consideration of the methodology and results of these studies suggest that they are ambiguous with respect to the contingency issue. In the case of Maki et al., although an irrelevant, four-character string consisting of red consonants produced an AB even when subjects were looking for a target defined by black letters, strings consisting of red digits or red false-font characters did not. Therefore, the capture effect was specific to the similarity between the distractor and target in terms of character type (i.e., "letterness") rather than colour, which is consistent with the contingent capture account of the present results. In the case of Dalton and Lavie, although an irrelevant character in a different in colour than the rest of the sequence lengthened response times for a target defined as the character different in size, it is possible that subjects had adopted "singleton search mode" (Bacon & Egeth, 1994) and were therefore searching for a discrepancy in any feature across characters rather than for a size difference in particular (i.e., "feature search mode"). Finally, in the case of Wee and Chua, the presentation of an irrelevant white box in the midst of a "traditional" dual-task AB lengthened the duration of the AB even though the target was defined by a specific colour. However, this effect was much smaller and of shorter duration than when the irrelevant box matched the target character. Moreover, it is again possible that at least some of the subjects had adopted a form of singleton detection mode, and that the presentation of an irrelevant box surrounding the stream constituted a type of singleton event that fell within this top-down setting.

Another, intriguing, interpretation of the Wee and Chua (2004) results comes from recent suggestions that the AB reflects the temporary loss of top-down attentional control settings (DiLollo, Kawahara, Ghorashi, & Enns, 2005). According to this account, the selection of T1 temporarily disrupts the maintenance of top-down control settings for targets in the stream, leaving the system vulnerable to "hijack" by subsequent stimuli. Thus, Wee and Chua's finding that an irrelevant white square captures attention in the midst of an attentional blink might be specific to cases where top-down control settings have been disrupted by T1 processing.

Interestingly, several other recent studies have shown that presentation of an irrelevant distractor during the AB actually *reduces* the magnitude of the blink (Nieuwenstein, 2006; Nieuwenstein, Chun, van der Lubbe, & Hooge, 2005; Olivers et al., in press). For example, in Nieuwenstein et al. (2005), subjects searched a stream of coloured letters for two digit targets of a particular colour (e.g., red). On critical trials, the letters preceding the second digit target were presented in the target colour. These "cue" letters, which were otherwise irrelevant to the task, improved performance on the second digit target relative to trials that contained no cue letters. Based on these results, Nieuwenstein and colleagues propose a new model of the AB in which the engagement of attention by T1 delays the attentional engagement of T2. The cue reduces the blink by capturing attention, which results in the disengagement of attention from T1 so that it is available for T2 when it appears.

How is it that the capture of attention by "same-colour" distractors produced a decrement in performance in the present studies, whereas it produced an improvement in the studies of Nieuwenstein and colleagues? We suspect that there are two key differences between the studies. First, in the present experiments, the capture of attention by the distractor puts subjects *into* an AB by engaging attention, whereas in the Nieuwenstein studies, the capture of attention by the distractor/cue presumably pulls subjects *out of* an AB that has already been produced by T1. However, Nieuwenstein et al. (2005) also found that if T1 was deleted from the stream (producing a stimulus sequence similar to that used in the present studies), the presence of the irrelevant cue letter had no effect on the report of the digit target (i.e., it produced no evidence of an AB).

Why shouldn't a same-colour distractor/cue that is not preceded by T1 produce an AB as in the present studies? A second key difference is that in the present studies, the character appearing with the distractor was from the same category (i.e., letters) as the target, whereas in the Nieuwenstein studies, the "cued" character is from a different category (i.e., letter cue, digit target). We suspect that when the distractor/cue character is from the same category as the target, attention is engaged more fully on that character, and the system is therefore less likely to disengage by the time the target appears.

When the distractor (cue) is from a different category, it is possible that more rapid disengagement occurs, and therefore AB effects are mitigated. Indeed, if the distractor/cue is from a different category *and* follows T1, then we might expect capture by the distractor to aid in the disengagement from T1 without producing much of a blink itself, thereby attenuating the AB produced by T1, as found by Nieuwenstein et al. (2005).

Attentional control settings and working memory

Although the present experiments provide clear evidence that top-down attentional control settings can influence the capture of nonspatial, in addition to spatial, attention, an important issue concerns the nature of attentional control settings. One possibility is that they consist of task-related goals that are held in working memory. Consistent with this idea, Pashler and Shiu (1999) had subjects hold an image of a specified object (e.g., a tiger) in working memory, and then presented an RSVP stream consisting of a sequence of pictures with a single target digit appearing at some point in the stream. On critical trials, a picture of the object subjects were holding in memory was presented either before or after the target digit. When the picture matching the contents of working memory appeared prior to the target, there was a significant decrement in digit detection (i.e., an AB). Such results would appear to implicate working memory representations as the source of top-down attentional control settings that guide the allocation of attention. Several recent studies have led to a similar conclusion in the context of a visual search task (Houtkamp & Roelfsema, 2006; Soto, Heinke, Humphreys, & Blanco, 2005). For example, Soto et al. (2005) found that search for a target was enhanced if it appeared within an object that matched the colour of an object held in working memory. However, several other recent studies have found no effect of working memory representations on the efficiency of visual search (Downing & Dodds, 2004; Woodman & Luck, in press). In addition, it is unclear whether the top-down control settings operating in the present studies are functionally identical to the working memory representations involved in the studies just described. Clearly additional research is needed to clarify the relationship between top-down attentional control settings and working memory.

Flexibility of attentional control

The third general conclusion to be drawn from the present results is that, just as in the spatial domain, the specificity of attentional control settings is sensitive to, and highly dependent on, task constraints. Consistent with the results of Bacon and Egeth (1994), varying the heterogeneity of the defining target dimension resulted in a change from feature search mode to singleton search mode. This, in turn, determined which distractor types elicited an involuntary AB. Specifically, in Experiment 1, subjects searched for a target defined by a specific colour among letters defined by various other colours. In this case, only distractors sharing the same specific colour as the target produced evidence of capture, consistent with the establishment of feature search mode. When, in Experiment 2, the colour of the nontarget letters in the stream was homogeneous (i.e., all grey), and the specific colour of the target was uncertain, colour distractors produced evidence of capture regardless of whether they matched the specific target colour or not, indicating that subjects had adopted singleton search mode. Thus, as in the spatial domain, top-down control settings for nonspatial selection can vary in specificity, and are determined by the constraints imposed by the task.

Relationship to other forms of distraction

One final issue concerns the specific nature of the nonspatial attentional selection produced by the distractors in these experiments. In work with spatial attentional capture, there is evidence for a form of nonspatial capture that can be dissociated from shifts in the spatial locus of attention resources. For example, Folk and Remington (1998) found that although spatial cues that did not match the target colour produced no evidence of shifts of spatial attention, they nonetheless produced an overall cost in performance relative to no-cue control conditions. They interpreted this nonspatial effect in terms of a "filtering cost" (Kahneman, Treisman, & Burkell, 1983) in which an irrelevant stimulus that competes for attention needs to be "filtered out" before a shift of attention to the target can be initiated.

Is the nonspatial capture observed in the present experiments a form of filtering cost? There are several reasons to suspect that these two effects reflect fundamentally different mechanisms. First, nonspatial filtering costs are largely eliminated when the stimuli competing for attention are presented asynchronously, and when shift of spatial attention to the target is unnecessary, such as when the spatial location of the target is known in advance (Kahneman et al., 1983). In the present experiments, distractor effects were obtained even though the distractor appeared at least 100 ms prior to the target, and the spatial location of the target was known with certainty (i.e., fixation). Second, although nonspatial filtering is assumed to "capture" resources needed for the filtering operation, it is not dependent on the selection or identification of the distractor. Indeed, one of the hallmarks of a filtering cost is that it is produced by stimuli that are highly discriminable from the target and that cannot be read and are not easy to name. In contrast, the presence of priming effects in Experiment 3 shows that the irrelevant distractor resulted in the selection and identification of the character appearing simultaneously with the distractor.

It should be pointed out, however, that it is not clear whether the selection and identification of the character appearing with the distractor is a *necessary* condition for the observed decrement in target identification. That is, the same effects may be observed if the distractor consisted of a colour change of an empty box, in which there is no character to select or identify. Thus, although the present experiments conclusively establish the existence of nonspatial attentional capture, as well as its dependence on top-down control settings, additional experiments are clearly needed to explore the precise conditions under which nonspatial attention capture emerges, and the mechanisms underlying its consequences for target identification.

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