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Irrelevant Singletons in Pop-Out Search: Attentional Capture or Filtering Costs?

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The aim of the present study was to investigate whether costs invoked by the presence of an irrelevant singleton distractor in a visual search task are due to attentional capture by the irrelevant singleton or spatially unrelated filtering costs. Measures of spatial effects were based on distance effects, compatibility effects, and differences between singleton and nonsingleton target trials. The results show that the distractor only regularly captures attention when it is nonpredictive of the target position and unpredictably changes its features. When the distractor is antipredictive of the target position and the irrelevant features of target and distractor remain constant throughout the experiment, spatially unrelated filtering costs prevail. Further experiments showed that filtering costs accrue from distractor inhibition or target activation processes, which in turn can be modeled as instances of priming of pop-out. The present study thus clarifies the notion of filtering costs and modifies present accounts of the distraction effect. Moreover, the results also relate to research of intertrial priming by showing that priming affects the stage of attentional selection and depends on top-down attentional control settings.

Keywords: attention, visual search, pop-out, filtering, priming

It is common knowledge that people cannot process and consciously perceive all information present in a visual scene. Attention selects only some items for further processing, whereas others are discarded. Given the importance of attention for perception and action, researchers around the world have taken great efforts to find out what guides attention. Attention research has been greatly influenced by studies using the visual search paradigm. In a typical visual search task, the observer has to search for a target among several other objects and to press a certain key in response.

Previous research suggests that response times (RTs) are usually affected by the number of objects in the display or the overall set size. Especially when the target is similar to the remaining objects, participants perform an inefficient or serial search. The hallmark of such searches is that search performance decreases as the overall set size is increased. In turn, the target can be found independently of the number of surrounding objects if it differs from the neighboring objects in a basic feature like, for example, color or form (Treisman, 1988; Treisman & Souther, 1985) or else if participants are highly trained for a particular search task (Shiffrin & Schneider, 1977). This independence of search performance from the overall set size has often been termed *efficient search* or *parallel search*. Such efficient searches most reliably occur in tasks in which the target constitutes a singleton (i.e., when it differs from a group of otherwise homogeneous objects in a unique feature).

The finding that efficient searches most reliably occur in the presence of singleton targets has formerly prompted salience-based explanations of attention: According to the *singleton capture hypothesis*, a salient item will usually capture attention to its position, thus ensuring that it is found as the first item in the display (Theeuwes, 1991, 1994; Theeuwes & Godijn, 2002). This process additionally was supposed to occur independently of the intentions of the observer in a purely bottom-up or stimulus-driven fashion.

However, the finding that singleton targets can be found efficiently in the above-mentioned experimental settings actually does not necessitate a singleton capture explanation. As Yantis (1998) pointed out, observers in these experiments certainly had an intention to find the target. Therefore, it is possible that the ability to conduct an efficient search depends on top-down attentional control settings (Folk, Remington, & Johnston, 1992, 1993). According to the *contingent capture hypothesis*, top-down attentional control settings allow observers to select the target singleton quickly in a goal-directed manner. The contingent capture view rejects the hypothesis that any item captures attention in a purely bottom-up way and instead proposes that objects only capture attention by virtue of their correspondence to the top-down controlled attentional sets.

Thus, as long as the target is constituted by a singleton, efficient search for the singleton target cannot indicate whether singletons can be efficiently found in virtue of bottom-up or top-down processes guiding attention. In order to eliminate these uncertainties, Yantis (1998) proposed that conclusions about bottom-up singleton capture should better be supported by experiments in which participants are required to ignore an irrelevant singleton. Only if it can be demonstrated that such a task-irrelevant singleton draws attention to its location should one conclude that the distractor indeed captured attention against the intentions or control settings of the observer.

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Today, researchers often investigate the question of bottom-up singleton capture with the help of a modified version of the visual search paradigm, which uses irrelevant singletons. The two most frequently used paradigms for assessing bottom-up capture are the irrelevant singleton paradigm (ISP) and the additional singleton paradigm (ASP). In both paradigms, participants are instructed to ignore the irrelevant singleton, and attentional capture is inferred, if it can be shown that the irrelevant singleton nevertheless has detrimental effects on search performance.

The ISP

The ISP has most frequently been used in serial search tasks, that is, in the absence of a pop-out target (see, e.g., Folk & Annett, 1994; Jonides & Yantis 1988; Turatto, Galfano, Gardini, & Mascetti, 2004; Yantis, 1988; Yantis & Egeth, 1999). In a typical ISP task, participants have to search for a complex stimulus like, for example, a letter among several heterogeneous nontarget letters and to indicate the presence or absence of the target by pressing a key. Additionally, participants are instructed to ignore a salient distractor that is, for example, constituted by one of the search elements appearing in a different color. The main difference to the ASP is constituted by the fact that this irrelevant distractor coincides with the target at chance level. The distractor thus occupies the same position as the target in 1/*d* cases, where *d* is the display size. Because the locations of target and distractor are not correlated and distractor positions are nonpredictive of target locations, there is no incentive to deliberately attend to the distractor. Attentional capture by the irrelevant singleton is inferred if the set size effect that normally accompanies serial searches is neutralized in those trials in which distractor and target occupy the same position (zero slope criterion).

Previous results with the ISP, however, indicate that most singletons do not produce such zero set size effects in the singleton target condition, in which irrelevant singleton and target occupy the same position (Yantis & Egeth, 1999). Concerning, for example, irrelevant color singletons, the set size effect for singleton target trials amounted to 40 ms/item, which was significantly different from zero. Moreover, the set size effect in singleton target trials also resembled performance in the distractor singleton condition, in which the distractor was located at one of the nontarget positions. Because the set size effect in the singleton target condition did not approach zero, Yantis and Egeth (1999) concluded that their results were incompatible with the hypothesis that singletons involuntarily capture the attention of the observer.

However, the zero slope criterion has also been subject to criticism: On the one hand, it might be argued that the absence of a set size effect at singleton target trials does not necessarily indicate involuntary bottom-up capture of the irrelevant singleton. Instead, such a result is also compatible with the hypothesis that observers deliberately took the distractor as a convenient starting point in their search, thus letting the irrelevant singleton decide where to begin their search (landmark effect). In this case, zero slope at singleton target trials would not be due to attentional capture of the irrelevant singleton but to the observer's deliberate choice to begin search at the singleton position.

Whereas these remarks indicate that the zero slope criterion might not be sufficient for involuntary attentional capture, other researchers criticized that the zero slope criterion would be too strict: As Turatto et al. (2004) argued, singletons might have effects on attention that do not result in a zero slope. Thus, for example, the ISP cannot rule out the possibility that attention is involuntarily guided by salient items even though it may not be captured (attentional misguidance effect; Todd & Kramer, 1994).

In order to circumvent these problems, in the present study, I did not use the zero slope criterion but instead used a pop-out search task, in which no set size effects were to be expected. In such a search task, attentional capture by an irrelevant singleton is normally inferred if search commences faster in trials in which the target and irrelevant singleton share a position than when target and distractor singleton occupy different positions (Theeuwes & Godijn, 2002; Turatto et al., 2004). Following the tradition of Yantis and Egeth (1999), trials in which target and distractor singleton share a position will be called *singleton target trials*, whereas trials in which target and distractor occupy different locations will be called *nonsingleton target trials*.

The ASP

Originally, the ASP was introduced to investigate more closely whether and to what extent participants are able to ignore an irrelevant distractor. As Theeuwes and Burger (1998) emphasized, the ASP directly tests whether participants are able to adopt an attentional set that matches only the target but not the distractor, which in turn allows immediate and efficient target selection.

In a typical application of the ASP, the observer has to search for a certain singleton target, whereas in half of all trials, an irrelevant singleton on a different dimension has to be ignored. The main difference to the ISP is constituted by the fact that the irrelevant singleton in the ASP never coincides with the target position.

In one of Theeuwes's (1992) experiments, one group of observers had to search for a green circle among four, six, or eight green diamond shapes in a circular array. Participants had to report the orientation of a line located inside the target form singleton, whereas simultaneously, an irrelevant color distractor had to be ignored. A second group of observers had to search for a green circle among red diamond objects and ignore an irrelevant form singleton distractor. Theeuwes (1992) found that during efficient search, the irrelevant color singleton disrupted search performance for the form singleton target but that the presence of a salient form could not influence search for a unique color target. Theeuwes (1992) concluded that selection processes at the preattentive stage are not subject to top-down control settings but are mainly determined by bottom-up influences. According to Theeuwes (1992), spatial attention is generally first guided to locations that show the greatest bottom-up activation that are generated by feature difference signals in certain locations. As was shown in further experiments, participants were obviously not able to ignore the irrelevant singleton once its activation levels exceeded those produced by the target. This finding constitutes a strong argument for salience-based explanations of the distractor effect.

One of the most damaging criticisms to the ASP concerns the fact that the distractor effect might not be due to attentional shifts to the location of the distractor but rather to filtering costs. As Folk and Remington (1998) pointed out, the ASP does not possess the means to measure spatially specific effects. Therefore, it is conceivable that salient objects induce longer RTs without eliciting a shift of attention to their position. Such spatially unspecific filtering costs could indeed be found in a cuing variant of the ISP (Folk & Remington, 1998). In this study, spatial attention was only deployed to irrelevant distractors that had the same features as a predefined target. Further experiments demonstrated that even distractors that did not elicit an attention shift to their location impaired performance, when compared with a distractor-absent control condition.

Folk and Remington (1998) speculated that these spatially unselective costs produced by dissimilar distractors could be akin to filtering costs observed with task-irrelevant distractors that are highly discriminable from the target (Kahneman, Treisman, & Burkell, 1983; Treisman, Kahneman, & Burkell, 1983). According to Folk and Remington's account, salient objects do not necessarily elicit an attentional shift to their location but induce longer RTs in the same way that the presence of any irrelevant object prolongs RTs compared with a condition in which the target appears in isolation. Such costs could, for example, be due to the fact that even highly dissimilar objects compete for attentional selection and thus slow down the process of allocating attention to the target (Kahneman & Treisman, 1984; Kahneman et al., 1983; Treisman, Kahneman, & Burkell, 1983).

The aim of the present study was to compare the ISP and ASP with respect to the question of whether the distractor effect is due to the fact that the irrelevant singleton draws spatial attention to its position or whether its effect is rather nonspatial. Moreover, if spatially unselective filtering costs occurred, the results should lead to a clarification of the concept of filtering: So far, costs arising in the distractor-present condition have been generally interpreted as reflecting attentional capture (Theeuwes, 1991, 1992, 1994), which left the notion of filtering costs considerably vague.

As already indicated, distraction costs in both ASP and ISP have been attributed alike to involuntary attention shifts to the distractor. However, it might also be doubted whether results obtained with the ASP and ISP reflect the same underlying processes. Several differences between the ASP and ISP point to the possibility that different mechanisms might account for the distraction costs. First of all, it should be noted that the instruction to the participants in the ASP and ISP only looks identical: In both cases, participants have to ignore the irrelevant distractor. However, given the different designs, this instruction actually results in two different tasks: Whereas participants in the ISP have to ignore a difference in a feature like color, in the ASP, an odd-colored object must be ignored. This at least holds if participants always are striving for a strategy that promises optimal performance. However, such differences in the task might result in different performance in the ISP and ASP, for instance, if hard-wired mechanisms favor attentional rejection of objects over features (Kahneman & Treisman, 1984).

Second, the irrelevant singleton is uncorrelated with the target position in the ISP, whereas it is actually antipredictive of the target position in the ASP. Participants in turn might tune their attentional control settings such as to select the irrelevant distractor according to its probability to occupy the same position as the target. Such an effect of informativity on search performance was found in an experiment using a serial search task in which the singleton distractor could coincide with the target at chance level ($1/d$), at half this probability ($1/2d$), or at twice this probability ($2/d$; Yantis & Egeth, 1999): As the informativity of the distractor increased from $1/2d$ to $2/d$, RTs to singleton target trials gradually decreased, while at the same time, costs for nonsingleton target trials increased. If the deployment of attention to the singleton distractor is always modulated by the predictivity of the singleton with respect to the target location, the ISP and ASP should show similar differences in attentional selection (but see also Olivers & Humphreys, 2003).

Third, in the ISP but not in the ASP, the target changes its color in the singleton target trials, with the nontargets being presented in the former target color and the target adopting the color that was previously associated with the distractors. Such switches in the features of the target have been demonstrated to produce costs even when the concerned feature is task irrelevant (Found & Müller, 1996; Hillstrom, 2000; Huang, Holcombe, & Pashler, 2004; Olivers & Humphreys, 2003). In the ISP, these changes in the target feature might lead to enhanced attentional selection of the distractor in those trials that immediately follow the singleton target trial, because the singleton distractor inherits the feature of the former target in those trials. In turn, attentional capture of the irrelevant singleton might be reduced or even absent in the ASP in which the features of target and distractor remain constant and are known in advance. In order to overcome these problems, I included a feature certainty and uncertainty condition in the present experiments: Whereas the colors varied unpredictably from trial to trial in the feature uncertainty condition, the assignment of colors to the irrelevant singleton and the remaining items was held constant in the feature certainty condition. This was done to ensure that changes of the target feature also occur, and can be assessed, within the scope of the ASP.

The critical remarks mentioned above conjointly point to the possibility that attentional capture might only occur in the ISP but not in the ASP, which in turn might be more prone to filtering effects. Whereas the first two points indicate that attentional capture in the ISP might be top-down controlled, the last remark suggests that attentional selection of the irrelevant distractor might be induced by bottom-up processes. In order to compare search performance between ASP and ISP with respect to these processes, I had participants search for a size singleton target and they were instructed to ignore an irrelevant singleton in the color dimension. The first experiment tested search performance in the ASP and ISP in a feature uncertainty condition, whereas the second experiment reified the feature certainty condition for both paradigms. With the help of the standardly used distractor-absent control conditions, the first experiment allowed an evaluation of the relative amounts of spatially unspecific filtering costs and attentional capture. Experiment 3 was designed to allow a more precise assessment of the role of intertrial contingencies in attentional capture versus filtering costs in the ASP and ISP. To that end, only performance in the distractor-present condition of the ASP and ISP was measured. Intertrial analyses were applied to the data in order to allow inferences about favorable and unfavorable conditions of attentional capture from the respective distributions of spatially selective and nonselective effects. Experiment 4 was designed such as to eliminate possible confounds between bottom-up and top-down manipulations between the ISP and ASP. This allowed comparisons of the two paradigms of visual search under highly similar conditions.

Given the priorities of the present investigation, the initial challenge was to find a method to distinguish attentional capture from spatially unrelated filtering costs. Three independent measures were invoked in order to accomplish that goal, which will be further discussed in the next section.

Comparing Singleton With Nonsingleton Target Trials in the ISP

Spatial effects can be better evaluated by invoking the ISP, because the comparison of singleton target trials and nonsingleton target trials provides a measure of spatially selective effects. In the following section, the singleton target trials will be called *P0* trials and those trials in which distractor and target occupy different positions will be called $P > 0$ trials (Turatto et al., 2004).

There is already some precedence for using comparisons of P0 with P > 0 trials in the ISP as a measure for attentional capture in pop-out searches. In a visual search task for a form singleton target, Theeuwes and Godijn (2002) observed significant benefits in the P0 condition in which target and an irrelevant color distractor occupied the same position. The significant differences between P0 and P > 0 trials were then attributed to attentional capture by the irrelevant distractor.

In the present study, the criterion for spatially selective effects was somewhat tightened: Attentional capture in the ISP should only be inferred if decrements in performance in the distractor-present condition compared with the distractor-absent condition could be attributed to differences between the P0 and the P > 0 trials. This criterion was invoked in order to pay tribute to one uncertainty attached with the notion of filtering costs: First, filtering processes might either be bound to the mere presence of a distractor, that is, they might equally apply to both P0 and P > 0 trials alike (Folk & Remington, 1998). Second, filtering processes might also in part show spatial dependence, that is, they might only occur in P > 0 trials but not in P0 trials in which both target and distractor singleton are located in one position, and thus no competition for selection occurs (Kahneman & Treisman, 1984; see also redundancy gain in Krummenacher, Müller, & Heller, 2002). All that can be said with certainty is that filtering will prevent attentional capture, which will reduce differences between P0 and P > 0 trials. Additionally, filtering costs will simultaneously increase differences between distractor-absent and distractor-present trials. A prevalence of filtering costs over instances of attentional capture in the data should thus become evident in large differences between distractor-absent and distractor-present trials, which are not paralleled by equal differences between P0 and P > 0 trials. Thus, the existence of attentional capture should only be inferred if differences in the spatial measures matched those observed between distractor-present and distractor-absent conditions.

The requirement of costs obtained in the distractor-present condition to be attributable to spatially selective costs and benefits in the P0 and the P > 0 condition was taken as the hard criterion that would decide the question of whether attentional capture could account for the overall distraction costs produced by the mere presence of an irrelevant distractor. However, this comparison is not applicable in the realm of the ASP. In order to distinguish spatially selective and unselective effects in the ASP, I took the compatibility effect and the distance effect as auxiliary spatial measures. However, the criteria associated with these measures first had to comply with this hard criterion in the ISP in order to demonstrate their reliability.

The Compatibility Effect

As mentioned before, one of the most damaging criticisms to the ASP concerns the fact that it does not allow separating effects of attentional capture from location unspecific filtering costs. As a remedy, Theeuwes and Burger (1998) included an additional factor into the ASP paradigm designed to measure identity intrusion or compatibility effects between irrelevant distractor and target. To that aim, items in the distractor were constructed such that they could be compatible or incompatible with the target at the response level. The authors reasoned that the presence of a compatibility effect would indicate attentional capture by the irrelevant singleton because, apparently, its identity interfered with that of the target.

Following this line of reasoning, the distractor items in the present study were designed such as to be compatible or incompatible with the target at the response level. With this design, response compatibility effects could be taken as an auxiliary measure for attentional capture.

However, this method of measuring attentional selective effects might also be subject to criticism. First of all, it might be doubted that compatibility effects indeed show that the irrelevant distractor received attention: After all, compatibility effects could also be attributable to flanker effects. If, for example, compatibility effects only occurred when the irrelevant distractor appeared in close proximity to the target, one would infer that flanker effects accounted for the interference instead of proposing that the irrelevant distractor interfered because it received spatial attention.

Folk and Remington (1998) also cautioned against the conclusion of attentional capture in the face of significant compatibility effects. As they pointed out, one should not preclude that identity information could influence response mechanisms in parallel or without the need to allocate spatial attention to its location (direct parameter specification; Neumann, 1989).[1]

In order to account for the difficulties with the compatibility effects as a measurement for attentional capture without overestimating them, I controlled the target distractor distance in the present experiments. Compatibility effects in the present study were consequently only reported when they were not simulta-

[1] According to the direct parameter specification hypothesis, it would be feasible that the distractor stimulus primes the response in virtue of its similarity with the response-relevant target. The danger of these response-priming effects contaminating experimental data is especially high if only two objects are present in the display or if only the singleton distractor and target items ever contain response-relevant features while all other objects contain neutral items (that are not associated to any responses). In order to preclude such a mechanism, in the present study I ensured that every object included the same response items as target and distractor. Moreover, the number of right- and left-oriented distractor lines was controlled: Every display thus contained equal numbers of right- and left-oriented stimuli. Because the response-relevant items were thus present in all objects, compatibility effects arising from the distractor bar can only be explained with reference to its singleton status. The luminance of the background colors of the response-relevant stimulus inside the distractor and the other items was controlled, thus ensuring that the distractor item did not enjoy a better perceptual detectability than the remaining items.

neously associated with an inverse distance effect that would point to flanker interference.

The Distance Effect

One proposal of Folk and Remington (1998) to eliminate the potential confound between filtering effects and attentional capture was to control the distance between target and distractor. They reasoned that if the irrelevant distractor indeed captured spatial attention, then the distractor effect should vary with the spatial relationship between target and distractor. More specifically, they would expect RTs to be larger with increasing target distractor distance (Folk & Remington, 1998, p. 849).

Various studies have shown that RTs to a target indeed increase as the distance to an irrelevant distractor increases (Downing, 1988; Egly & Homa, 1991; Eriksen & St. James, 1986; Handy, Kingstone, & Mangun, 1996; Hughes & Zimba, 1985; Kahneman et al., 1983; Treisman et al., 1983). This positive distance effect and its linear increase with distance often has been taken to indicate that the shifts of attention are executed at a constant speed, which results in longer RTs with greater distances to traverse (Shulman, Remington, & MacLean, 1979; Tsal, 1983). Alternatively, the results could be explained by attention taking the form of a gradient that has a peak in its center and decreases toward the periphery (Downing, 1988).

Although linear increases in RTs with growing target distractor distance could indeed be found by a number of studies using different paradigms, there is also much evidence to the contrary. Whereas in some studies no distance effects could be found at all (Cheal & Lyon, 1989; Remington & Pierce, 1984; Weichselgartner & Sperling, 1995), other experiments resulted in findings of inverse distance effects (Caputo & Guerra, 1998; Kwak, Dagenbach, & Egeth, 1991; Starreveld, Theeuwes, & Mortier, 2004). Such a reversed result pattern was also obtained by Theeuwes, Kramer, and Kingstone (2004) with the ASP. When participants searched for a form singleton target while simultaneously an irrelevant color singleton should be ignored, search performance increased as the target-distractor distance increased. As a result, some researchers have questioned the basic proposition that the time course of attention shifts is proportional to distance. Instead they claimed that attention shifts are time invariant and thus invariant to the target-distractor distance (see also Theeuwes et al., 2004; Weichselgartner & Sperling, 1995; Yantis, 1988).

This unreliableness of the distance effect as well as the theoretical uncertainties attached to it render it difficult to use the distance effect in definite predictions. On the other hand, the finding of a positive distance effect—that is, increased RTs at greater target distractor distance—would effectively rule out filtering costs as an explanation for overall RT inflations found in the distractor-present trials. Hence, the absence of a distance effect shall not be interpreted as ruling out attentional capture in the present study, whereas its presence shall serve as a diagnostic tool for attentional capture.

Experiment 1

The first experiment was designed along the lines of the ISP and ASP feature uncertainty conditions and served a double purpose: First, the relative amounts of spatially specific and unspecific distraction costs should be assessed with respect to ISP and ASP. Second, the reliability of the spatial measures of compatibility and distance effects should be assessed by comparing them with the hard criterion, which consists of comparing singleton target trials (P0) with nonsingleton target trials ($P > 0$) in the ISP.

Method

Participants. Thirty-six students from the University of Bielefeld, Germany, took part in the experiment for small monetary exchange (€3 [$3.90]). There were 16 participants in the ISP feature uncertainty condition (Experiment 1a) and 20 in the corresponding ASP condition (Experiment 1b). All participants had normal or corrected-to-normal vision and were naive as to the purpose of the experiment.

Materials. All experiments reported in this article used a standard keyboard, a microcomputer with an Intel 80486/100-MHz central processing unit, and a 15-in. (38.1-cm) computer monitor for stimulus presentation and response registration. Stimuli were presented with a resolution of 640×480 pixels and a refresh rate of 72.5 Hz. The arrow down (↓) and arrow left (←) keys of the computer keyboard were used as right and left response buttons, respectively. For event scheduling and RT measurement, the experimental runtime system ERTS (Beringer, 1996) was used.

Stimuli. The stimuli consisted of black lines tilted to the right or left by an angle of 22.5° presented on red or green colored discs with a diameter of 1°. Participants were to search for a bar that was thicker and longer than the rest of the stimuli. At a head monitor distance of 114 cm, the thick line measured $0.18° \times 1.3°$ and the thin lines measured $0.09° \times 1.1°$. Red and green colored discs were matched for luminance with a Mavolux digital photometer (25 cd/m^2) and placed on the outline of an imaginary circle with a diameter of 3.6°. All stimuli were presented on a constantly white background (100 cd/m^2) together with a small black fixation cross.

All stimuli were equally spaced from each other, beginning at the 12 o'clock position. The set size was varied blockwise between four and six stimuli in order to ensure that the target could be found by performing an efficient search. Because eccentricity was kept constant across the different set sizes, the density of the stimuli varied.

Design. The experiment consisted of the blocked 2×2 within-subjects conditions set size and distractor presence. In the distractor-absent condition, the discs that contained the oriented bars were all homogeneously colored red or green. The color of all items varied on a random basis, constituting the feature uncertainty condition. In the distractor-present condition, an irrelevant singleton distractor on the color dimension was present. The color singleton could be either red or green, with the remaining items being presented in the opposite color. In Experiment 1a with the ISP, the color singleton distractor coincided with the target location in $1/d$ trials and was therefore uncorrelated with the target position. In Experiment 1b with the ASP, the distractor never coincided with the target and was thus antipredictive of the target position. All participants were fully informed about this ratio and were instructed to ignore the irrelevant color differences.

The factors set size and distractor were both blocked, whereas the variables target-distractor distance and compatibility varied within each block. In all conditions, the two target types (left- vs. right-oriented) were presented at each target position with equal frequency. Moreover, the number of right- and left-oriented bars was controlled such that every display contained equally as many right- and left-oriented bars, excluding the target. In the distractor-present trials, the orientation of lines located inside the target and distractor items was balanced, such as to ensure equal numbers of compatible and incompatible trials, in which the lines inside the target and distractor were oriented alike versus differently. Moreover, the target-distractor distance was controlled: Each target type occurred on each position, combined with all possible target-distractor distances equally. This procedure ensured that equal numbers of trials occurred in the near and far target-distractor distance conditions, whereby the near condition included all trials in which the distractor was located in the direct vicinity of the target, whereas trials in which the target-distractor distance was greater were subsumed to the far condition.

In Experiment 1a, participants completed 64 and 72 trials each in the distractor-present and distractor-absent conditions of Set Sizes 4 and 6, respectively. In the corresponding conditions of Experiment 1b, 72 and 60 trials were completed. Possible effects arising from the order of the blocks were controlled by balancing different sequences according to a Latin square procedure. Each block was preceded by an instruction about the next block, an example, and 10 practice trials chosen randomly from the following block. On average, it took participants 30 min to complete each of the experiments.

Procedure. Each trial started with the presentation of a small black fixation cross. After 500 ms, the stimulus display consisting of the colored discs and the tilted lines was presented. Participants were required to search the display for a thick line and to press a right key when the thick line was tilted to the right and a left key when it was oriented to the left. The stimulus display remained on screen for 200 ms. This stimulus duration was chosen in order to render eye movements ineffective. After this period, a blank white screen was presented for 2,800 ms or until response. RTs longer than 3,000 ms were counted as errors. A feedback was provided on every trial and consisted of the written words *correct* or *wrong* (in German), which were presented for 1,000 ms. After an intertrial period of 750 ms, the next trial started with the presentation of the fixation cross. Participants were instructed to maintain fixation on the fixation cross throughout the presentation of the stimulus display and to prevent eye movements. Moreover, participants were instructed to respond as fast as possible without making mistakes. Figure 1 depicts an example of one trial.

Results

Data. In this and all subsequent experiments, RTs below 200 ms or above 1,500 ms were excluded from all analyses. Removing the outliers resulted in a loss of 0.15% and 0.26% of the data in Experiments 1a and 1b, respectively. One participant in the latter condition was excluded because his mean error scores exceeded 10%.

RTs. The mean RTs and errors for Experiment 1 are depicted in Table 1. RTs were first analyzed separately for Experiments 1a and 1b with a multivariate analysis of variance (MANOVA), including the variables set size (4 vs. 6), distractor (absent vs. present), spatial congruence (P0 vs. $P > 0$ trials, restricted to the ISP), target distractor distance (near vs. far), and response compatibility (compatible vs. incompatible). Concerning the ISP condition of Experiment 1a, the MANOVA showed that the different set sizes did not affect RTs, $F(1, 15) = 1.16$, $p = .30$, indicating that the target could be found by performing an efficient search. Equally, the main effect of distractor presence was not significant, $F(1, 15) = 0.2$, $p = .70$. However, the analysis yielded a significant main effect of spatial congruence, $F(1, 15) = 11.6$, $p = .004$: On average, RTs were 15 ms faster in the P0 trials ($M = 550$ ms)

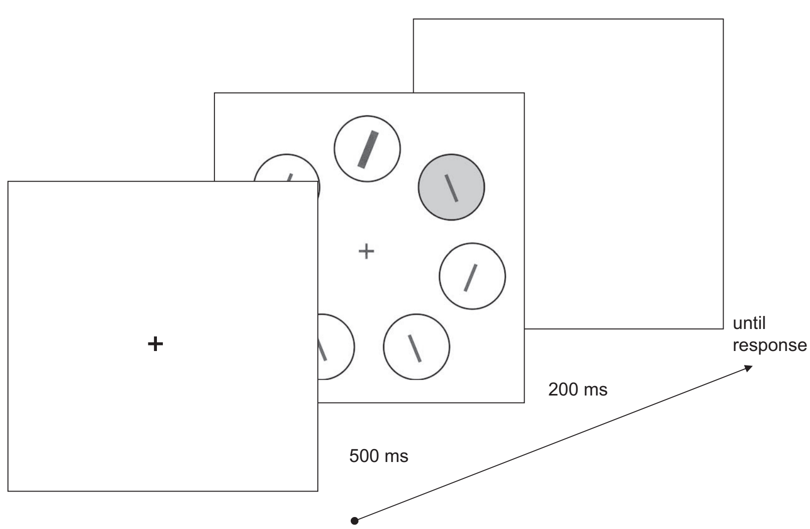

Figure 1. Example of a trial in the distractor-present condition with Set Size 7. Participants were required to find the thick line and to respond to its orientation. The gray colored disc represents the distractor (red or green) enclosed by a group of homogenously colored discs.

Table 1
Mean Reaction Times (RTs) and Error Scores for All Experiments, Separated According to the Used Set Size Distractor-Presence and Location-Specific Effects, Comparisons Between Singleton (P0) and Nonsingleton (P > 0) Trials, and Near and Far Target-Distractor Distances and Compatibility

Dependent variable	Set 1/Set 2	Absent/Present	P0/P > 0	Near/Far	Compatible/Incompatible
		Experiment 1			
ISP					
RTs	560/566	564/562	550/565*	560/569*	559/569*
Errors	1.86/1.74	1.61/1.98	2.03/1.97	1.90/2.04	1.31/2.58*
ASP					
RTs	570/566	556/579*		575/586*	578/581
Errors	1.79/1.51	1.72/1.61		1.93/1.32	1.46/1.77
		Experiment 2			
ISP					
RTs	567/573	556/583*	579/584	583/585	577/591*
Errors	1.92/1.67	1.41/2.18*	1.92/2.23	2.30/2.20	1.95/2.53
ASP					
RTs	565/570	560/575*		575/575	575/576
Errors	1.59/1.71	1.95/1.36		1.28/1.41	1.36/1.35
		Experiment 3a			
ISP					
RTs		–/533	528/534*	530/540*	529/539*
Errors		–/1.99	0.86/2.27*	2.11/2.43	2.02/2.52
ASP					
RTs		–/538		537/539	535/541
Errors		–/1.89		1.85/1.94	1.53/2.28
		Experiment 3b			
ISP					
RTs		–/588	581/592	586/598	586/598*
Errors		–/2.22	0.84/2.57*	2.82/2.31	2.37/2.76
ASP					
RTs		–/586		588/585	585/587
Errors		–/1.89		2.18/1.59	1.71/2.04
		Experiment 4			
ISP					
RTs		534/558*	547/560*	558/562	555/565*
Errors		1.30/2.18*	1.30/2.27*	2.03/2.55	1.84/2.73*
IASP					
RTs		572/587*		586/586	584/591
Errors		1.89/2.51		2.70/2.27	2.41/2.64

Note. Dashes indicate that no data were gathered in the respective condition. ISP = irrelevant singleton paradigm; ASP = additional singleton paradigm; IASP = hybrid of ISP and ASP.
* $p < .05$.

in which target and distractor shared a position than when they occupied different positions (P > 0 trials: $M = 565$ ms). Moreover, the main effect of target distractor distance proved to be significant, $F(1, 15) = 9.8$, $p = .007$, with participants responding faster when the distractor was located in the direct vicinity of the target ($M = 560$ ms) than when it was farther away ($M = 569$ ms). Last, average RTs were faster on compatible trials ($M = 559$ ms) than on incompatible trials ($M = 569$ ms), and this effect also reached significance, $F(1, 15) = 8.34$, $p = .011$.

In Experiment 1b with the ASP feature uncertainty condition, the same MANOVA (excluding the spatial congruency condition) yielded no significant effects of set size, $F(1, 18) = 0.5$, $p = .50$. The main effect of distractor presence proved to be significant, $F(1, 18) = 15.5$, $p = .001$, as RTs were 23 ms faster in the distractor-absent condition ($M = 556$ ms) than when a distractor was present ($M = 579$ ms). Concerning the spatial measures, the distance effect reached significance, $F(1, 18) = 7.1$, $p = .016$, with participants responding faster when the distractor was located near to the target ($M = 575$ ms) than when it was farther away ($M = 586$ ms). However, the compatibility effect failed to reach significance, $F(1, 18) = 0.9$, $p = .35$, as performance on compatible trials was only 3 ms faster than on incompatible trials (see also Table 1).

Errors. The same MANOVA conducted over the mean error scores of the ISP (Experiment 1a) yielded only a significant main effect of compatibility, $F(1, 15) = 6.41$, $p = .023$. None of the remaining effects approached significance (all $ps > .50$). The same MANOVA conducted over the mean error scores of the ASP (Experiment 1b) did not show any significant effects (all $ps > .15$) either.

Discussion

The observed result pattern of the ISP feature uncertainty condition (Experiment 1a) is in line with the conjecture that the irrelevant singleton captured the attention of the observer: The irrelevant singleton obviously did not incur any spatially unspecific costs indicative of filtering effects, as reflected in the zero difference between distractor-present and distractor-absent trials. In turn, significant differences could be found with respect to the different spatial positions of the irrelevant distractor, as indicated by significant spatial congruency effects and significant distance and compatibility effects. This result indicates that the distractor indeed captured the spatial attention of the observer in the ISP, whereas no evidence could be obtained for spatially unselective filtering costs.

In turn, Experiment 1b with the ASP showed significant distraction costs of 23 ms, which cannot be clearly attributed to spatially selective costs: Although a significant distance effect could be observed, no compatibility effect was found. Moreover, the error scores for the distance effect show an inverse trend, which points to the possibility of a speed–accuracy trade-off in the data. The fact that no differences between compatible and incompatible trials could be obtained indicates that the bulk of the distraction costs must be attributed to spatially unselective effects. Before selective and unselective effects in the ASP and ISP are discussed in more detail, however, the feature certainty conditions of ISP and ASP were investigated in the same way.

Experiment 2

The results of Experiment 1 were obtained under conditions in which the features of target and irrelevant distractor varied unpredictably. The aim of Experiment 2 was to examine whether the same result pattern would emerge if the properties of target and distractor were known in advance and remained constant throughout the experiments. Experiment 2 was very similar to Experiment 1, with Experiment 2a representing the ISP, and Experiment 2b representing the ASP, in a feature certainty condition.

Method

Participants. Forty-eight participants took part in the present experiments for small monetary exchange (€3 [$3.90]). Half of the participants took part in Experiment 2a in the ISP feature certainty condition and the other half took part in the ASP of Experiment 2b. In both experimental conditions, 1 participant had to be excluded because each committed more than 30% errors.

Stimuli. The stimuli of Experiment 2 were identical to Experiment 1, with the exception that the set size was slightly increased to include Set Sizes 5 and 7. The stimuli were placed equidistantly on an imaginary circle with a diameter of 4°.

Design. The overall design was very similar to the design of Experiment 1: Set size variations and distractor-present versus distractor-absent conditions were presented blockwise. In this experiment, the color of the singleton distractor was held constant throughout a block, constituting the feature certainty condition. For half of the participants, the singleton distractor was red, whereas the remaining items remained consistently green. For the other half of the participants, this color assignment was reversed. The ISP of Experiment 2a consisted of four blocks that comprised 98 and 100 trials in the Set Size 5 and 7 conditions, respectively, for each distractor-absent and distractor-present trials. In Experiment 2b with the ASP, P0 trials were excluded, yielding 80 and 84 trials in each Set Size × Distractor condition, respectively. The only difference between Experiment 2a and 2b consisted in the fact that the distractor occupied the same position as the target in $1/d$ cases in the ISP of Experiment 2a, whereas this was never the case in the ASP condition of Experiment 2b. As in the previous experiments, participants were informed about this ratio and were encouraged to ignore the color difference.

Procedure. The procedure of Experiment 2 was the same as in Experiment 1.

Results

Data. Excluding RTs greater than 1,500 ms and smaller than 200 ms resulted in a loss of 0.36% of the data in Experiment 2a and 0.32% of all data in Experiment 2b.

RTs. Mean RT and error scores for Experiment 2 are depicted in Table 1. A MANOVA comprising the variables set size, spatial congruency, target-distractor distance, and compatibility calculated over the data of the ISP feature certainty condition (Experiment 2a) showed that set size did not significantly affect RTs, $F(1, 22) = 2.2$, $p = .15$. Second, the main effect of distractor presence was significant, $F(1, 22) = 20.63$, $p = .000$. On average, mean RTs were 27 ms slower when a distractor was present in the display than when it was absent. However, there was no main effect of spatial congruency, as RTs were only 5 ms faster when target and distractor were located at the same position than when they were on different positions, $F(1, 22) = 0.5$, $p = .40$. Similarly, mean RTs were not affected by whether the distractor was located in the vicinity of the target or farther away, $F(1, 22) = 0.36$, $p = .55$. However, the effect of response compatibility was significant, $F(1, 22) = 13.18$, $p = .001$: On average, RTs were 14 ms faster on compatible ($M = 577$ ms) than on incompatible ($M = 591$ ms) trials.

The same analysis conducted over the mean RTs of Experiment 2b of the ASP showed no significant effect of set size, $F(1, 22) = 0.5$, $p = .49$, but a significant effect of distractor presence, $F(1, 22) = 6.1$, $p = .022$: On average, RTs were 15 ms longer in the presence of an irrelevant distractor. Concerning the spatially specific measures, the distance effect failed to reach significance, $F(1, 22) = 0.0$, $p = .90$. Similarly, no significant compatibility effect was obtained, $F(1, 22) = 0.17$, $p = .69$.

Errors. The same analysis was conducted over the error scores of Experiments 2a and 2b. Concerning the ISP feature certainty condition of Experiment 2a, the MANOVA only showed a significant effect of distractor presence, $F(1, 22) = 6.21$, $p = .021$, with more errors in the distractor-present than in the distractor-absent condition. The remaining effects were not significant (all $ps > .20$). The same

MANOVA conducted over the mean error scores of Experiment 2b did not indicate any significant effects (all *p*s $> .13$).

Discussion

In the ISP feature certainty condition of Experiment 2, large distraction costs of 27 ms could be found. However, these distraction costs cannot be attributed to spatially selective effects, because no significant differences between target (P0) and nontarget singleton trials (P > 0) occurred. The finding of nonsignificant positive trends for spatial congruency as well as the finding of significant compatibility effect probably indicates that the distractor captured attention on a certain portion of trials. However, a major part of the overall distraction costs in the ISP feature certainty condition must be attributed to spatially unselective filtering costs.

In a similar vein, the ASP of Experiment 2 also yielded significant distraction costs of 15 ms, which were neither modulated by spatial relations between target or distractor nor were modulated by the compatibility of the response-relevant items. Therefore, it must be concluded that the distraction costs in the ASP cannot be attributed to spatially selective effects.

Summary for Experiments 1 and 2

The results from the first experiments can be summarized as follows: First, applying spatial measures to the visual search paradigms showed that attentional capture can only fully account for the distraction effect in the ISP feature uncertainty condition (Experiment 1a). In the corresponding condition of the ASP (Experiment 1b), the result pattern was somewhat mixed: Spatially selective effects could have been due to attentional capture or to a speed–accuracy trade-off. Although attentional capture might have occurred to a certain extent, the overall distraction costs could not be attributed to spatially selective effects. Similarly, in the feature certainty conditions of ISP and ASP (Experiments 2a and 2b, respectively), the bulk of the overall costs produced by the singleton distractor have to be ascribed to spatially unspecific filtering costs.

The finding that spatially unspecific filtering costs indeed exist in visual search tasks with an irrelevant singleton lends empirical support to the filtering hypothesis of Folk and Remington (1998). However, the finding that spatially specific effects were restricted to the ISP feature uncertainty condition and did not play a role in the ISP feature certainty condition or in any of the conditions of the ASP is somewhat unexpected in light of earlier conjectures. More precisely, the results appear to be incompatible with a purely top-down or bottom-up account of filtering versus attentional capture: With regard to possible bottom-up influences on attentional capture arising from changes of the irrelevant feature, the feature uncertainty conditions of both ASP and ISP should have exhibited greater amounts of attentional capture than the corresponding feature certainty conditions of both paradigms. On the other hand, presupposing a prevalence of top-down influences like, for example, informativity, on attentional capture, one would have expected attentional capture to occur to a greater extent in the ISP than in the ASP. The finding that attentional capture only occurred to a large extent in the ISP feature uncertainty condition is thus difficult to reconcile with either bottom-up or top-down controlled processes, if these are considered in isolation.

Instead, it is proposed that the result pattern can be explained by assuming an interaction between top-down and bottom-up controlled processes. The finding that spatially specific and unspecific distraction costs were dissociated from each other suggests that filtering serves the purpose of preventing attentional capture by the irrelevant singleton. Counteracting attentional capture could be done either by inhibition of the irrelevant feature or by activation of the target feature. (As the present experiments cannot distinguish between processes of target activation and distractor inhibition, I will sometimes refer to inhibition processes instead of both processes.) In order to account for the absence of filtering costs in Experiment 1a, it must be assumed that the occurrence of inhibition depends on the goals or intentions of the observers. More precisely, when participants are given information about the properties of either the distractor (as in both AS paradigms) or more frequent target features (as in the ISP feature certainty condition), this information forms part of the attentional control settings, which in turn determine whether inhibition of irrelevant features will occur. For example, if participants know about the antipredictivity of the distractor in the ASP, this could constitute an incentive to inhibit the odd-one-out feature at the beginning of search, which in turn leads to a prevalence of filtering costs. Similarly, in the feature certainty condition of the ISP, participants knew that the target would possess the more frequent color in a majority of trials, which presumably led to the same result. In turn, in Experiment 1a, participants were warned that both the colors of the singleton distractor and the remaining items switched, and they were informed that target and distractor would occupy the same position in 1/*d* cases. Thus, there was no incentive for the participants to adjust their attentional control settings either to the features of the irrelevant object or to the target features. Given these conditions, the target and distractor singleton equally competed for attention in all trials, with the distractor frequently receiving spatial attention. In all other experimental conditions, the participants were given information either about more frequent properties of the target and the distractor or about the antipredictivity of the distractor. This knowledge might in turn have induced participants to inhibit the irrelevant distractor, which in turn prevented attention shifts to its position but incurred inhibition or suppression costs instead (Duncan & Humphreys, 1989; Treisman & Sato, 1990). Assuming that inhibition is itself a time-consuming process, this hypothesis can explain both the occurrence of spatially unspecific filtering costs and the dissociation between spatially specific and unspecific costs.

Experiment 3

Experiment 3 was designed to test the hypothesis that inhibition of the irrelevant singleton only occurred in the ASP and the feature certainty condition of the ISP but not in the feature uncertainty condition of the ISP. Moreover, this experiment was designed to clarify whether attentional capture only occurred on a certain portion of trials in Experiments 1b and 2a. To that purpose, spatially selective effects were measured on a trial-by-trial basis in the distractor-present trials of the ASP and ISP.

Intertrial analyses can help to decide the question of whether the distractor is filtered out, because in case the irrelevant distractor is inhibited on trial *n,* search should be facilitated when target and distractor features remain the same in the next trial but hampered when the color assignment switches. This prediction can be derived from two observations: First, distractor inhibition or target activation processes pertain to specific features and not, for example, to abstract properties such as being a singleton. Second, whenever processes of target activation or distractor inhibition are involved, the respective activation or inhibition patterns carry over to the next trial and produce a noticeable pattern of repetition facilitation: RTs get successively shorter when the target possesses the same feature as in previous trials. Conversely, in switch trials, when the target inherits features that were formerly associated with the nontargets, RTs are enhanced (switch costs). According to the priming of pop-out account, activation of target features or inhibition of distractor features can be modeled by positive valencing of the target feature or negative valencing of the nontarget feature. Importantly, these valence settings will automatically transfer to the next trial, which leads to priming of the respective features, that is, facilitated selection of the target at repetition trials and erroneous selection of the distractor at switch trials (Maljkovic & Nakayama, 1994, 1996, 2000; for a similar conception of activation and inhibition patterns, see the dimension weighting account in Found & Müller, 1996; Müller, Heller, & Ziegler, 1995).

Deviating from the priming of pop-out account, the present explanation assumes that priming of irrelevant features does not occur automatically but instead depends on the top-down attentional control settings of the observers. Thus, for the purpose of referencing, the corresponding hypothesis will be called *contingent priming*.

The question of whether inhibition processes occurred only in certain conditions of Experiment 3 can thus be tested by comparing the respective patterns of intertrial facilitation with each other. If the contingent priming hypothesis explains the results from the first experiments, the typical intertrial facilitation patterns should only occur in the ASP feature uncertainty condition and the ISP feature certainty condition but not in the ISP feature uncertainty condition. This holds because it was hypothesized that the information given to the observers would only prompt inhibition of the irrelevant distractor in the former conditions but not in the latter in which both the features of the target and the relative positions of target and distractor were uncertain.

A second aim of the present experiments was to check whether attentional capture occurred only on a portion of trials in the ASP feature uncertainty and ISP feature certainty condition, which might have escaped earlier analyses. Probing for instances of attentional capture on a trial-by-trial basis moreover allows evaluating one major assumption of the priming of pop-out account: If intertrial priming effects really operate on the level of attentional selection, one would expect attentional capture of the irrelevant distractor to be strongest at switch trials, in which the valence settings favor selection of the distractor, and to decrease with increasing repetitions of the same target color. (Conversely, if such priming processes are really absent in the ISP feature uncertainty condition, the distribution of spatially specific effects should be independent of intertrial contingencies.)

In order to provide a critical test for the hypothesis advanced above and to probe more precisely for occurrences of attentional capture in an intertrial sequence, I computed compatibility effects for each intertrial repetition condition separately (intertrial compatibility effect). In the next experiments, only the distractor-present conditions of ASP and ISP were tested, and participants performed 400 trials in each condition. This was done in order to obtain enough data for the intertrial analyses. Experiment 3a included the distractor-present condition of the ISP and ASP feature uncertainty conditions, whereas Experiment 3b represented the feature certainty conditions of the respective paradigms.

Method

Participants. Twenty-eight participants took part in the present experiment for small monetary exchange (€6 [$7.79]). Sixteen of them took part in Experiment 3a in the feature uncertainty conditions of ISP and ASP. Twelve participants took part in Experiment 3b, which comprised the feature certainty conditions of ISP and ASP.

Stimuli, design, and procedure. Experiments 3a and 3b used the same stimuli and procedure as in the previous experiments, with the following exceptions: In Experiment 3, only the distractor-present conditions of the ISP and ASP were tested in the Set Size 5 condition.

In Experiment 3a, the colors of singleton distractor and the remaining items changed unpredictably, whereas in Experiment 3b, the features of the singleton distractor remained constant throughout the block. The order of the two blocks was balanced across participants in both conditions.

The ISP and ASP conditions were blocked, with each block consisting of 400 trials. Before each block, participants received a written instruction and performed a short practice block of 10 trials. At the beginning of the test block, there were another five practice trials of which participants were not informed. None of the practice trials were recorded. As before, participants were fully informed about the different informativity values of the singleton distractor in each block and were instructed to ignore the color difference. On average, it took 1 hr to complete each experiment.

Results

Data. Removing RTs below 200 ms and greater than 1,500 ms resulted in a loss of 0.15% of all data in Experiment 3a and 0.46% in Experiment 3b.

RTs. Mean RTs and error scores for Experiment 3 are depicted in Table 1. First, the same MANOVAS (excluding distractor-absent trials) as in the previous experiments were conducted over the data from Experiments 3a and 3b in order to ensure compatibility of the present results with the results from former experiments.

Concerning effects of spatial congruency, spatial benefits for the P0 compared with the $P > 0$ condition could only be obtained in the feature uncertainty condition of the ISP (Experiment 3a): Participants were 14 ms faster in the singleton target P0 condition than in the nonsingleton target $P > 0$ condition, $F(1, 15) = 5.5$, $p = .033$. Conversely, in Experiment 3b with the ISP feature certainty condition, spatial congruency did not have an effect ($p = .70$).

Similarly, distance effects could only be found in the ISP feature uncertainty condition: Participants were 10 ms faster when the distractor was located near to the target than when it was more distant, $F(1, 15) = 7.4$, $p = .014$, whereas in the ASP feature uncertainty condition, no significant differences emerged ($p = .30$). In the feature certainty conditions of Experiment 3b, the distance effect did not reach significance either in the ISP feature certainty condition ($p = .30$) or in the ASP ($p = .60$).

Compatibility effects were also restricted to the ISP feature uncertainty condition (Experiment 3a): Participants were 10 ms faster on compatible trials than on incompatible trials, $F(1, 15) = 7.82$, $p = .014$. Conversely, in the ASP feature uncertainty condition, RTs were in the general direction of a compatibility effect, without this effect approaching significance ($p = .60$). In Experiment 3b, participants responded significantly faster in the compatible condition of the ISP, $F(1, 11) = 9.0$, $p = .012$, whereas in the ASP, compatibility did not have an effect ($p = .60$).

Errors. A corresponding MANOVA calculated over the mean error scores of each paradigm showed a significant difference between the P0 and P > 0 condition in the ISP feature uncertainty condition (Experiment 3a): On average, participants committed 1.41% more errors in the P > 0 condition than in the P0 condition, $F(1, 15) = 5.14$, $p = .039$. In Experiment 3b, participants also committed 1.73% less errors in the P0 condition in which target and distractor position coincided than in the P > 0 condition, which also proved to be significant, $F(1, 11) = 7.45$, $p = .02$. None of the auxiliary spatial measures showed significant effects in the error scores of any condition.

Intertrial Effects

RTs. Figures 2 and 3 depict the mean RTs and error scores in the ASP and ISP feature uncertainty conditions, respectively. Intertrial contingencies are presented on the *x*-axis, with *switch* denoting trials in which the assignment of colors to distractor and the remaining items switched, and *rep.* denoting one, two, three or more repetitions of the color assignment. In the ISP feature uncertainty condition, there are basically two kinds of switches or changes that must be taken into consideration: In transitions from P0 trials to P > 0 trials and vice versa, either the target changes its color while the features of the singleton distractor remain constant, or the target has the same color as in trial $n - 1$ while the singleton distractor changes its color. Naturally, the RTs and error scores from P0 trials were excluded from the present analyses in order to ensure comparability with the ASP. However, their presence in a sequence of trials should not be ignored. Thus, data from the P > 0 trials were separated according to whether they implied a change in the features of the irrelevant singleton (singleton feature) or a change in the color of the target (target feature). Finally, Figure 4 depicts the mean RTs and errors in the intertrial conditions of the ISP feature certainty condition (Experiment 3b).

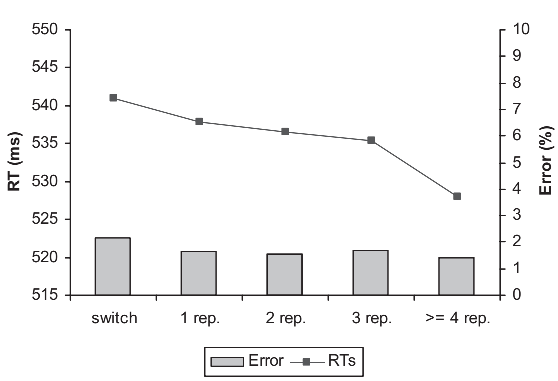

Figure 2. Results from the ASP feature uncertainty condition in Experiment 3. Mean errors are represented by bars; mean reaction times (RTs) are represented by filled squares. *Switch* denotes trials in which the color assignment to irrelevant distractor and the remaining items switched. *Rep.* signifies one, two, three, or more repetitions of the same color assignment. Means in the repetition conditions are based on 198, 98, 48, 32, and 24 trials, respectively. ASP = additional singleton paradigm.

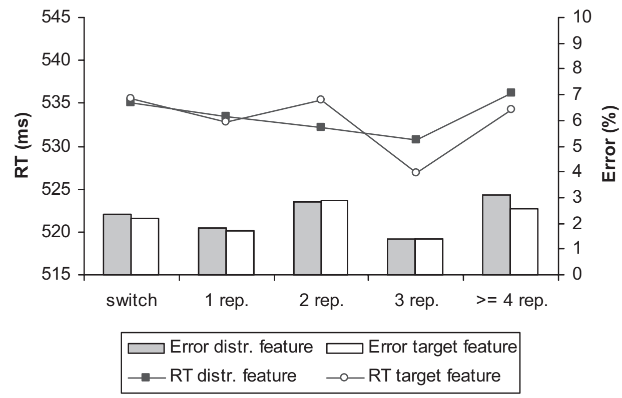

Figure 3. Mean reaction times (RTs) and errors in the ISP feature uncertainty condition (Experiment 3) are plotted separately for switches and repetitions (rep.) of the distractor (distr.) and target features. Mean errors are depicted as white and gray bars; mean RTs are represented by filled and open squares, respectively. Means of the distractor feature condition are based on 155, 79, 41, 23, and 22 trials per repetition condition, respectively; means of the target condition rest on 65, 53, 45, 34, and 123 trials, respectively. ISP = irrelevant singleton paradigm.

As can be seen in Figure 2, mean RTs in the ASP feature uncertainty condition are enhanced at switch trials and successively decrease with increasing repetition of the same color assignment. No such effects can be discerned in the RT data of the ISP feature uncertainty condition (see Figure 3), either with respect to changes pertaining to the distractor or to the target color. Conversely, inspection of Figure 4 suggests repetition facilitation effects for the feature certainty condition of Experiment 3b.

Statistical analyses confirm this impression: In the ASP feature uncertainty condition, RTs were significantly slower at switch trials ($M = 541$ ms) than in repetition trials ($M = 536$ ms), $t(15) =$

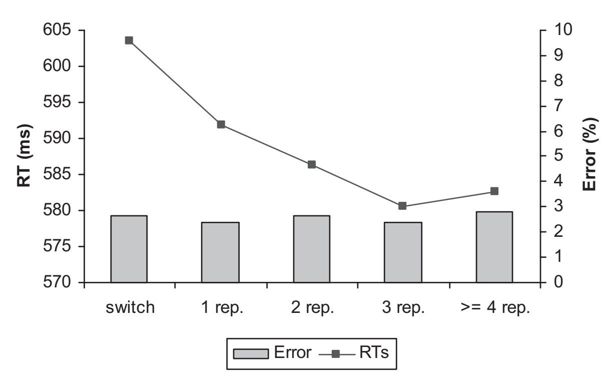

Figure 4. Results from the ISP feature certainty condition in Experiment 3b. Mean errors (gray bars) and reaction times (RTs; filled squares) are depicted with respect to intertrial contingencies. Means are based on 72, 64, 54, 47, and 24 repetitions (rep.) per condition, respectively. ISP = irrelevant singleton paradigm.

2.22, p = .042. Conversely, in the ISP feature uncertainty condition, comparing performance in the switch condition with the pooled data from all repetition conditions did not show any significant differences: With respect to switches in the assignment of colors to distractor and remaining items (singleton feature), participants were 1 ms faster in the repetition trials (M = 534 ms) than in switch trials (M = 535 ms), $t(15) = 0.15$, $p = .90$. In trials in which the color of the target changed (target feature), likewise no significant repetition facilitation effect could be obtained: Participants were 2 ms faster when the target color was repeated (M = 532 ms) than when it was switched (M = 534 ms), $t(15) = 1$, p = .30. Conversely, in the ISP feature certainty condition (Experiment 3b), RTs in switch trials were significantly slower (M = 603 ms) when compared with repetition trials (M = 584 ms), $t(11) = 2.1$, p = .043.

Errors. The t tests calculated over the switch versus repetition trials only yielded significant repetition facilitation effects in the ASP feature uncertainty condition (Experiment 3a), with participants committing 0.57% more errors in switch trials than in repetition trials, $t(15) = 2.44$, $p = .028$, but in none of the remaining conditions (all ps $>$ .50).

Intertrial Compatibility Effects

In order to probe more precisely for single occurrences of attentional capture, I more closely investigated data from each repetition condition for spatially selective effects. To that end, compatibility effects in the switch and each of the repetition conditions were calculated for the mean RTs of Experiments 3a and 3b.[2]

Figure 5 depicts the mean RT data from the ASP separated according to the compatibility effect in the respective repetition conditions. Mean RTs in the feature uncertainty condition of the ISP are depicted in Figure 6, with black bars referring to switches in the color of the irrelevant distractor (singleton feature) and gray bars reflecting switches in the target color (target feature). Figure 7 shows mean search performance as a function of compatibility

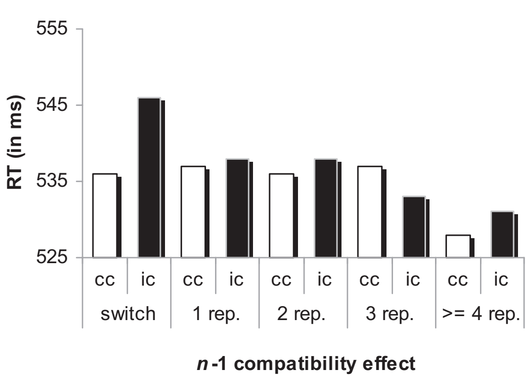

Figure 5. Mean reaction times (RTs) of the ASP feature uncertainty condition (Experiment 3a) are depicted as a function of intertrial contingencies and compatibility between the response-related items of target and distractor. White bars represent compatible trials (cc), whereas black bars represent incompatible trials (ic). *Switch* denotes the condition in which the distractor switched colors with the remaining items, whereas *rep.* denotes conditions in which the assignment of colors was repeated for one, two, three, or more successive trials. ASP = additional singleton paradigm.

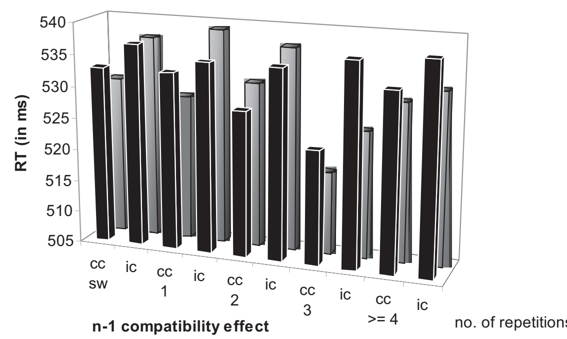

Figure 6. Results from the ISP feature uncertainty condition (Experiment 3a): Mean reaction times (RTs) are depicted as a function of intertrial contingencies and compatibility. The black bars in the front represent mean performance in the intertrial contingencies of the distractor feature; the gray bars in the row behind represent intertrial contingencies of the target feature. sw = switch; cc = compatible condition; ic = incompatible condition. ISP = irrelevant singleton paradigm.

and intertrial contingency with respect to the feature certainty condition of the ISP of Experiment 3b. For statistical analysis of the compatibility effect, pairwise t tests were calculated over the mean RTs in compatible versus incompatible trials in each repetition condition.

In the ASP feature uncertainty condition of Experiment 3a (see Figure 5), significant compatibility effect could only be found in trials in which the assignment of colors to target and irrelevant distractor switched, $t(15) = 2.58$, $p = .021$, but not in any of the repetition trials (all ps $>$ .70). In the ISP feature uncertainty condition, compatibility effects had to be calculated according to whether switches in the color concerned relations between the distractor and the remaining items (represented by the black bars in Figure 6) or whether switches concerned changes of the target color (represented by gray bars). Concerning first changes of the irrelevant distractor, there were no significant compatibility effects in the switch or any of the repetition trials (all ps $>$ .07). The compatibility effect was only reliable in the pooled data from all repetition conditions, $t(15) = 2.32$, $p = .035$. Similarly, with respect to changes in the target color (gray bars; see Figure 6), there were no significant differences between compatible and incompatible trials in the switch or in any of the single repetition conditions (all ps $>$ .089). Additionally, the compatibility effect was only marginally significant in the pooled data from all repetition conditions, $t(15) = 2.0$, $p = .063$. Conversely, in the ISP feature certainty conditions (Experiment 3b; see Figure 7), pairwise t tests calculated over the mean RTs in each repetition condition showed that the compatibility effect was significant in the first trial after the P0 trial, $t(11) = 2.21$, $p = .05$, and the first repetition trial, $t(11) = 2.22$, $p = .048$, but in none of the remaining conditions (all ps $>$ .10).

[2] Sequential or $n - 1$ distance effects generally followed the same pattern as the sequential compatibility effect. However, the results from the distance effect are not reported in the present study because performance in the switch trial showed signs of a speed–accuracy trade-off, and the distance effect at switch trials did not reach significance across all experiments.

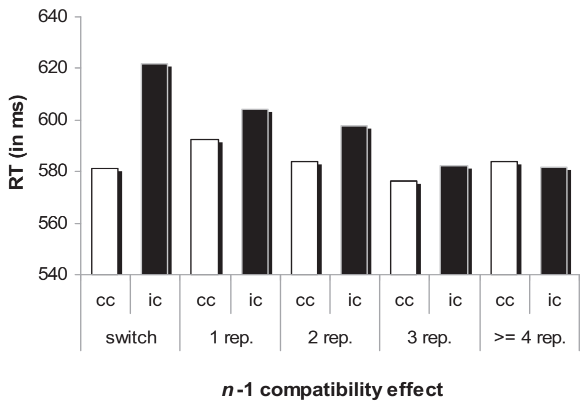

Figure 7. Mean reaction times (RTs) in the ISP feature certainty condition (Experiment 3b) are depicted as a function of intertrial contingencies and compatibility: White bars indicate compatible trials (cc); black bars indicate incompatible (ic) ones. rep. = repetition. ISP = irrelevant singleton paradigm.

The results so far indicate that inhibition of the irrelevant distractor indeed only occurred in the ISP feature certainty condition and in the ASP feature uncertainty condition but not in the ISP feature uncertainty condition. However, the results from the intertrial analyses might be doubted on grounds that the $n - 1$ effects could have been confounded with repetition of the same responses. If feature repetition was by accident simultaneously associated with response repetition, the observed RT effects also could be due to response priming and not to priming of the irrelevant features. Moreover, it is possible that response priming effects and repetition facilitation effects pertaining to the irrelevant feature interacted with each other (see, e.g., Hillstrom, 2000; Huang et al., 2004). To exclude the possibility that results from the present experiments were due to response priming effects or interactions between response and feature priming effects, a further test was invoked: RTs in the feature uncertainty condition of the ASP and the feature certainty condition of the ISP were separately pooled according to whether they included a change in the response key and the distractor color.

Figure 8 depicts the mean RTs in the respective conditions. As can be seen in the figure, mean RTs were not slower when the orientation of the target line switched than when it remained constant. Conversely, switching the color led to slower RTs compared with the repetition condition. A 2 × 2 analysis of variance, including the variables color and orientation, confirmed this impression: In the ASP feature uncertainty condition, only the main effect of color reached significance, $F(1, 15) = 6.38$, $p = .023$, whereas neither the main effect of orientation nor the interaction approached significance (all ps $> .60$). A corresponding analysis conducted over the RT data of the ISP feature certainty condition of Experiment 3b did not show any significant effects (all ps $>$ .20). Thus, it is safe to assume that the results from the intertrial analyses are not due to response priming effects or to interactions between response and feature priming effects.

Discussion

The present experiment yielded several interesting results: First, spatially selective effects in the overall data could only be observed in the ISP but not in the ASP. This finding replicates the results from the first two experiments and suggests that longer trial sequences do not influence the result pattern. Second, intertrial facilitation effects pertaining to switches and repetitions of the irrelevant feature could only be observed in the feature uncertainty condition of the ASP but not of the ISP. However, repetition facilitation effects occurred in the ISP feature certainty condition. Third, analyses of the intertrial compatibility effect showed that the distractor in the ASP only produced compatibility effects when the color assignment to target and the remaining items switched but not in any of the repetition trials. These intertrial facilitation effects could only be found with respect to switches or repetitions of color but not with respect to the irrelevant line orientations. In turn, spatially selective effects in the ISP feature uncertainty condition were not modulated by the trial history. Although the irrelevant singleton was apparently more frequently selected in this condition than in the ASP, attentional capture by the irrelevant distractor was not modulated by either changes in the color of the irrelevant distractor and the remaining items or by changes in the target color. In the ISP feature certainty condition, the compatibility effect in turn was again modulated by the trial history, being strongest at switch trials and showing a decreasing impact of compatibility with an increasing number of repetitions.

These results are thus compatible with the contingent priming hypothesis, which proposes that the differences between the ISP and ASP are due to participants inhibiting the distractor only in the ASP feature uncertainty condition and the ISP feature certainty condition but not in the ISP feature uncertainty condition. The results from the intertrial analyses support this view, because intertrial facilitation effects indicative of inhibition processes can only be observed in the ASP but not in the ISP feature uncertainty condition.

However, although the contingent priming hypothesis received strong support from the intertrial analyses of the experiments, it

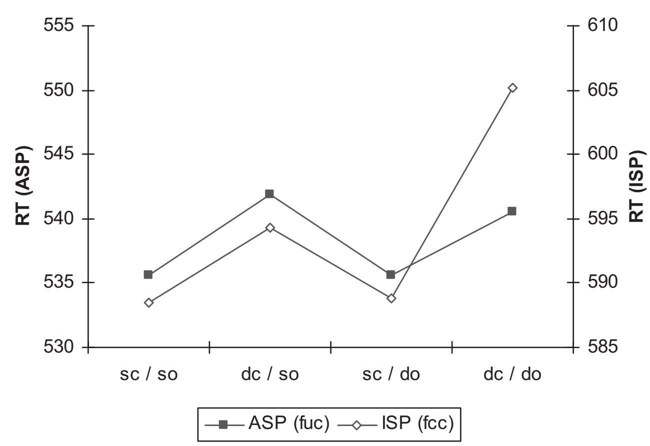

Figure 8. Results from the conditions that showed significant repetition facilitation effects: Mean reaction times (RTs) of the ASP feature uncertainty condition (fuc) are depicted by squares and belong to the left *y*-axis; diamonds indicate mean RTs in the irrelevant singleton paradigm (ISP) feature certainty condition (fcc) and belong to the right *y*-axis. Categories on the *x*-axis indicate whether trial *n* invoked a change of the color of the distractor or the line orientations of the target compared with trial $n - 1$. ASP = additional singleton paradigm; sc = same color; so = same orientation; dc = different color; do = different orientation.

could be asked whether it is sufficient to explain the result patterns. Actually, there still appear to be differences between the ASP feature uncertainty condition and the ISP feature certainty condition that are not sufficiently accounted for by the present approach. First of all, spatially selective effects in the overall result pattern could only be discerned in the data of the ISP feature certainty condition, as indicated by significant compatibility effects and effects of spatial congruency. Conversely, overall performance in the ASP feature uncertainty condition did not show any spatially selective effects. Second, the intertrial analyses suggest that attentional capture of the irrelevant distractor in the ASP seems to be very narrowly restricted to those trials in which the colors of target and distractor switch. Significant compatibility effects could not be found in any of the repetition conditions. Although the ISP feature certainty condition showed a very similar result pattern of enhanced spatially selective effects at switch trials, spatially selective effects could still be found in the first repetition condition. Moreover, spatially selective effects also were more pronounced at switch trials in the ISP, reaching 40 ms between compatible and incompatible trials in switch trials, whereas in the ASP, this difference only amounted to 10 ms. Thus, attentional capture is apparently longer lasting and more frequent in the ISP than in the ASP.

This difference between the ISP and ASP suggests the presence of additional processes or a modulation of distractor inhibition not considered so far. At a first glance, the sole difference between the ISP feature certainty and ASP feature uncertainty conditions appears to be that the distractor is antipredictive of the target position in the ASP, whereas it is uninformative in the ISP.

However, the ASP and ISP differ in more respects than the informativity of the distractor. First, the colors of distractor and target switch more frequently in the ASP feature uncertainty condition than in the feature certainty condition of the ISP. This results in a greater probability for longer sequences in the ISP as well as much rarer occurrences of switch trials. In turn, the scarcity of switch trials in the ISP might lead to enhanced attentional selection of the irrelevant distractor in switch trials. Second, the control conditions of the two experiments also differ in important respects: In the distractor-absent condition of the ASP, the colors of all items switch in a random fashion, whereas they remain constant in the ISP feature certainty control condition. (The control conditions of the ISP and ASP only are identical within the feature certainty and uncertainty conditions of the two paradigms but not across these conditions.) However, varying the colors in the control condition might in itself produce costs that dwarf the overall distraction costs in the ASP when compared with the ISP.

The next experiment was conducted in order to overcome the inequalities in the designs between ASP feature uncertainty condition and the ISP feature certainty condition and to allow more precise comparisons between the two conditions.

Experiment 4

Experiment 4 was quite similar to the previous experiment, insofar as it included an ISP and ASP condition. Experiment 4a was almost identical to the ISP feature certainty condition of Experiment 3a, with the exception that it included a control condition. Moreover, the control condition of the ISP was designed such that the colors of all items also switched in 1/*d* cases.

Experiment 4b reinstated the ASP but also included characteristics of the ISP. Thus, the distractor was antipredictive of the target location throughout the experiment, but target and distractor only switched colors in 1/*d* cases. Accordingly, the control condition also included color switches of the same frequency. Because the ASP included as many characteristics from the ISP feature certainty condition as possible, it will be referred to as *IASP*.

Switching the colors in the IASP and ISP as well as in the respective control conditions of Experiments 4a and 4b has the following advantages: First, it eliminates obvious differences between the ASP feature uncertainty condition and the ISP feature certainty condition. Second, this manipulation of the control condition guarantees that the distraction effect does not include costs that could possibly accrue from the fact that the target was associated with two different colors in the distractor-present trials but only with one in the distractor-absent control condition (as was the case in the ISP feature certainty condition). Because the target changed colors as often in the distractor-absent condition as in the distractor-present condition, the distraction costs are not confounded with intertrial switch costs. Hence, this atypical control condition allows a more precise estimate of the costs solely due to the presence of a singleton distractor. Third, varying the irrelevant feature of all objects in the control condition allows an evaluation of whether switches of the color of all items would also result in heightened costs, as in the distractor-present condition.

According to the contingent priming hypothesis, an inflation of RTs in switch trials in the distractor-absent control condition certainly is not to be expected. In the absence of a singleton distractor, there can be no inhibition of irrelevant features and hence no priming effects should occur. However, the heightened costs and enhanced spatial effects at switch trials could also be ascribed to processes different from distractor inhibition or target activation. It might, for example, be feasible to explain these switch costs with reference to an inability to form target templates that abstract from the irrelevant feature. If, for example, participants could not restrict their search set to relevant features, switch costs should also occur in the distractor-absent trials of the control condition. Hence, the control conditions of the ISP and IASP also serve to exclude alternative explanations for the observed effects in the distractor-present trials of the ISP and ASP.

Method

Participants. Forty participants took part in Experiment 4 for small monetary exchange (€9 [$11.69]). Half of the participants participated in the ISP feature certainty condition (Experiment 4a) and the other half participated in the IASP (Experiment 4b).

Stimuli, design, and procedure. In Experiment 4a, the same stimuli and presentation procedure was used as in the other ISP feature certainty conditions. In contrast to previous experiments, the number of stimuli throughout the experiments was seven. The overall set size was increased in order to obtain a higher probability for longer sequences in the intertrial analyses. Experiment 4a reinstated the ISP feature certainty condition, that is, the irrelevant distractor could be found at the same location as the target in 1/*d* trials. In the distractor-absent control condition, the colors of all items accordingly switched in 1/*d* trials.

Experiment 4b closely resembled Experiment 4a. The only difference was that the distractor could never be found at the location of the target. Deviating from former experiments, the color of the singleton distractor and the remaining items switched on 1/*d* trials in the distractor-present condition. In the distractor-absent control condition of the IASP, the colors of all items switched with the same frequency.

The distractor-absent and distractor-present conditions for each ISP and IASP were blocked, and the order of the blocks was balanced. Each participant completed 196 trials in the distractor-absent control condition and 588 trials in the distractor-present condition. The two blocks were preceded by a written instruction and a short practice block of 10 trials, which was not recorded. The participants were allowed short rests every 70 trials in both conditions and experiments. On average, it took 90 min to complete the experiment.

Results

Data. Excluding RTs above 1,500 ms and below 200 ms resulted in a loss of 0.39% of the data in Experiment 4a and a loss of 0.71% of the data in Experiment 4b. In order to ensure comparability with the results from the ISP, rare trials in the IASP that parallel the P0 trials in the ISP were excluded from all analyses.

RTs. First of all, MANOVAs were conducted over the overall data of the ISP and IASP of Experiments 4 in order to find out whether performance was significantly impaired by the presence of an irrelevant distractor and whether the distraction effect would show spatial specificity.

In Experiment 4a with the ISP, comparing performance in the distractor-absent and distractor-present conditions showed that the distractor significantly disturbed search: Participants were on average 24 ms slower in the distractor-present condition than in the control condition, $F(1, 19) = 10.65$, $p = .004$. A corresponding analysis of the IASP of Experiment 4b equally showed a significant effect of distractor presence: Participants were on average 16 ms slower in the distractor-present condition than in the control condition, $F(1, 19) = 7.76$, $p = .012$.

Comparisons of the P0 trials with performance in the P > 0 trials in the ISP yielded benefits of 13 ms for the P0 singleton target condition, which just failed to reach significance, $F(1, 19) = 3.69$, $p = .072$.

Finally, analyses of the compatibility effect showed that in the ISP, participants were 10 ms slower in the incompatible condition than in the compatible condition, $F(1, 19) = 7.89$, $p = .011$, whereas in the IASP, the compatibility effect failed to reach significance ($p = .16$).

Errors. The same MANOVA calculated over the mean error scores of ISP and IASP yielded significant distraction costs in the ISP, $F(1, 19) = 8.39$, $p = .009$, with participants committing 0.88% more errors in the presence of a distractor. The distraction costs in the IASP were 0.62% and only approached significance, $F(1, 19) = 2.92$, $p = .104$. Comparing search performance in the P0 and P > 0 trials showed that participants committed 0.97% fewer mistakes in the former than in the latter, $F(1, 19) = 6.78$, $p = .017$. Finally, analyses of the compatibility effect showed nearly significant differences in the ISP, $F(1, 19) = 3.79$, $p = .066$, with participants committing 0.89% more errors on incompatible than on compatible trials but no significant compatibility effects in the IASP ($p = .30$; see Table 1). None of the remaining effects approached significance.

Intertrial Effects

RTs. Figures 9 and 10 show the mean RTs in each repetition condition of the distractor-present and distractor-absent control conditions of the IASP and ISP, respectively. As can be seen in the figures, an inflation of RTs in switch trials seems to be present in both distractor-present conditions of IASP and ISP. However, no traces for slower RTs at switch trials are apparent in the distractor-absent control condition of both IASP and ISP.

Statistical analyses confirmed this first impression: Pairwise *t* tests calculated over the mean RTs of the distractor-present condition of the ISP showed that participants were 11 ms slower in switch trials than when the assignment of colors was repeated, $t(19) = 2.3$, $p = .032$. Conversely, no significant differences emerged in the distractor-absent control condition between switch and repetition trials ($p = .15$; mean difference = 5 ms). A corresponding result pattern emerged in the IASP: In the distractor-present trials, performance in switch trials was equally 13 ms slower than at repetition trials, $t(19) = 4.1$, $p = .001$, whereas this was not the case in the distractor-absent control condition ($p = .80$; mean difference = 1 ms).

Errors. The mean error scores in each repetition condition are depicted in Table 2. However, no significant intertrial facilitation effects could be observed either in Experiment 4a or 4b (all *p*s > .20). Thus, the results from the RT analyses are not due to a speed–accuracy trade-off.

Intertrial Compatibility Effects

Figures 11 and 12 show the mean RTs in compatible and incompatible trials in each repetition condition for ISP and IASP. The figures suggest that compatibility effects in both experiments are enhanced at switch trials and decrease with increasing number

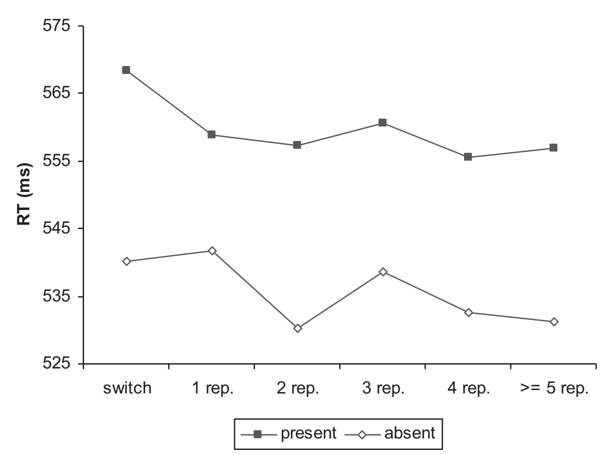

Figure 9. Results of the ISP feature certainty condition (Experiment 4a): Mean reaction times (RTs) are depicted as a function of number of repetitions (rep.) of the target color and are separately plotted for distractor-present trials (squares) and distractor-absent trials (diamonds). Means in the distractor-absent condition rest on 24, 21, 19, 17, 13, and 74 trials, respectively, and means in the distractor-present condition are based on 72, 64, 54, 47, 24, and 247 trials, respectively. ISP = irrelevant singleton paradigm.

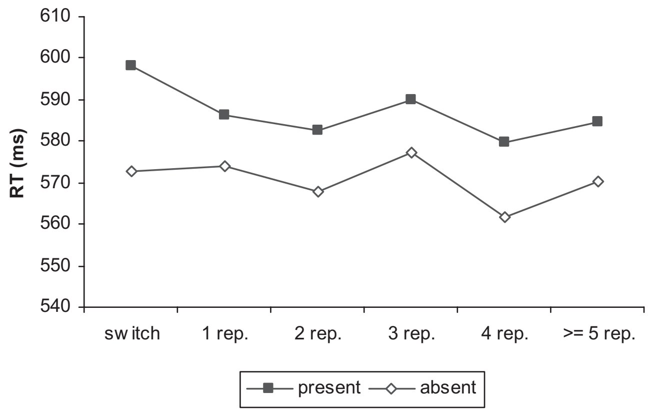

Figure 10. Results of the IASP (Experiment 4b): Mean reaction times (RTs) are separately plotted for distractor-present trials (squares) and distractor-absent trials (diamonds) in each repetition condition. Means in the distractor-absent condition rest on 24, 20, 17, 12, 8, and 87 trials, respectively, and means in the distractor-present condition are based on 70, 63, 54, 41, 29, and 247 trials, respectively. IASP = hybrid of irrelevant singleton paradigm and additional singleton paradigm.

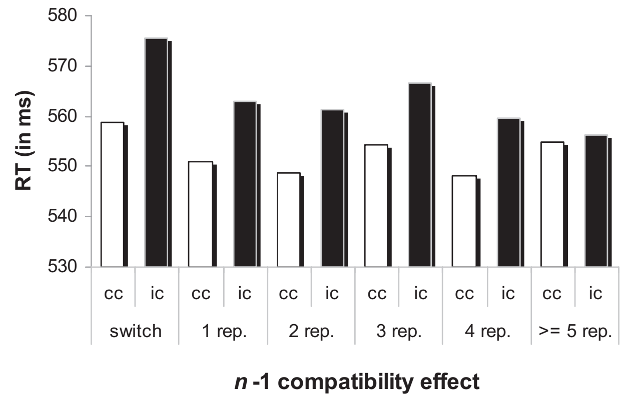

Figure 11. Mean reaction times (RTs) in the ISP feature uncertainty condition (Experiment 4a). White bars represent mean RTs in the compatible condition (cc); black bars represent mean RTs in incompatible trials (ic) of each repetition (rep.) condition. ISP = irrelevant singleton paradigm.

of repetitions of the same assignment of colors to target and distractor.

Several *t* tests computed over the switch and each repetition condition confirmed this impression: In the ISP of Experiment 4a, significant compatibility effects could be obtained in the switch trial, $t(19) = 2.5$, $p = .021$, and the first repetition of a P > 0 trial, $t(19) = 2.6$, $p = .015$, but in none of the other repetition conditions (all $ps > .05$). In Experiment 4b with the IASP, significant compatibility effects could only be obtained in the switch trial, $t(19) = 3.1$, $p = .006$, whereas no compatibility effects occurred in any of the repetition conditions (all $ps > .20$).

Discussion

The findings of the present experiments with the ISP feature certainty condition and the transformed IASP replicate the result pattern of earlier experiments: In both ISP and IASP, significant distraction costs emerged. Because the distractor-absent control condition of the ISP (Experiment 4a) also included switch trials in 1/*d* cases, it can be ruled out that the distraction effect in previous experiments of the ISP feature certainty condition was due to the fact that the target color only switched in the distractor-present condition.

As in former experiments, traces of spatially selective effects could be obtained in the ISP, as reflected in comparisons between P0 with P > 0 trials and in the significant compatibility effect. However, although spatially selective effects could be discerned in the ISP data, part of the overall distraction costs have to be attributed to spatially unselective filtering costs. The present experiment probably yielded the most clear evidence of filtering processes in the ISP, because performance in P0 trials was worse than in the distractor-absent control condition. This result is incompatible with the hypothesis that the irrelevant distractor regularly captures attention. Evidence for distractor inhibition (or target activation) processes could also be found by the intertrial analyses: In both ISP and IASP, significant repetition facilitation effects emerged, which have to be attributed to priming. Remarkably,

Table 2
Mean Error Scores as a Function of Intertrial Contingencies in the Distractor-Absent and Distractor-Present Conditions of Experiment 4

		Repetitions					
	Switch	1	2	3	4	≥5	Pooled
ISP							
Present	2.09	3.01	2.31	2.03	3.02	2.09	2.30
Absent	1.21	1.63	1.42	1.08	1.41	1.24	1.32
IASP							
Present	2.61	2.00	3.42	3.04	2.61	2.32	2.49
Absent	1.71	2.18	0.87	2.56	1.44	2.02	1.91

Note. ISP = irrelevant singleton paradigm; IASP = hybrid of ISP and additional singleton paradigm.

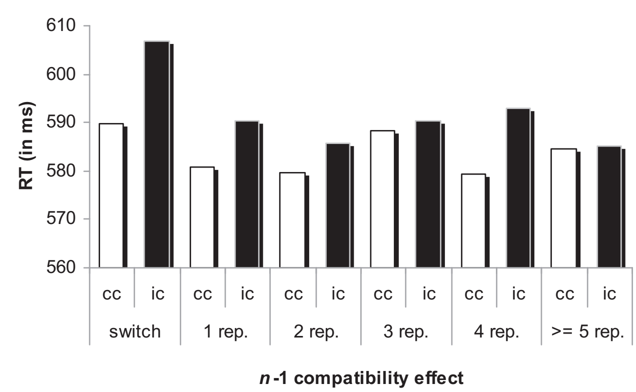

Figure 12. Mean reaction times (RTs) in the IASP (Experiment 4b) plotted as a function of intertrial contingency and compatibility. cc = compatible condition; ic = incompatible condition; rep. = repetition; IASP = hybrid of irrelevant singleton paradigm and additional singleton paradigm.

these intertrial facilitation effects were absent in the distractor-absent control conditions of both ISP and IASP. The results thus show that switching the color of all items in the display apparently does not produce any costs in itself. Enhanced costs at switch trials and repetition facilitation effects only occur in the presence of an irrelevant distractor that competes for attention with the target. The result thus provides empirical support for the contingent priming hypothesis, which predicted intertrial facilitation effects to be restricted to the distractor present condition. Moreover, alternative explanations that, for example, attribute intertrial switch costs to an inability to exclude irrelevant features from the target template can be ruled out.

Finally, probing the data from the intertrial conditions for spatially selective effects yielded very similar result patterns for ASP and IASP: In both conditions, spatially selective effects were enhanced at switch trials and decreased with increasing repetitions of the same color assignment to distractor and the remaining items. As in previous experiments, spatially selective effects were slightly more pronounced in the ISP than in the IASP, as indicated by the results from the intertrial compatibility effect and the overall MANOVA. Thus, it is possible that search performance was either influenced by the operational experience of P0 trials in the ISP or else by the information about the different degrees of distractor informativity in the ASP and ISP (which were 0 vs. $1/d$). Because neither the occurrence of P0 trials nor informativity was systematically manipulated in the course of the present experiments, it can only be speculated whether such effects arise from slightly different inhibition strengths or time courses of inhibition in ISP and ASP, or from participants voluntarily selecting the irrelevant distractor on a portion of trials in the ISP. However, by and large, the analyses of the intertrial compatibility effect showed very similar results for ISP and ASP, when the stimulus conditions were comparable. Therefore, the present experiment does not provide support for the assumption that ISP and ASP differ in important respects because of the different informativity values of the distractor.

General Discussion

Summary

Formerly, costs occurring in the distractor-present condition of the ASP compared with the distractor-absent condition have regularly been attributed to attentional capture by the irrelevant singleton (see, e.g., Bacon & Egeth, 1994; Pinto, Olivers, & Theeuwes, 2005; Theeuwes, 1992, 1994). Similarly, stimulus-driven singleton capture has been regularly inferred to account for the overall distraction costs in the ISP whenever significant benefits in the P0 condition could be observed (Theeuwes & Godijn, 2002; Turatto et al., 2004).

In contrast to the singleton capture view, the first two experiments showed that attentional capture could only account for the overall distraction effect in the feature uncertainty condition of the ISP. However, spatially unselective filtering costs were responsible for the major part of the distraction costs in both feature certainty and feature uncertainty conditions of the ASP and also in the feature certainty condition of the ISP.

The finding of spatially unselective and spatially selective distraction costs that were dissociated from each other corroborates earlier results with a spatial cuing procedure (Folk & Remington, 1998). Therefore, it seems safe to conclude that filtering costs that are logically independent of attentional capture do exist and are partially responsible for distraction costs observed both with cuing and with visual search paradigms. In order to clarify the concept of filtering, I invoked the contingent priming hypothesis and subsequently tested it. The contingent priming hypothesis clarifies the concept of filtering costs by linking it to processes of priming, describes the relationship between top-down and bottom-up influences in feature priming effects, and thereby specifies the conditions for attentional capture by irrelevant singletons.

Concerning, first, the association between filtering and priming, results from two more experiments showed that filtering processes could be identified with target activation or distractor inhibition processes that carry over to the next trial: Intertrial facilitation effects that indicated that the irrelevant distractor feature had been inhibited on the previous trial could only be observed in those conditions in which formerly filtering costs had been observed. Conversely, search performance in the ISP feature uncertainty condition—which was devoid of spatially unspecific filtering costs (Experiment 1a)—was also devoid of intertrial facilitation effects (Experiment 3a). Moreover, in those conditions that showed filtering costs (Experiments 1b, 2a, and 2b), the irrelevant distractor apparently only captured attention on switch trials. In turn, spatially selective effects were either strongly reduced or eliminated when the assignment of colors to target and distractor was repeated (Experiments 3b and 4a), which indicates that filtering processes prevented erroneous attention shifts to the distractor. Conversely, in the ISP feature uncertainty condition, which was devoid of spatially unselective filtering costs, attentional capture by the irrelevant distractor was not modulated by intertrial contingencies.

Taken together, these results suggest that the occurrence of filtering processes is contingent on previous top-down controlled settings: According to the contingent priming hypothesis, task-irrelevant features will only be subject to filtering processes if there is an incentive to inhibit irrelevant items (or else to activate features associated with the target). This conjecture could be supported by the last two experiments (Experiments 4a and 4b), which showed that switch costs did not occur in the distractor-absent control condition but were refined to the distractor-present trials.

The last experiment additionally proved to be quite illuminating with respect to the question of whether differences in the informativity of the irrelevant distractor in ASP and ISP produce differences in attentional capture? Search performance in the ASP and ISP was quite similar once the paradigms were matched with respect to their stimulus conditions: In both ASP and ISP, spatially selective and unselective effects of approximately the same magnitude occurred. Although attentional capture was apparently still a bit more frequent in the ISP than in the IASP, the results certainly do not indicate that different mechanisms are at work in both paradigms. Conversely, the results were interpreted as support for the contingent priming hypothesis, which proposes similar mechanisms for both ASP and ISP. The fact that evidence for attentional capture was somewhat stronger in the ISP than in the ASP might be explained with reference to the different degrees of distractor informativity. However, because informativity was only varied to a very small degree in the present experiments, such an effect cannot be ascertained and must be corroborated by further research.

Methods: The Spatial Measures

In the present study, compatibility effects, distance effects, and comparisons of singleton target trials (P0) with nonsingleton target trials (P > 0) were taken as dependent measures to decide the question of whether attentional capture or filtering costs are mainly responsible for the distraction effect. The output of these measures can best be assessed in the ISP in which all three of them could be invoked. A close inspection of the ISP results, however, reveals that the three measures did not always yield the same results (see Table 1).

Of all measures, the distance effect is probably the least sensitive spatial measure: Significant differences between near and far target-distractor distances could only be obtained in the ISP feature uncertainty conditions of all experiments, in which the distractor captured attention very frequently. In all other experimental conditions, the distance effect mostly failed to indicate the presence of spatially selective effects.

A similar problem applies to measures of differences between singleton target (P0) trials and nonsingleton target (P > 0) trials, albeit to a lesser extent: In the feature certainty conditions of the ISP, comparisons of P0 with P > 0 trials sometimes failed to show minor occurrences of attentional capture, which could later be demonstrated in the intertrial analyses. This specifically applies to Experiment 2b and in part also to Experiment 3b, in which differences between P0 and P > 0 trials only occurred in the error scores.

This observation indicates that the distance effect and the location-specific measures became somewhat unreliable indicators of attentional capture once filtering costs were also present in the overall data. Conversely, the compatibility effect reliably indicated attentional capture, even when it only occurred on a portion of trials and when simultaneously filtering costs were present. Thus, the compatibility effect seems to constitute a slightly more sensitive measure for spatial selectivity.

The question of why only the compatibility effect would be sensitive to traces of attentional capture in the presence of filtering processes but not the distance effect or comparisons of P0 with P > 0 trials can be explained by proposing that both latter measures suffer from opposing forces in the absence of attentional capture, whereas the compatibility effect is free of such opposing forces that neutralize the effect. Presumably, filtering or inhibition of the irrelevant singleton leads to lower performance in those P0 trials in which the target inherits the former features of the distractor. As a consequence, RT benefits accruing from attentional capture in one portion of P0 trials would be neutralized by RT costs stemming from occurrences of filtering. This reverse effect of filtering on the location-specific measure is to be expected on the basis of the present results from the intertrial analyses and has already been found in similar contexts (see Olivers & Humphreys, 2003).

The same logic also seems to apply to the distance effect: If filtering processes show a spillover of inhibition, this would lead to worse detectability of targets in the immediate vicinity of the inhibited distractor position. This hypothesis receives some support by noting that the RTs repeatedly showed a trend toward an inverse distance effect (see, e.g., Experiments 3b and 4b), that is, increasing performance with increasing target-distractor distance. Support for this conjecture also can be derived from the finding that intertrial facilitation and inhibition effects also apply to positions adjacent to target and distractor positions (Maljkovic & Nakayama, 1996). Taken together with the small magnitude of the distance effect, this hypothesis can explain why the distance effect failed to show occurrences of attentional capture in the presence of filtering processes. Additionally, it might also serve to explain the unreliableness of the distance effect observed in other studies.

In sum, the first two location-specific measures must be suspected of being counterbalanced by filtering effects, whereas no such counterpart exists for the compatibility effect: If attention is deployed to the irrelevant distractor, the compatibility of the stimulus will influence RTs to the target, but in case the distractor location is filtered out, no reverse effect will occur. Therefore, contrary to the distance effect and the comparison of P0 and P > 0 trials, compatibility effects will not be neutralized or dwarfed by reverse effects that occur with instances of distractor inhibition. This explains why the compatibility effect appears to be the most sensitive tool for detecting occurrences of attentional capture.

A New Concept of Filtering

Up until now, the notion of filtering costs has been very vague: All that seems to be clear from the literature is that the presence of an irrelevant distractor can harm search performance, without eliciting a shift of attention to its position (Folk & Remington, 1998). Folk and Remington (1998) speculated that these nonspatial distraction costs might be due to encoding costs, akin to the costs associated with the presence of a new object in the display (new objects theory; Yantis & Hillstrom, 1994) or an object that is highly dissimilar from the target (Kahneman et al., 1983; Treisman et al., 1983). More precisely, Folk and Remington suggested that “even though this irrelevant object may not draw spatial attention to itself, it may, if salient enough, compete for selection, ultimately slowing down the allocation of attention to the target” (p. 859).

The results of the present experiments, however, do not lend support to this notion of filtering costs: Filtering costs obviously do not consist of costs associated with the mere presence of an irrelevant distractor that competes for attention with the target. This could be most clearly shown in the feature uncertainty condition of the ISP (Experiment 1a) in which no such costs could be observed, although the distractor was exactly the same as in all other experiments. This result rules out the possibility that filtering costs are due to the mere presence of a salient item.

Instead, the present results show that filtering processes are contingent on top-down controlled processes and that they serve a purpose; that is, they ensure efficient selection of target features and/or prevent erroneous selection of features associated with an irrelevant distractor. The hypothesis that filtering processes are associated with target activation and/or distractor inhibition processes also is in line with the basic concept of filtering, which was introduced to signify processes that exclude distractors from attentional search by filtering them out. Moreover, the proposal that priming itself is a time-consuming process does not only explain the present results but might also account for the spatially unselective filtering costs found in other studies.

However, it might also be questioned whether the filtering costs observed in Folk and Remington's (1998) study and the present one are really comparable or whether the present study has discovered a different kind of spatially unselective costs. The latter conjecture seems to be rather improbable because the used paradigms as well as the methods to assess spatially selective versus unselective effects were very similar: Folk and Remington used a cuing variant of the ISP, in which participants had to find a target square defined by a certain color and to indicate the letter inside the square by pressing one of two keys. Before the target display was presented, a distractor display was displayed, in which each of the (noncolored) squares was surrounded by four circles that could either be of the same color as the target or of a different color. Moreover, these distractors occupied the same position as the target in $1/d$ trials, which permitted assessment of spatially specific effects. Folk and Remington found that differences between P0 trials and P > 0 trials only occurred when the distractors in the preview display matched the target-defining feature but not when the distractors were of a different color. Although the target nonmatching distractors did not produce spatially specific effects, they produced significant distraction costs of approximately 26 ms compared with a distractor-absent control condition. Deviating from the present experiments, the participants always knew the exact target feature, and the distractor was always constructed as being either identical or nonidentical to the target.

The magnitude of the filtering costs as well as the dissociation of spatially specific and unspecific effects seems to be quite similar to the present results. More important, the results of Folk and Remington (1998) are in line with the contingent priming hypothesis, which predicts a prevalence of spatially unspecific filtering costs, provided that participants have an incentive to inhibit irrelevant features. Because this condition was clearly fulfilled in all experiments of the cited study, the present account of filtering costs as inhibition costs can also account for filtering processes in other paradigms.

However, with respect to the visual search paradigm, it might also be asked why this is the first study that has found evidence for spatially unselective filtering costs. A previous study investigating the question of whether distraction costs might be due to filtering or attentional capture clearly ruled out filtering costs in visual search. In a study by Theeuwes and Godijn (2002), inhibition of return was taken as a measure for bottom-up induced attentional shifts to the distractor location. Finding the expected pattern of early facilitation and late inhibition at the singleton distractor position, they concluded that the irrelevant distractor had captured the attention of the observer in a bottom-up fashion. However, the results from that study are actually compatible with the present one, because the authors used the ISP, which showed spatially selective effects in the present study as well. Moreover, the procedure of Theeuwes and Godijn was akin to Experiment 3, insofar as they probed for occurrences of attentional capture by the irrelevant distractor. However, contrary to the present study, the authors did not try to find positive evidence for filtering costs. Thus, it is possible that in this study, too, there were additional filtering costs that remained undetected.

Relation to Other Studies: The Distraction Effect

As already mentioned above, distraction costs in the ASP and ISP have regularly been attributed to singleton capture: According to this account, a salient item will always draw attention to its position in a stimulus-driven fashion, independently of the goals or intentions of the observers (e.g., Theeuwes, 1992, 1994). The present finding that spatially unselective filtering costs account for the distraction effect is at odds with this view and suggests the need to revise the singleton capture account.

However, it might also be doubted whether the distraction effect of the present study is identical to the one observed in other studies. Specifically, one might object that the distraction effect in the present ASP was not modulated by the feature certainty versus uncertainty conditions, whereas in other studies with the ASP, distraction costs were markedly higher in the feature certainty than in feature uncertainty condition: In a study by Theeuwes (1991), participants had to search for a uniquely shaped target that was either constituted by a circle among diamond shapes or a diamond shape among circles. In this feature uncertainty condition, distraction costs amounted to 153 ms, whereas in a twin experiment in which the target shape remained constant (Theeuwes, 1992), distraction costs only amounted to about 23 ms. Similarly, a study by Theeuwes, deVries, and Godijn (2003), which was primarily concerned with the characteristics of overt and covert attention, demonstrated that the presence of a singleton distractor inflated RTs by 208 ms in the feature uncertainty condition but only by 20 ms in the feature certainty condition. In contrast to these findings, performance in the present ASP was not visibly influenced by feature certainty. In the feature uncertainty condition of the ASP (Experiment 1b), distraction costs amounted to 22 ms, whereas in the ASP feature certainty condition, they were 15 ms.

However, it should be noted that the experimental conditions differ in one important respect: Whereas in the cited studies, the target-defining feature switched randomly, in the present study, only the task-irrelevant feature varied. In all experiments of the present study, participants searched for a target bar that was consistently larger than the remaining items, and thus no uncertainty with respect to the target-defining feature was invoked.

Other studies in which the task-irrelevant feature was varied in turn showed very similar results: In a study by Pinto et al. (2005), in which both task-relevant and irrelevant features varied, only switches in the relevant dimension visibly enhanced the distraction effect (see also Olivers & Humphreys, 2003). Thus, the present findings that distraction costs are not greatly affected by switches in the irrelevant feature seem to be compatible with previous studies investigating distraction costs in the ASP.

Logical Relations: Filtering and Attentional Capture

There are still some open questions about the relation between filtering costs and attentional capture: Are they mutually exclusive of each other, do they interact with each other, or are their respective effects additive?

The results from the first experiments might be taken to suggest that attentional capture and filtering processes are mutually exclusive: Whenever spatially selective effects could be found, there were no overall distraction costs indicative of filtering processes (Experiment 1a). On the other hand, whenever differences between the distractor-present and distractor-absent trials appeared, there were hardly any spatially selective effects (Experiments 1b and 2a).

However, subsequent experiments showed that spatially selective effects can also be mediated by priming processes. More precisely, distractor inhibition and target activation processes were obviously responsible for the erroneous selection of the distractor at switch trials, whereas they prevented attentional capture by the irrelevant distractor at repetition trials. Thus, filtering processes and attentional capture also can obviously co-occur.

Hence, the question of whether attentional capture and filtering are mutually exclusive of each other depends on the definition of the term *attentional capture*. If it is restricted only to bottom-up induced instances of attentional capture, then attentional capture and filtering processes are clearly mutually exclusive of each other. If, on the other hand, attentional capture is allowed to describe all instances of spatially selective effects, it can also be mediated by top-down controlled processes and the trial history. In this case, however, filtering processes and attentional capture would not be logically independent of each other: Because filtering processes have been identified with priming processes and because attentional capture is mediated by such priming, it does not make sense anymore to ask whether filtering effects and spatially selective effects are additive or whether they interact. (This question is only applicable when two effects are logically independent of each other.)

The contingent priming hypothesis states that attentional capture in the classical sense only occurs when participants do not have an incentive to inhibit the irrelevant distractor. If they do, inhibition of the competing feature will prompt erroneous selection of the distractor at switch trials and correct rejection of it in repetition trials. The respective inhibition and activation processes in turn are assumed to cost time. If the distractor is selected first, the erroneous selection will of course produce additional costs, because the target still has to be selected. In this limited sense, attentional capture and filtering costs could be viewed as being additive.

However, on the theoretical level, it seems to be better to distinguish between two forms of attentional capture, a stimulus-driven form of attentional capture and a primed form of attentional capture, which is mediated by inhibition processes that carry over to the next trial. This terminology allows for the conclusion that filtering costs and stimulus-driven attentional capture are mutually exclusive of each other, whereas primed attentional capture is naturally accompanied by filtering costs, that is, costs associated with priming.

Intertrial Priming Effects

Priming as an attentional effect. Intertrial priming effects have been observed in numerous studies: They have formerly been demonstrated to occur in conjunction with relevant dimensions (Found & Müller, 1996; Müller et al., 1995; Müller, Reimann, & Krummenacher, 2003); task-relevant features like color (Found & Müller, 1996; Maljkovic & Nakayama, 1994) and form (Pinto et al., 2005); irrelevant dimensions (Olivers & Humphreys, 2003); and irrelevant features like position (Maljkovic & Nakayama, 1996), color, size and orientation (Hillstrom, 2000; Huang et al., 2004). Dimensions and features are thereby called *relevant* when switches or changes of the target and/or distractor concern the target-defining feature or dimension.

In order to explain intertrial facilitation effects with respect to features and dimensions, researchers have developed two different theoretical accounts, the priming of pop-out hypothesis and the dimension weighting hypothesis.

The accounts share some central assumptions; most notably, both theories assume that intertrial facilitation effects affect the speed of attentional selection and not the speed of perceptual, decisional (Hillstrom, 2000; Huang et al., 2004), or response-related effects (Cohen & Magen, 1999; Kumada, 2001; Mortier, Theeuwes, & Starreveld, 2005).

In the present study, intertrial facilitation effects with respect to the task-irrelevant colors of target and distractor could be observed. In the realm of intertrial effects for color, both the dimension weighting hypothesis and priming of pop-out are applicable. This is because changing the target color has been observed to produce weight-shifting costs typically associated with changes of the target dimension (Found & Müller, 1996). This finding led the authors to propose that colors should be regarded as subdimensions rather than features, which in turn can definitely be subject to dimension weighting processes (Found & Müller, 1996; Müller et al., 2003).

The results from the present study also can be taken to provide compelling evidence for the hypothesis that priming indeed affects processes of attentional selection. The finding that selection of an irrelevant distractor was mediated by intertrial contingencies presents the most direct evidence for the central assumption that repetition facilitation effects and switch costs are due to processes of attentional selection (see also Goolsby & Suzuki, 2001). This result obviously cannot refute the possibility that priming might also, in some other experimental settings, be based on decisional or response-related processes. However, in the present experiments, response-related or decision-related priming were excluded as alternative explanations by additional analyses that showed that response priming obviously did not play a role (see Figure 5).

One might wish to object to this conclusion that the decisional view of priming can still account for the effects observed in the present study. It might, for example, be argued that switch trials produce slower RTs because it takes longer to find the target template in short-term memory (Pinto et al., 2005) or else because it takes longer to decide whether the selected target is in fact the target of search (Huang et al., 2004). Alternatively, it is also conceivable that the distractor is selected on every trial and that attention lingers only longer on it in switch trials. Furthermore, it could be claimed that with increases in these decision times, the response-relevant item somehow gains influence, which would explain the enhanced compatibility effects at switch trials.

Although these explanations might at first sound quite plausible, they cannot account for the results of the present study: First of all, Experiment 4 clearly showed that intertrial facilitation effects only occurred in the presence of a salient distractor. On the other hand, if priming was related to difficulties in finding the target template, intertrial facilitation effects should have also occurred in the distractor-absent control condition. However, the finding that this condition was devoid of intertrial priming effects demonstrates that the irrelevant feature did not form part of the target template. Second, on decision-based accounts, the response-relevant item of the target should not only play a role in switch trials but should be part of the decision procedure in all trials, switch and repetition trials alike. Moreover, on the episodic retrieval account, these decision-related processes are based on holistic representations of the target item, and thus intertrial contingencies on the response-related level should interact with intertrial contingencies on the feature level (Huang et al., 2004). However, additional analyses ruled out the possibility that the present intertrial facilitation effects were produced by such an interaction (see Figure 5).[3] In sum, the present study obviously provides compelling evidence for the hypothesis that priming indeed affects the attentional stage.

Contingent priming: Top-down or bottom-up? Although the present results thus provide support for one of the basic tenets of the dimension weighting and priming of pop-out account, they might also be viewed as conflicting with the priming of pop-out account, for the following reasons: First, priming of pop-out asserts that priming occurs automatically, without or even against the intentions and goals of observers. Second, priming was originally supposed to be restricted to the target-defining features and was not supposed to apply to task-irrelevant features (exempting position, which is allowed a special status because attention shifts are presumably location based; Maljkovic & Nakayama, 1996, 2000; see also Huang et al., 2004).

However, it should be noted that no one could hold both of these hypotheses to be true, because they lead to a direct contradiction: either participants are able to restrict priming to task-relevant features but then priming would be contingent on previous top-down attentional control settings (and could not occur automatically), or priming occurs automatically, in which case it is impossible to prevent priming of task-irrelevant features.

However, the apparent contradiction can be easily resolved by distinguishing more clearly between preconditions for priming and characteristics of the priming process itself. As Bargh (1992) has pointed out, the classical concept of automaticity that only includes involuntary, unintentional, autonomous, unconscious, and effortless processes seems to be much too strict: There are hardly any processes that fulfill all of these criteria, which severely limits the applicability of the concept. The majority of automatic processes is at least dependent on previously conscious, intentional decisions: For example, the Stroop effect is eliminated if observers do not actively attend to the stimulus. The observation that most automatic processes occur as a consequence of previous top-down controlled processes led Bargh to propose the notion of conditional automaticity to describe the most frequent occurrences of automatic processes (Bargh, 1989, 1992).

In the same vein, the contingent priming hypothesis only asserts that priming of irrelevant features is subject to top-down attentional control settings that decide which features are subject to distractor inhibition or target activation processes. This hypothesis is very much in line with previous findings that task-irrelevant features are not subject to intertrial priming effects (Maljkovic & Nakayama, 1994, 2000). Even studies that show priming also with respect to irrelevant features have consistently demonstrated that priming of the task-relevant feature is stronger than priming of irrelevant features (Hillstrom, 2000; Huang et al., 2004; Maljkovic & Nakayama, 1996; Olivers & Humphreys, 2003). This presents the most direct evidence that priming effects are contingent on previous top-down controlled settings that distinguish between target and nontarget features.

However, these results do not imply that the priming process itself is a top-down controlled process: In other words, the contingent priming hypothesis does not have to assert that priming is due to participants' choices to actively attend to the more frequent target feature on a trial-by-trial basis, for example, because they expect the target to be the same as in the previous $n - 1$ trial. Studies that explored this question have mostly found that intertrial facilitation effects are somewhat reduced but not eliminated by knowledge about the forthcoming target feature (Müller et al., 2003; Maljkovic & Nakayama, 1994, 2000). Thus, a balanced conclusion appears to be that feature priming might be to some extent top-down penetrable but that it is also automatic in the sense that its effects cannot be completely abolished by top-down control.

In this respect, the contingent priming hypothesis can probably also be said to resolve a puzzle of the feature priming effects, by explaining how the occurrence of priming is contingent on top-down controlled attentional settings, while simultaneously maintaining that priming itself may be largely automatic. Thus, priming is viewed as an instance of contingent automaticity or, more precisely, goal-dependent automaticity (Bargh, 1992; see also Olivers & Humphreys, 2003, for a similar account).

Dimension weighting, priming of pop-out, and contingent priming. Last but not least, one could ask how the present results as well as their interpretation by the contingent priming hypothesis relate to the dimension weighting account and the priming of pop-out hypothesis: Do the present results favor one of these hypotheses over the other, and how is contingent priming related to these two accounts?

First of all, it should be evident that the contingent priming hypothesis does not contradict either the dimension weighting account or the priming of pop-out approach. Instead, it provides a specific description of the attentional mechanism of priming, the contributions of top-down and bottom-up processes in priming, the effects for priming of nominally task-irrelevant features, and other attentional effects, like the distraction effect.

Despite its label, the contingent priming hypothesis seems to be more closely related to the dimension weighting hypothesis than the priming of pop-out account for the following reasons: First, the contingent priming hypothesis subscribes to a contingent automaticity view by claiming that top-down processes select the features that are later subject to priming, while asserting that priming itself may be largely automatic and stimulus driven. As was argued above, any conception that simultaneously claims automaticity and sensitivity of priming to task settings must adhere to a contingent automaticity view. Thus, it seems to be plausible that the priming of pop-out

[3] The question of why priming of the target-defining and the response-relevant and task-irrelevant features in the present experiments did not interact with each other, whereas such results were obtained in a similar visual search task by Huang et al. (2004), can probably be explained by differences in the stimuli: Whereas in the present study response-relevant and task-irrelevant features were constituted by different objects that only accidentally shared a position, the bars used by Huang et al. combined all of these features together into a single object. As the authors themselves pointed out, this combination of features into a single object might have promoted the interaction, because deploying attention to the target might have triggered processing of all of its features (p. 18).

account, too, has always implicitly adhered to a contingent automaticity view of priming, without explicitly stating this.

In contrast, the dimension weighting account has long since explicitly recognized that priming processes are subject to top-down attentional control settings (Hillstrom, 2000; Müller et al., 2003). According to dimension weighting, the instance that decides the question of whether a dimension will be subject to weighting processes can be located at the level of the enabling set. As Krummenacher, Müller, and Heller (2003) proposed, the enabling set holds all possible target dimensions within a given task and enables their principal involvement in weight-shifting processes. The enabling set itself is not directly susceptible to intertrial contingencies but determines the dimensions that are susceptible to it. The authors moreover hypothesized that the contents of the enabling set are determined in a top-down controlled manner. If this conceptualization is correct, the present finding that nearly identical stimulus conditions can lead to an inclusion or exclusion of irrelevant features in weight shifting processes also can be seen as the first experimental evidence for such an instance as the enabling set in intertrial priming.

Second, and probably more important, the contingent priming account is also more akin to dimension weighting in its conception that filtering costs can be equated with costs accruing from priming. The dimension weighting account seems to be more in line with the present finding that distractor inhibition or target activation processes are time consuming: According to the dimension weighting account, activation and inhibition patterns can be described in terms of attentional weight settings (Found & Müller, 1996; Müller, Heller, & Ziegler, 1995). These weights are distributed from a limited source to dimension-specific modules or maps. Importantly, the weight settings from the current trial will transfer to the next trial and thus modulate search performance according to intertrial contingencies: If the target dimension is the same as in the previous $n - 1$ trial, only small adjustments of the weight settings are necessary for attentional selection and, consequently, only small (if any) weight-shifting costs occur. If, however, the target dimension changes, large adjustments in the weight settings are required, which results in time-consuming switch costs.

On the priming of pop-out account, intertrial facilitation effects are, in contrast, mediated by short-term memory traces that separately contain information about the valence of different features. Information about the respective valences is then stored in capacitor-like memory elements that guide attention in accord with the valence values attached to each feature (Maljkovic & Nakayama, 1994, 1996). Although the latter conception of intertrial priming effects is certainly not incompatible with the claim that inhibition processes are themselves time consuming, I would not have expected such a result: First, if the pop-out effect of an item is fairly and squarely modulated by negative and positive valences, benefits from repetition trials and costs occurring from switch trials should have cancelled out each other. Second, on the priming of pop-out account, it is unclear at which stage inhibition costs might be located (i.e., at the stage of valencing or at the stage of transfer by memory elements etc.).

By virtue of these differences between priming of pop-out and dimension weighting, the contingent priming account should probably be regarded as being more closely related to the latter than to the former. However, as Olivers and Humphreys (2003) suggested, maybe there is no real dichotomy between dimension weighting and feature priming effects: The dimension weighting account might also be applicable to feature priming effects, if it is assumed that attentional weights are primarily tuned to dimensions and to a lesser extent also to specific features.

Such an integrated approach seems to be very desirable from a theoretical standpoint. Moreover, the conception also seems to be compatible with the present data and might even provide an explanation for one somewhat puzzling result of the present experiments, that the overall data of the ASP were mostly devoid of spatially selective effects: If it is assumed that participants primarily tuned their weight settings to the color dimension in order to filter out the irrelevant distractor, this strategy would have been more successful in the ASP in which the color singleton never coincided with the size singleton target. In turn, such a strategy is not available in the ISP, which might explain the evidence for more frequent attentional capture in the ISP than in the ASP (see also Experiment 4). However, as already mentioned above, the questions of how feature priming relates to dimension weighting and how both relate to the contingent priming approach certainly require further research.

Conclusion

The present study investigated distraction and intertrial effects in two different visual search tasks involving irrelevant singletons. The investigation yielded several important results: First, costs produced by an irrelevant distractor were shown to depend largely on spatially unselective filtering costs instead of attentional capture. Differences between the ISP and ASP could be explained by the contingent priming hypothesis, which identifies filtering costs with costs accruing from distractor inhibition or target activation processes. These in turn could be identified as instances of priming, and intertrial priming effects could be shown to apply selectively to task-irrelevant features without affecting response-defining features. Second, erroneous selection of the distractor was shown to be more frequent at switch trials than at repetition trials. This in turn provides experimental support for the hypothesis that priming affects attentional processes and not processes at the decision or response-related stage. Finally, the occurrence of intertrial priming effects was dependent on certain stimulus conditions and on the top-down attentional control settings of the observers: First, priming of irrelevant features only occurred in the presence of an irrelevant distractor that competed for attention with the target. Second, even in the presence of an irrelevant distractor, priming of irrelevant features only occurred when participants were given information about more frequent features of the target or the distractor. Taken together with findings of other studies, which showed priming to be related to task relevance, these findings indicate that priming is guided by top-down attentional control settings that classify features according to their task relevance. Last but not least, erroneous selection of the distractor was more frequent in the ISP in which the irrelevant distractor is nonpredictive of the target location than in the ASP in which the distractor is antipredictive. Because this result could be obtained even though ISP and ASP had almost identical stimulus conditions, it suggests that top-down processes do not only determine whether priming occurs at all but also modulate the strength of priming processes in a more fine-grained way. However, additional research is necessary to further elucidate the interaction between top-down and bottom-up processes in priming.

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