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# Top-down contingent capture by color: evidence from RT distribution analyses in a manual choice reaction task

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## Abstract

According to the contingent capture hypothesis, observers can specify their control settings in advance of the target's presentation to quickly attend to relevant target colors. Two predictions were derived from this hypothesis and tested in a manual choice response task. First, contingent capture by color was expected: capture of spatial attention by a better-matching color stimulus should be stronger than capture by a less-matching color stimulus. Second, with the control settings specified in advance, the contingent capture by color should commence early after the stimulus onset and should be evident among fast correct responses in an RT distribution. Both predictions are shown to hold true in two experiments. Results are discussed in light of contrasting evidence for saccadic instead of manual responses.

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## 1. Introduction

The deployment of visuospatial attention to a circumscribed region within the visual field is thought to be one of the main requirements for the representation of stimulus input from that region (cf. Helmholtz, 1896; Neisser, 1967; Posner, 1980; Treisman & Gelade, 1980). Beginning with the first studies on visuospatial attention, it has become increasingly clear that humans can exert top-down control on where to direct their attention (Helmholtz, 1896). In his ingenious study, Helmholtz instructed his participants to attend to specific regions away from fixation on a newspaper front page. The page was illuminated for a fraction of a second. It turned out that participants were able to report words from the attended region at the cost of reporting words at fixation. Helmholtz considered this as evidence that his participants deployed attention willingly or in a goal-directed manner to a particular location. Note also that Helmholtz was the first to observe that shifts of visuospatial attention do not require overt eye movements, but can proceed covertly (cf. Posner, 1980; Wolfe, 2003).

Similar top-down contingencies of the deployment of attention seem to hold true for attentional selection of visual stimuli by a pre-specified color. In investigations that have used manual choice responses or saccades to discriminate between targets, it has been found that participants are able to selectively attend to task-relevant color targets and to ignore—at least to some extent—nontargets with a task-irrelevant color (cf. Ansorge & Heumann, 2003, 2004; Eriksen, 1953; Folk & Remington, 1998, 1999; Gibson & Kelsey, 1998; Green & Anderson, 1956; Remington, Folk, & McLean, 2001; Theeuwes & Burger, 1998; Williams, 1966; Yantis & Egeth, 1999; for a more general argument see Duncan & Humphreys, 1989).

Studies that used color stimuli as nontarget cues to capture attention illustrate this capability (Folk & Remington, 1998; Folk, Remington, & Johnston, 1992). Folk and Remington (1998) asked their participants to report the shape of a red target (whether it was an '=' symbol or an 'x') by means of a manual choice response. The authors used a green or a red cue in advance of the target at one of four possible target locations. In valid conditions, the cue appeared at the same position as the target, whereas in invalid conditions, the cue was shown at a different position. The cue did not predict the most likely position of the target—it was a so-called nonpredictive singleton. Therefore, participants had no incentive to attend to the cue as such.

In accordance with the aforementioned capability to selectively attend to the relevant target colors and to successfully ignore the irrelevant nontarget colors, Folk and colleagues found that a nontarget cue with a target-similar color captured spatial attention and could not easily be ignored. That the target-similar valid cue captured attention to the target was evident from a decreased time to correctly discriminate the target shape—that is, it led to a shorter correct choice RT (reaction time). Yet, with an invalid target-similar cue, the opposite held true: the target-similar cue directed attention away from the target, so that attention needed to be redirected to the target, thereby, delaying the discrimination of the target shape (see also Posner, 1980). In contrast, a cue with a target-dissimilar color was more efficiently

ignored. For example, a green cue that was presented in advance of a red target did not capture spatial attention (i.e., performance was not better in valid than in invalid conditions), although the authors found an unspecific RT cost in both valid and invalid conditions relative to a neutral condition without a cue, presumably because color-heterogeneous displays cannot be as efficiently processed as color-homogeneous displays (Folk & Remington, 1998).

Supporting evidence comes also from more typical visual search experiments in which target and nontargets had concomitant onsets. Green and Anderson (1956), for instance, asked their participants to search for a target within a display that consisted of 50% red objects and of 50% green objects. In this situation, prior information about the target color reduced search times by half. Again, it seems that participants were able to willingly ignore the irrelevant color nontargets.

These and analogue observations can be explained by top-down contingent attentional capture (cf. Folk et al., 1992; Logan, 1978; Scharlau & Ansorge, 2003). According to the *contingent capture hypothesis*, participants specify their control settings in advance of the displays (Folk et al., 1992). As a consequence, they are better able to attend to the target's features (e.g., its color) and to better ignore the nontarget's features, right from the onset of these stimuli.

According to the contingent capture hypothesis, an irrelevant nontarget stimulus with a target-similar color better matches the control settings—it is therefore called a better-matching nontarget—and more often erroneously captures spatial attention. Likewise, an irrelevant nontarget with a target-dissimilar color matches the control settings less—it is therefore called a less-matching nontarget—and can be ignored more easily.<sup>1</sup> Again, with the attentional control settings being specified in advance, it should be possible to pay less attention to the less-matching nontarget than to the better-matching nontarget, right from the display's onset.

If the contingent capture hypothesis holds true and control settings for attentional capture by color can be specified in advance, we expect contingent capture by color to be evident very early after the onset of a nontarget. To test this hypothesis in the current investigation, the capture of spatial attention by better-matching and less-matching nontargets is studied as a function of the distribution of the correct manual choice RTs. Basically, with the top-down control settings for target color being specified in advance, a better-matching nontarget has the potential to capture spatial attention right from its onset. Of course, even a simple feature, such as a particular stimulus color, needs some time before it is processed and before it becomes behaviorally relevant (i.e., before it can capture attention). Therefore, the effect of the better-matching nontarget on spatial attention might not be present among the fastest responses. In any case, however, on the basis of the contingent capture hypothesis, contingent capture by color is predicted to show up as fast as capture of spatial attention itself—that is, among the lower correct RTs, evidence

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<sup>1</sup> To denote the different conditions, we use better-matching and less-matching instead of the terms matching and nonmatching to acknowledge that it is virtually always possible to find aspects of the nontargets that matched some of the control settings (e.g., Gibson & Kelsey, 1998).

for contingent capture by color and for capture of spatial attention per se should coincide.

A previous investigation that used saccadic responses seems to be at odds with this prediction of the contingent capture hypothesis (Van Zoest, Donk, & Theeuwes, 2004). In one of the experiments of that study, participants had to make a saccade toward a predefined color target. Simultaneously with the color-singleton target, a number of uniformly colored nontargets, and a color-singleton nontarget (with a color different from both the target color, and the uniformly colored nontargets) were shown. It turned out that in 50% of the trials the fastest saccades were first erroneously directed to the color-singleton nontarget. Only among the slower responses, the participants were successful in directing their initial saccade to the color-singleton target more frequently than to the color-singleton nontarget.

To explain their results, Van Zoest et al. assumed that capture of spatial attention is initially stimulus-driven by feature contrasts (such as color differences) rather than top-down contingent. Therefore, both color singletons—target and nontarget—were equally likely to initially capture attention, and to specify the direction of the quickest saccades. Top-down control settings to search for a particular color were assumed to be effective only at a later point in time. As a consequence, contingent capture by color, and a corresponding successful programming of the saccade's target location was only observed among the slower saccades.

However, as outlined above, spatial attention can be shifted covertly without a following or a concomitant saccade (cf. Posner, 1980). In the visual search for a target, for example, the estimated search time per stimulus in the display is generally much faster than the latencies of even the fastest saccades (Wolfe, 2003). Thus, saccadic performance cannot fully account for the shifting of spatial attention. Beyond that, visual search performance in saccadic tasks and manual choice reaction tasks is not necessarily the same (cf. Ludwig & Gilchrist, 2002; for a more general argument see Posner, 1978, 1980).

To put the contingent capture hypothesis to a more exhaustive test, in the current study, participants had to give manual choice responses to the targets. If it is true that the saccadic task is special, we might find more evidence for the contingent capture hypothesis in the current experiments than has been found in the study of Van Zoest et al. (2004).

## 2. Experiment 1

Predictions derived from the contingent capture hypothesis were tested with manual choice responses to the different shapes (or orientations) of color targets (cf. Ansorge & Heumann, 2003, 2004; Folk et al., 1992). In each trial, one color target was presented together with a nontarget stimulus in the display. The color target was a semi disk of a known color with a vertical or a horizontal bar in it. Participants had to respond to the orientation of the bar of the color target.

The nontarget stimulus was either better-matching or less-matching to the set of searched-for target colors. Suppose, for example, that the target was either red or

white, and participants had been informed about the possible target colors in advance. Under these conditions, a green nontarget stimulus that was presented together with a red target was a less-matching nontarget because the target itself was never green. Under the same conditions, a red nontarget stimulus that was presented together with a white target was a better-matching nontarget because the target itself was red in 50% of the other trials. If the control settings for the target colors can be specified in advance, attentional capture should be less for the less-matching nontarget than for the better-matching nontarget.

To assess the capture of spatial attention, we used an index proposed by [Turatto and Galfano \(2001\)](#) that applies a similar logic as the use of valid-to-invalid performance differences. Former studies have often considered an RT increment induced by a nontarget color stimulus away from the target (relative to a color-homogeneous display without such a nontarget) as an index of the nontarget's capture of spatial attention (cf. [Theeuwes, 1992, 1994](#)). Yet, as has been explained above, this index could be misleading because this kind of interference may also reflect the nonspatial costs of the processing of a color-heterogeneous relative to a color-homogeneous display (cf. [Folk & Remington, 1998](#)).

Therefore, we varied the spatial distance between the target and the nontarget to test whether RT interference by the nontarget is a function of the target–nontarget distance (i.e., whether RT increases along with an increasing distance; cf. [Egley & Homa, 1991](#)). Note that the expected result cannot easily be explained by the nonspatial filtering-out of the irrelevant nontarget's color from the color-heterogeneous displays, because a nonspatial process could not account for the strength of interference being a function of the spatial target–nontarget distance (i.e., the spatial gradient of the interference) (cf. [Turatto & Galfano, 2001](#)).

We investigated four target–nontarget distances: the distance was zero (in terms of display positions between target and nontarget) or minimal (in terms of spatial distance) in condition p0 and increased in three steps (by equal amounts per step) up to condition p3. We expected the amount of interference to be the least in the condition p0 and to increase along with the target–nontarget distance (cf. [Egley & Homa, 1991](#)).

On the basis of the contingent capture hypothesis, we predicted the following results: first, we expected contingent capture by color—that is, a stronger capture of spatial attention by the better-matching nontarget relative to the less-matching nontarget. In [Figs. 2–5](#), this pattern of effects corresponds to a steeper ascending slope (from left to right) of the RT function that relates RT to target–nontarget distance in the better-matching conditions (broken lines) than in the less-matching conditions (unbroken lines).

Second, we expected concurrent onsets among the lower correct RTs of (1) the contingent capture by color and (2) the capture of spatial attention per se. In [Figs. 2 and 4](#), this pattern of results corresponds to a co-occurrence among the faster RTs (i.e., among the lower quintiles of the RT distribution) of (1) a steeper ascending slope of the RT function in the better-matching relative to the less-matching conditions and (2) any evidence for an ascending RT function in any of the two conditions.

## 2.1. Method

### 2.1.1. Participants

Twenty-four volunteers (12 female, 12 male) with a mean age of 27 years participated. Here and in the following experiments, participants were mostly students at Bielefeld University. All had normal or fully corrected vision, and were paid for their participation.

### 2.1.2. Apparatus

The experiment was controlled by a computer that also registered responses. Stimuli were presented on a 15-in. color monitor. A serial mouse was used for the responses. Participants pressed left and right mouse buttons with the index fingers of the corresponding hands. Latencies were measured from the beginning of the target to the nearest millisecond. The participants were seated in a dimly lit room, 65 cm in front of the screen, with their line of gaze straight ahead, head supported by a chin rest.

### 2.1.3. Stimuli and procedure

See also Fig. 1. Each trial started with the presentation of seven gray disks (each with a radius of  $.5^\circ$ ), one at each of the seven equidistant positions ( $3.2^\circ$  of visual angle between positions) on an imaginary circle (centered on the screen with a radius of  $3.9^\circ$ ). After 1000 ms, three changes occurred simultaneously. First, the top-half or the bottom-half of one of the seven disks changed color (e.g., turned red), and a vertical or a horizontal bar appeared inside this semi-disk. This stimulus was the target. Second, one complementary oriented semi-disk changed into a different color than the target. This semi-disk was the nontarget. Third, all other disks and semi-disks were turned off.

Participants had to give a fast and accurate choice response (left vs. right key press) to the orientation of the target bar (horizontal vs. vertical). Different S–R (stimulus–response) mappings were balanced across participants. For half of the participants (Group 1), the target was red (RGB: 255, 43, 0) in 50% of the trials and it was white for the other 50% of the trials. For the other half of the participants (Group 2), the target was green (RGB: 0, 255, 0) in 50% of the trials and it was white for the other 50% of the trials.

As a consequence, the nontarget color equally likely matched the set of searched-for target colors well or less well. In Group 1, the better-matching nontarget was red and the less-matching nontarget was green. For example, if a white bottom-half semi-disk was presented as a target, a red top-half semi-disk was used as a better-matching nontarget, because a red semi-disk was a target in 50% of all the other trials. In contrast, if a red top-half semi-disk was presented as a target, a green bottom-half semi-disk was used as a less-matching nontarget, because a green semi-disk was never used as a target in any of the trials. Likewise, in Group 2, the better-matching nontarget was green and the less-matching nontarget was red. Thus, the use of green vs. red colors for the better-matching and the less-matching nontargets, respectively, was balanced across participants.

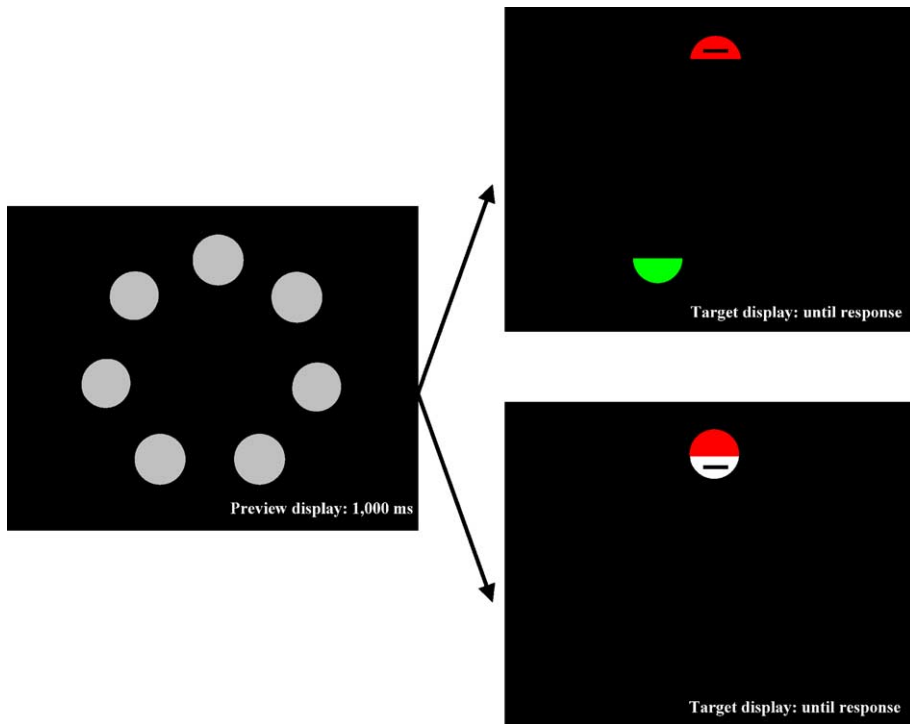


Fig. 1. Depicted are different possible conditions of Experiment 1. Left: the preview displays consisted of seven gray disks. Right: the target displays consisted of a target semi-disk and a second nontarget semi-disk of a different color. Right/top: depicted is an example of a display with a red target and a less-matching green nontarget. The nontarget is presented at a location three positions away from the target (condition “p3”). Right/bottom: depicted is an example with a white target and a better-matching red nontarget in the display. The nontarget is presented with a minimal distance to the position of the target (condition “p0”). For further information refer to the Method section.

The target and nontarget positions were uncorrelated, and (across trials) equally likely distributed among the seven possible disk locations. As a consequence, four different target–nontarget distances were created. In condition p0, the nontarget was at the target position—that is, it completed the target semi-disk to a full disk. For instance, a less-matching green bottom-half semi-disk at position p0 completed a red top-half target semi-disk above it to appear as a full disk. In condition p1, the nontarget was shown at one of the positions next to the target. In condition p2, the nontarget was at one of the one-but-next positions from the target. In condition p3, the nontarget was presented with a distance of three positions away from the target.

Participants were instructed to ignore the irrelevant nontarget. To that end, before the data recording started, participants were fully informed, both by instruction and by practice, about the different possible colors of the targets and of the nontargets. Additionally, participants were informed that the nontarget did not predict the position of the target.

The inter-trial-interval was 2000 ms. This was also the maximal latency which was allowed for the responses. After an incorrect response, an error message was presented for 700 ms. If the RT exceeded 1250 ms, a feedback was presented for 700 ms which instructed participants to respond faster.

The two possible S–R mappings and the two possible target-color mappings (Group 1; Group 2; see above) were balanced across participants. Also, target and nontarget semi-disks were equally likely top-halves or bottom-halves. Each of the combinations that resulted from a complete crossing of the two target shapes (vertical; horizontal)  $\times$  seven target positions  $\times$  seven nontarget positions  $\times$  two target colors (red or white; green or white; between participants) was repeated twice during each of two sessions, resulting in a total of 784 trials. Prior to the first session, participants practiced the task. Each session had a duration of about one hour.

## 2.2. Results

Figs. 2 and 3 show the main results. Out of all the trials, .2% were excluded from the analyses because responses were faster than 100 ms or slower than 2000 ms. Mean RTs of correct responses were vincentized (Ratcliff, 1979), separately for each of the eight conditions resulting from the combinations of the variables nontarget type (better-matching or less-matching) and target–nontarget distance (p0, p1, p2, or p3): individual mean RTs were derived for each quintile of the rank-ordered raw RT data, and analyzed by an ANOVA, with *nontarget* type (better-matching

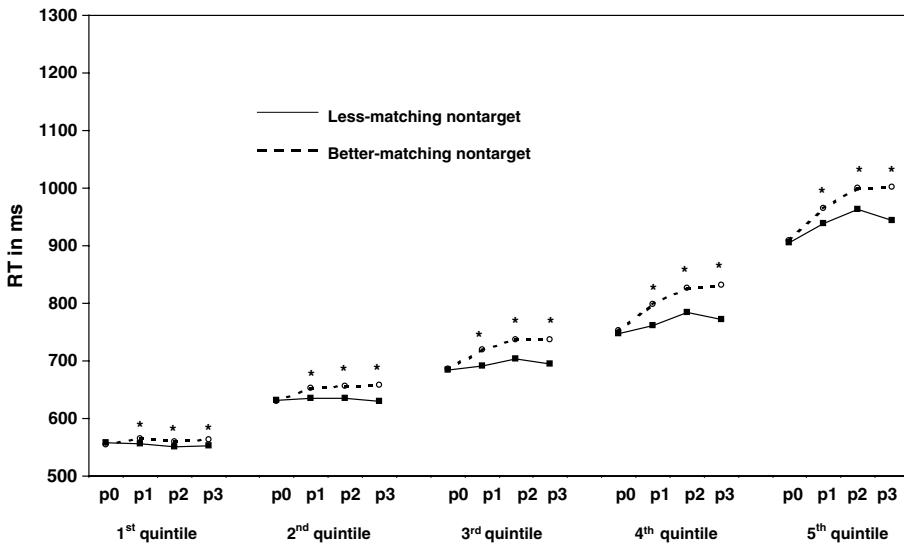


Fig. 2. Mean correct reaction time (RT) as a function of nontarget type (better-matching vs. less-matching nontarget condition), of target–nontarget distance (p0–p3 from small to large), and quintile of the RT distribution of Experiment 1. \*: significant difference between better-matching and less-matching nontarget conditions for an alpha level of  $p < .05$  or lower.



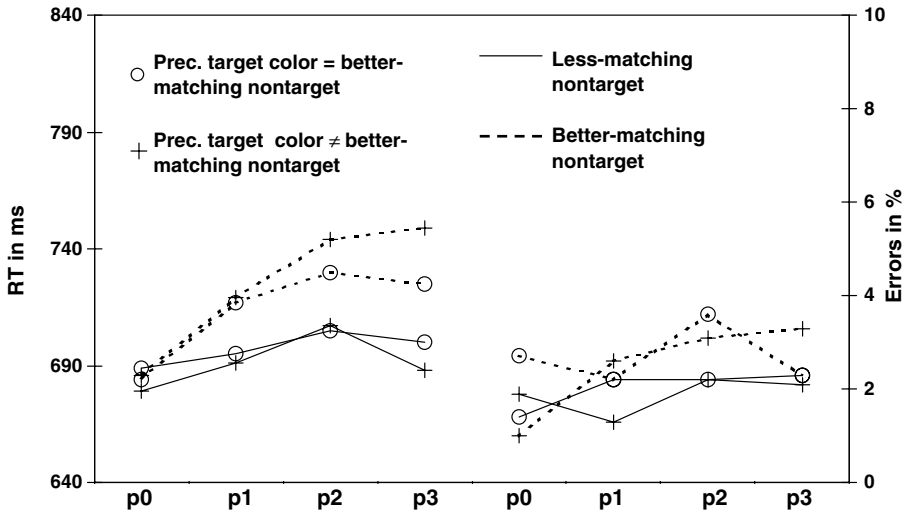


Fig. 3. Mean correct reaction time (RT; on the left) and mean percentage of error (on the right) as a function of nontarget type (better-matching vs. less-matching nontarget condition), preceding target color (same as the better-matching nontarget vs. different from the better-matching nontarget) and of target–nontarget distance (p0–p3 from small to large) of Experiment 1. Prec.: preceding.

or less-matching), target–nontarget *distance* (p0, p1, p2, or p3), and *quintile* (first to fifth, from fast to slow responses) of the RT distribution as within-participant variables. Significant main effects of nontarget,  $F(1, 23) = 12.75$ ,  $p < .01$ , distance,  $F(3, 69) = 31.46$ ,  $p < .01$ ,  $\epsilon = .44$ , and quintile,  $F(4, 92) = 387.23$ ,  $p < .01$ ,  $\epsilon = .28$  (degrees of freedom were adjusted by Greenhouse-Geisser coefficients of  $\epsilon$  where sphericity tests indicated that this was appropriate), and significant interactions of Nontarget  $\times$  Distance,  $F(3, 69) = 22.35$ ,  $p < .01$ , Distance  $\times$  Quintile,  $F(12, 276) = 35.32$ ,  $p < .01$ ,  $\epsilon = .18$ , and Nontarget  $\times$  Distance  $\times$  Quintile,  $F(12, 276) = 8.96$ ,  $p < .01$ ,  $\epsilon = .39$ , were observed. RT was lower with a less-matching nontarget (717 ms) than with a better-matching nontarget in the display (740 ms). The capture of spatial attention was evident from an increasing RT with an increasing target–nontarget distance: as confirmed by pair-wise  $t$ -tests between cell means of adjacent distance conditions, RT increased from p0 to p1, and from p1 to p2, both  $t(23) > 3.30$ , both  $ps < .01$  (Bonferroni-adjusted), but not from p2 to p3,  $t < 1.00$ . Trivially, RT also increased from the first to the fifth quintile of the RT distribution. The contingent capture by color was also observed. Only with the better-matching nontarget, RT increased from p0 to p1, and from p1 to p2, both  $t(23) > 4.40$ , both  $ps < .01$ , but not from p2 to p3,  $t < 1.00$ . In contrast, with the less-matching nontarget, RT only increased from p1 to p2,  $t(23) = 3.13$  (Bonferroni-adjusted),  $p < .01$ , but not from p0 to p1,  $t(23) = 1.23$ ,  $p = .23$ , and significantly decreased from p2 to p3,  $t(23) = 2.48$ ,  $p < .05$  (Bonferroni-adjusted). Finally, in line with the contingent capture hypothesis, onsets of the capture of spatial attention and of the contingent capture by color coincided among the fast responses. As can be seen in Fig. 2,

throughout all five quintiles, responses were significantly slower (symbolized by asterisks) with a better-matching nontarget (broken lines) presented away from the target (conditions p1–p3) than with a less-matching nontarget presented away from the target (unbroken lines). This was confirmed by pair-wise *t*-tests for adjacent target–nontarget distances that were made for each quintile and nontarget condition in turn. Among the fastest responses (in the first quintile), the tests failed to confirm any significant difference between adjacent distance conditions in both nontarget conditions. The better-matching nontarget led to a spatial gradient (or a distance effect) from the second to the fifth quintile which was evident from at least one significant difference ( $p < .05$ , Bonferroni-adjusted) per quintile, whereas the less-matching nontarget led to significant distance effects only from the third quintile onwards.

Additional analyses included the variable preceding trial's target color instead of the variable quintile of the RT distribution to test for a contribution of priming of pop-out to the capture of spatial attention by the better-matching nontarget. *Priming of pop-out* denotes the observation that participants are particularly fast in finding a color target if the target in a preceding trial  $N - 1$  has the same color as that in the actual trial  $N$  (cf. Maljkovic & Nakayama, 1994). Only attentional capture by the better-matching nontarget, but not the attentional capture by the less-matching nontarget, could have benefited from this kind of trial-by-trial pop-out priming: in trial  $N$ , the color of the better-matching nontarget could have been the same as that of the target in trial  $N - 1$ . In contrast, in trial  $N$ , the color of the less-matching nontarget was always different from that of the target in trial  $N - 1$ .

As a consequence, for example, a red, better-matching nontarget might capture the attention more reliably than a green, less-matching nontarget only if a red target was presented in the immediately preceding trial. However, with a white target in the preceding trial, capture by a red, better-matching nontarget might be the same as capture by the equally salient green, less-matching nontarget. It is therefore possible that priming of pop-out gives rise to more capture of spatial attention by the better-matching nontarget (relative to the less-matching nontarget) too (cf. Olivers & Humphreys, 2003).<sup>2</sup>

The first trial of each session was excluded from the additional ANOVAs of RTs and error rates, with *nontarget* type (better-matching or less-matching), target–nontarget *distance* (p0, p1, p2, or p3), and *preceding trial's target color* (same as the better-matching nontarget or different from the better-matching nontarget) as within-participant variables, because the initial trial of a session had no preceding trial. In the additional ANOVA of the means of individual median latencies of correct responses, significant main effects of nontarget,  $F(1, 23) = 14.91$ ,  $p < .01$ , and distance,  $F(3, 69) = 17.37$ ,  $p < .01$ ,  $\epsilon = .54$ , and significant interactions of Nontarget  $\times$  Distance,  $F(3, 69) = 9.07$ ,  $p < .01$ , and Nontarget  $\times$  Preceding trial's target color,  $F(1, 23) = 6.54$ ,  $p < .05$ , were observed. RT was lower with a less-matching nontarget (695 ms) than with a better-matching nontarget (719 ms) in the display. Again, the capture of spatial attention was observed: RT increased with an increasing target–

<sup>2</sup> We are grateful to Chris Olivers for pointing out this alternative hypothesis to us.

nontarget distance as confirmed by pairwise *t*-tests between adjacent distance conditions from p0 to p1, and from p1 to p2, both  $t(23) > 3.00$ , both  $ps < .01$ , but not from p2 to p3,  $t(23) = 1.84$ ,  $p = .08$ . Most importantly, the two-way interaction of Nontarget  $\times$  Distance again reflected the predicted contingent capture by color. With the better-matching nontarget, *t*-tests between adjacent distance conditions confirmed an increasing RT from p0 to p1, and from p1 to p2, both  $t(23) > 3.70$ , both  $ps < .01$ , but not from p2 to p3,  $t(23) < 1.00$ . However, with the less-matching nontarget, *t*-tests only confirmed an RT increment from p1 to p2,  $t(23) = 2.60$ ,  $p < .05$ . With the less-matching nontarget, the difference between distance conditions p0 and p1 failed to become significant,  $t(23) < 1.00$ , whereas the difference between p2 and p3 even indicated a significant RT facilitation with an increasing target–nontarget distance,  $t(23) = 3.00$ ,  $p < .01$ . Finally, a trial-by-trial *repetition of the nontarget color* incurred a slight cost in trial *N* (better-matching nontarget: RT = 724; less-matching nontarget: RT = 697 ms) relative to a trial-by-trial change of the nontarget color (better-matching nontarget: RT = 714 ms; less-matching nontarget: RT = 692 ms). This can be seen on the left side of Fig. 3. Responses were slower in conditions with a nontarget in trial *N* that had the same color as the nontarget in trial *N* – 1 (broken line/cross symbols: better-matching nontarget colors do not change from trial *N* – 1 to trial *N*; unbroken line/circular symbols: less-matching nontarget colors do not change from trial *N* – 1 to *N*) than in conditions with a nontarget that had not the same color as the nontarget in trial *N* – 1 (broken line/circular symbols and unbroken line/cross symbols). This particular result was responsible for the interaction of Nontarget  $\times$  Preceding trial's target color. It indicated that the nontarget color in trial *N* – 1 could have facilitated capture by the nontarget color in trial *N*. Yet, this kind of facilitation of attentional capture (by the preceding nontarget color rather than by target color) can neither account for the capture of spatial attention nor for the contingent capture by the color of the better-matching nontarget, because facilitation was observed with better-matching and less-matching nontargets, and (a) the two-way interaction of Distance  $\times$  Preceding trial's target color,  $F(3, 69) = 1.11$ ,  $p = .35$ , and (b) the three-way interaction of all variables,  $F(3, 69) = 1.36$ ,  $p = .26$ , failed to become significant. The main effect of the preceding trial's target color was also not significant,  $F < 1.00$ .

A corresponding ANOVA of the arcsine-transformed error rates yielded significant main effects of nontarget,  $F(1, 23) = 9.85$ ,  $p < .01$ , distance,  $F(3, 69) = 5.53$ ,  $p < .01$ , and a significant three-way interaction of Nontarget  $\times$  Distance  $\times$  Preceding trial's target color,  $F(3, 69) = 3.37$ ,  $p < .05$ . To test whether the capture of spatial attention or the contingent capture by color in the error rates might have been confined to the conditions in which target color of trial *N* – 1 primed capture by the better-matching nontarget in trial *N*, separate ANOVAs were conducted for each of the two levels of the variable preceding trial's target color. Results indicated that trial-by-trial priming of pop-out was not responsible for the capture of spatial attention by the better-matching singleton. The capture of spatial attention (variable distance) was only significant if the color of the target in trial *N* – 1 was *not* the same as that of the better-matching nontarget in trial *N*,  $F(3, 69) = 7.15$ ,  $p < .01$  (broken line/cross symbols on the right side of Fig. 3). In contrast, the capture of spatial attention

was absent if the color of the target in trial  $N - 1$  was the same as that of the better-matching nontarget in trial  $N$ ,  $F(3, 69) = 1.38$ ,  $p = .26$  (broken line/circular symbols on the right side of Fig. 3). Whatever be the reason for this finding, it certainly rules out that the trial-by-trial priming of the color of the better-matching nontarget by the target's color in the preceding trial was responsible for the capture of spatial attention. In fact, there was no significant contingent capture by color in the error rates at all. The interaction of Nontarget  $\times$  Distance only tended toward significance in those conditions in which the target in trial  $N - 1$  had the same color as that of the better-matching nontarget in trial  $N$ ,  $F(3, 69) = 2.51$ ,  $p = .07$ . The same interaction was nonsignificant in those conditions in which the target in trial  $N - 1$  had a different color than the better-matching nontarget in trial  $N$ ,  $F(3, 69) = 1.20$ ,  $p = .32$ .

### 2.3. Discussion

Experiment 1 revealed a number of noteworthy results that are in line with the contingent capture hypothesis. First, we observed evidence for contingent capture by color. The capture of spatial attention (variable distance) by the better-matching nontarget was stronger than the capture of spatial attention by the less-matching nontarget (cf. Folk et al., 1992). The capture of spatial attention by the better-matching nontarget had a spatial gradient: a nontarget that was presented further away from the target interfered to a larger degree than a more target-adjacent nontarget (cf. Downing, 1988; Egly & Homa, 1991; Scharlau, 2004). Usually, interference that increases across target–nontarget distances is attributed to analogue movements of visual attention through space (cf. Egly & Homa, 1991). In any case, we consider this spatial gradient of the better-matching nontarget's interference effect to be an unambiguous hallmark of the capture of spatial attention. We regard it as unlikely that a nonspatial process of filtering-out the nontarget color from the image provides a better account of the effect of the color singleton (cf. Folk & Remington, 1998). Nonspatial filtering costs in color-heterogeneous displays should be the same for conditions with a color nontarget presented near the target and for conditions with a color nontarget presented away from the target (cf. Turatto & Galfano, 2001).

Second, the contingent capture by color had a rapid onset: a stronger capture of spatial attention by the better-matching nontarget relative to the less-matching nontarget was present among the lower RTs in the distribution of the correct RTs. In fact, in the current experiment, the onset of the capture of spatial attention by the better-matching nontarget preceded the onset of the capture of spatial attention by the less-matching nontarget. The coincidence of the capture of spatial attention and the contingent capture by color among the lower RTs is well in line with the assumption of the contingent capture hypothesis that participants specified their control settings for capture of spatial attention by the target colors in advance of the displays, so that a better-matching nontarget captured more attention than a less-matching nontarget, right from its onset.

This result, however, is in disagreement with previous findings of a saccadic reaction study by Van Zoest et al. (2004) in which contingent capture by color seemingly trailed behind stimulus-driven capture of spatial attention by stimulus salience.

Taken together the results of the current study and of Van Zoest et al. suggest that participants might have used different control settings to direct overt saccades than to direct spatial attention. Why participants might have used different control settings in the two tasks will be thoroughly discussed in Section 4.1.

A third important finding of Experiment 1 is that contingent capture by color was approximately equally strong, regardless of whether the target in the preceding trial  $N - 1$  did or did not have the same color as the better-matching nontarget in an actual trial  $N$ . Again, this result is in line with the assumptions of the contingent capture hypothesis, according to which control settings for attentional capture can be specified in accordance with the instructions, and in advance of the displays. The results rule out that trial-by-trial priming of the nontarget color by the color of the target in the preceding trial is responsible for the stronger capture of spatial attention by the better-matching nontarget.

Beyond that, we also observed capture of spatial attention by the less-matching nontarget. This effect cannot be explained by a match between the color of the nontarget and the top-down controlled search settings for the target colors. It is possible that the capture of spatial attention by the less-matching nontarget was due to the stimulus-driven capture by this salient color singleton (cf. Bergen & Julesz, 1983; Lamy & Egeth, 2003; Theeuwes, 1992; Van Zoest et al., 2004). However, it is also possible that the less-matching nontarget captured attention by virtue of matching an additional control setting besides that for target color. For example, the less-matching nontarget's shape-singleton status (e.g., its being the single differently oriented semi-circle in the display) matching a top-down controlled set to search for another shape singleton (i.e., the line of the target) may have been responsible for its capture of spatial attention (cf. Bacon & Egeth, 1994). Alternatively, participants may also specify some of their control settings in advance to discriminate between different target colors where this is needed (as in the current experiment with its two different target colors). This would lead to the inevitable consequence that even an unspecified color stimulus can capture attention at least to some extent or in some of the trials by virtue of a match to this particular top-down controlled attentional setting.

In summary, it is possible that the RT effect of the less-matching nontarget reflects a mode of stimulus-driven capture or that it is due to some other kind of top-down matching process beyond the one that is responsible for contingent capture by color. In any case, however, the capture by the less-matching nontarget could have never been as strong as that of the better-matching singleton: only the latter also had a color that matched the settings for the to-be-searched-for target colors in addition to all of the conceivably matching and, hence, capturing features that were shared by the better-matching and the less-matching nontarget.

### 3. Experiment 2

In the previous Experiment 1, top-down control of attentional capture by color was seemingly less than perfect. This was evident from the RT interference effect

of the less-matching nontarget. In contrast, in the previous experiments less-matching nontargets sometimes did not capture the spatial attention at all (cf. Ansorge & Heumann, 2003; Ansorge & Neumann, in press; Folk & Remington, 1998; Folk et al., 1992). Several putative top-down control settings for other aspects of the target might have fostered the capture of spatial attention by the less-matching nontarget in Experiment 1. In particular, the most unequivocal evidence for the contingent capture by color has been observed with a very small set size of only one to-be-searched-for target color (cf. Folk & Remington, 1998; Folk et al., 1992; Theeuwes & Burger, 1998).

To optimize conditions for the contingent capture by color, we used a single target color in Experiment 2. The target was either always red or always green (differing between participants) and the less-matching nontarget was always green if the target was red, or it was always red if the target was green. Under these conditions, participants need not discriminate between different target colors. Hence, if the necessity to discriminate the target colors between trials allows for an occasional match of the less-matching nontarget to this attentional setting (see also Duncan & Humphreys, 1989), the capture of spatial attention by the less-matching nontarget might be further reduced in the present experiment, thereby, substantiating the assumption of the contingent capture hypothesis.

In addition to this experimental group, we used a control group to show that the diminished capture of the spatial attention by the less-matching nontargets can be overcome, once the colors match the top-down control settings. The control group received the very same displays as the experimental group, but target colors were either red or green and changed unpredictably from trial to trial. As a consequence, the very same green or red nontargets that were less-matching in the experimental group were better-matching in the control group. If the contingent capture hypothesis holds true, we expected the capture of spatial attention in the control group but not in the experimental group.

### *3.1. Method*

#### *3.1.1. Participants*

Twenty-four participants (13 female, 11 male) with a mean age of 25 years participated in Experiment 2.

#### *3.1.2. Apparatus, stimuli, and procedure*

These were the same as those in Experiment 1, with the following exceptions. First, half of the participants searched for only one target color, either red or green (between participants). In conditions with a green target, the less-matching nontarget was red and in conditions with a red target, the less-matching nontarget was green. Second, the other half of the participants were in a control group, in which it was to be shown that the same nontargets captured attention in conditions in which their color matched the settings for the to-be-searched-for target colors. As in the experimental group, in the control group, displays with a red target contained a green nontarget, and displays with a green target contained a red nontarget. However,

in the control group, red and green nontargets both matched well to the set of to-be-searched-for target colors, because, unforeseeable to the participants, targets were either red or green.

### 3.2. Results

Main results are depicted in Figs. 4 and 5. Out of all trials, .2% were excluded from the analyses because responses were faster than 100 ms or slower than 2000 ms. In an ANOVA of the mean correct RTs in the less-matching nontarget conditions, with target–nontarget *distance* (p0, p1, p2, or p3) and *quintile* of the RT distribution (first to fifth from fast to slow responses) as within-participant variables, there was no evidence for the capture of spatial attention: the main effect of distance was far from significant,  $F < 1.00$ . There was a significant effect of quintile,  $F(4, 44) = 206.63$ ,  $p < .01$ ,  $\epsilon = .30$ , and a tendency toward a significant interaction of Distance  $\times$  Quintile,  $F(12, 132) = 2.51$ ,  $p = .07$ ,  $\epsilon = .28$ . RT increased as a function of quintile. With a less-matching nontarget (unbroken lines), there was a single significant RT difference due to the capture of spatial attention between conditions p0 and p3 in the fifth quintile,  $t(11) = 2.34$ ,  $p < .05$  (unadjusted). All other pair-wise comparisons of RTs of adjacent distance conditions were not significant, all other  $t_s(11) < 1.51$ , all  $p_s > .16$  (unadjusted).

By comparison, the same nontargets captured spatial attention in the better-matching control condition. In contrast to the less-matching nontargets that did not capture spatial attention (the unbroken lines in Fig. 4 are all flat), the

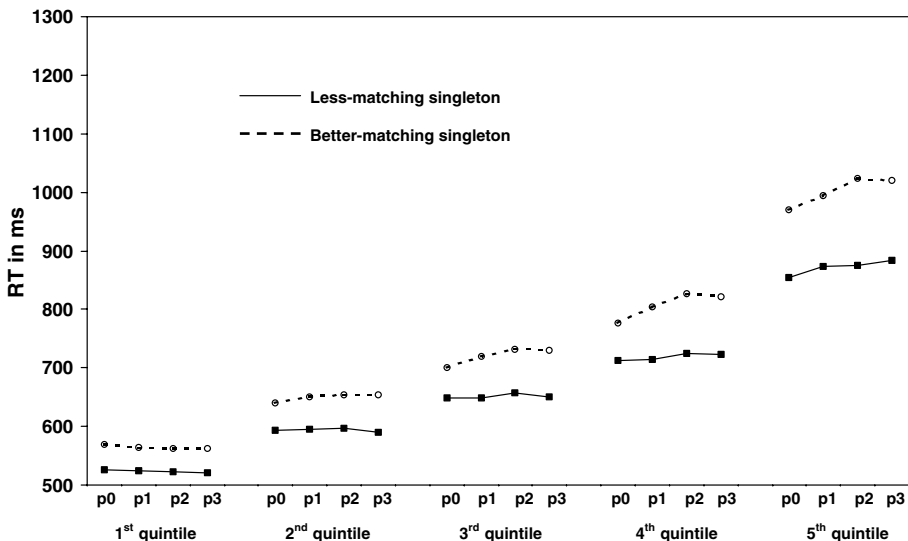


Fig. 4. Mean correct reaction time (RT) as a function of nontarget type (better-matching vs. less-matching nontarget condition), of target–nontarget distance (p0–p3 from small to large), and quintile of the RT distribution of Experiment 2.

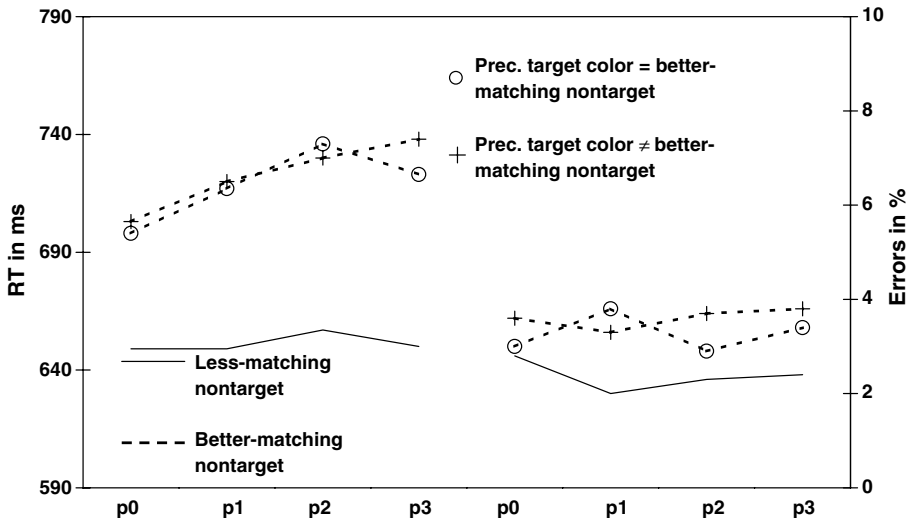


Fig. 5. Mean correct reaction time (RT; on the left) and mean percentage of error (on the right) as a function of nontarget type (better-matching vs. less-matching nontarget condition), preceding target color in better-matching nontarget conditions (same as the better-matching nontarget vs. different from the better-matching nontarget) and of target–nontarget distance (p0–p3 from small to large) of Experiment 2. Prec.: preceding.

better-matching nontargets seemingly interfered as a function of target–nontarget distance (some slopes of the broken lines in Fig. 4 are ascending). An ANOVA conducted on the correct mean RTs of the better-matching nontarget condition, yielded a significant main effect of distance,  $F(3, 33) = 8.68, p < .01$ . RT significantly increased from p1 to p2,  $t(11) = 2.64, p < .05$  (Bonferroni-adjusted), but not from p0 to p1,  $t(11) = 1.93, p = .08$ , and from p2 to p3,  $t(11) < 1.00$ . Also, a significant main effect of quintile,  $F(4, 44) = 184.42, p < .01, \epsilon = .28$ , and a significant interaction of Distance  $\times$  Quintile,  $F(12, 132) = 4.19, p < .05, \epsilon = .19$ , were observed. With a better-matching nontarget in the display, there was a significant RT increment in p1 as compared with p0 in the third and in the fourth quintile, both  $t_s(11) > 3.0$ , both  $p_s < .05$  (Bonferroni-adjusted).

Beyond that, as can be seen from Fig. 4, responses with a better-matching nontarget in the display (broken lines) were slower than responses with a less-matching nontarget in the display (unbroken lines),  $F(1, 22) = 6.45, p < .05$ .

To test for an influence of priming by pop-out to the capture of spatial attention by the better-matching nontargets (in the control conditions), individual median latencies of correct responses in the control condition were collapsed across the levels of the variable quintile and subjected to an ANOVA, with target–nontarget distance (p0, p1, p2, or p3) and preceding trial's target color (same as the current nontarget, or different from the current nontarget) as within-participant variables. Again, the capture of spatial attention was confirmed by a significant main effect of distance,  $F(3, 33) = 9.14, p < .01$ . As can be seen in Fig. 5, there was no indication of a contri-



bution of priming by pop-out to the capture of spatial attention in the RTs. The main effect of the preceding trial's target color,  $F < 1.00$ , and the two-way interaction of the variables,  $F(3, 33) = 1.22$ ,  $p = .33$ , were not significant. A corresponding ANOVA of the arcsine-transformed error rates rendered no significant main effects or interactions, all  $F_s < 1.00$ .

### 3.3. Discussion

In Experiment 2, the capture of spatial attention by the less-matching nontarget was successfully prevented. Therefore, it seems that with a single to-be-searched-for target color (or, more generally, with a relatively small set of relevant features) less-matching nontargets with a color different from the searched-for targets lose their power to capture spatial attention. This result is in line with the assumption that a match of the nontarget to an additional top-down controlled setting to discriminate between different target colors may be responsible for the residual effect of the less-matching nontarget in the preceding Experiment 1.

Additionally, in the control conditions, the same nontargets better matched the attentional control settings for the target color, and the capture of spatial attention was observed. Taken together, data from the two conditions qualified for top-down contingent capture by color, with the better-matching nontarget capturing attention to a larger extent than the less-matching nontarget. Also, in line with the contingent capture hypothesis, the contingent capture by color had an early onset as estimated from its coincident presence with the capture of spatial attention per se among the lower RT quintiles. Moreover, trial-by-trial priming of pop-out does not account for the capture of spatial attention by the better-matching nontarget: the capture of spatial attention by the better-matching nontarget was not significantly affected by whether the target in the preceding trial did or did not have the same color as the better-matching nontarget in the actual trial.

It is also interesting to note that the more demanding attentional control settings in the control conditions in which two target colors were relevant incurred a small but reliable RT cost relative to the less demanding experimental conditions in which only one relevant target color had to be searched for. In conclusion, participants were seemingly able to specify their attentional control settings for color in advance of the displays, so that the initial capture of spatial attention by the nontarget is already contingent on the degree of the match between the nontarget color and the set of searched-for target colors.

## 4. General discussion

At the outset of the current investigation, we hypothesized that participants are able to exert top-down control over where to direct spatial attention. In particular, according to the contingent capture hypothesis, participants should be able to specify their top-down settings in accordance with the instructions and in advance of the displays to direct their attention to the relevant target colors and to more successfully

ignore the irrelevant nontarget colors. As a consequence, the amount of attention that is captured by a stimulus should be a function of how well the color of that stimulus matches the top-down control settings. In confirmation of this hypothesis, we found evidence for contingent capture by color. In two experiments, a nontarget stimulus with a color that matched the set of searched-for target colors well interfered with the processing of the target stimulus to a larger extent than a nontarget stimulus with a less-matching color (Ansorge & Heumann, 2003, 2004; Folk & Remington, 1998, 1999; Folk et al., 1992; Remington et al., 2001; Theeuwes & Burger, 1998).

The stronger interference by the better-matching nontarget was likely due to the capture of spatial attention. This was indicated by the fact that interference had a spatial gradient. With a better-matching nontarget, RT increased as a function of an increasing target–nontarget distance. Therefore, a nonspatial interference effect of the better-matching nontarget, such as a cost incurred by the need to filter-out a currently irrelevant color from a color-heterogeneous display (cf. Folk & Remington, 1998), does not account for the interference effect (cf. Turatto & Galfano, 2001).

Most importantly, on the basis of the contingent capture hypothesis, we predicted and observed a rapid onset of contingent capture by color among the faster responses. In two experiments, the onset of contingent capture by color coincided with that of the capture of spatial attention *per se*. Therefore, it seems that participants can set up their control settings to search for the particular target colors in advance of the displays. As a consequence, nontargets captured attention to the extent that they matched to these preemptively specified control settings, right from their onset. From the additional analyses, it is also clear that the stronger capture by the better-matching nontarget in the actual trial  $N$  was not a mere stimulus-driven consequence of the target color in the immediately preceding trial  $N - 1$ . Stronger capture of spatial attention by the better-matching nontarget was not restricted to conditions in which the actually displayed better-matching nontarget had the same color as the target in the preceding trial.

The predominance of top-down contingent capture in the current study is seemingly at variance with several previous investigations in which it has been shown that salient stimuli can capture attention in a salience-driven or stimulus-driven way, regardless of the attentional top-down control settings of the participants (e.g., Horstmann, 2002; Lamy & Egeth, 2003; Theeuwes, 1994; Turatto & Galfano, 2001). One or several of the following differences may account for the divergent results. First, part of the evidence for salience-driven capture is based on the interference effects in color-heterogeneous relative to color-homogeneous displays (e.g., Theeuwes, 1994). However, as was noted in Section 1, such interference effects might not be due to the capture of spatial attention. Instead, they might reflect the nonspatial process of filtering-out a color during the perception of the color-heterogeneous displays (cf. Folk & Remington, 1998). Second, some evidence for salience-driven capture has been obtained without asking participants to ignore the irrelevant nontarget colors (cf. Horstmann, 2002, *in press*; Turatto & Galfano, 2001). However, it is unclear whether participants indeed selectively attend to the target colors if they are not instructed to do so. Participants that are free to either selectively attend to

the target colors or not may opt to attend to both target and nontarget colors for simple reasons, such as being unaware of a relatively minor cost that is incurred by their choice of a strategy. Third, virtually all of the aforementioned studies have focused on demonstrating the existence of salience-driven capture and have not included control conditions with a better-matching nontarget (cf. Lamy & Egeth, 2003). Therefore, it is always possible that a better-matching nontarget captures attention more readily, more frequently, or more reliably than a less-matching nontarget. However, such an additional effect of contingent capture goes unnoticed if no procedural provisions are made to pinpoint it. In fact, the current Experiment 1 might be considered to be in line with this view: there, a less-matching nontarget captured attention but to a lesser degree than the better-matching nontarget. Note, however, that the present Experiment 2 revealed that even the capture of spatial attention by the less-matching nontarget in Experiment 1 may have been due to subtle top-down contingencies (cf. Duncan & Humphreys, 1989; Theeuwes & Burger, 1998).

#### *4.1. Saccadic versus manual choice responses*

An early onset of the contingent capture by color that coincides with that of the capture of spatial attention per se among the faster RTs, as it was observed in the current study, is seemingly in conflict with some previous observations of Van Zoest et al. (2004). As was described in Section 1, they found the opposite pattern of results: saccades toward a predefined and searched-for target color only started to be more frequent than saccades toward an equally salient nontarget color among the slow responses, in the fifth quintile of the distribution of the saccadic onset times. These observations were interpreted as being in line with the existence of independent stimulus-driven and goal-driven mechanisms of attentional capture, operating in different time windows. According to the account of Van Zoest et al., attention can initially be directed to visual stimuli in a display as a function of stimulus salience, and regardless of the features that the participants intentionally search to find the target. This is the reason that correct saccades (toward the target shape) are as frequent as erroneous saccades (toward an equally salient nontarget) among the fast saccades. Top-down control over the attentional capture should only be possible at a later point in time—therefore, one might conclude that top-down selection criteria are applied later and are usually not effective right from the onset of a display.

The conflicting data of the current study and of the investigation of Van Zoest et al. can be reconciled under one or several of the following assumptions. First, the most convincing evidence for contingent capture by color comes from investigations that have either carefully ruled out conceivable matches between nontarget location and search sets for target locations, or have systematically investigated whether these conceivable matches actually have an influence on the contingent capture by color (e.g., Ansorge & Heumann, 2003, 2004; Folk & Remington, 1998; Folk et al., 1992). Correspondingly, we used left and right finger responses to discriminate between two different target orientations (with target orientation being uncorrelated with target location) as the to-be-reported target features in the current study. In doing so, we ruled out that nontarget location could have matched the set of

to-be-reported target features and, thus, could have contributed to the performance differences between the different attentional conditions (cf. Posner, 1978; Spence & Driver, 1994; Yantis, 1993).

In contrast, requiring a saccade toward the target makes target location the reported feature (cf. Theeuwes, Kramer, Hahn, & Irwin, 1998; Van Zoest et al., 2004). As a consequence, target as well as nontarget location matches this set of response-relevant features, so that capture of the spatial attention that is contingent on a match of the nontarget colors to the set of searched-for target colors might have been masked by the predominance of the attentional capture of spatial attention that is contingent on a match of nontarget location to the set of response-relevant features in the saccadic response studies.

Second, it is not entirely clear whether or how performance in a saccadic response task can account for results obtained in a manual choice RT task, because (a) attention can be shifted without a concomitant saccade, and (b) choice RT effects and saccadic responses do not necessarily lead to the same results in the study of spatial attention (cf. Ludwig & Gilchrist, 2002; Wolfe, 2003). There is overwhelming evidence for the contention that saccadic responses only provide a non exhaustive measure of the effects of visuospatial attention. Attentional shifts as measured by the “scanning duration” per item (derived from measuring search times for a target as a function of the number of nontargets in the display in visual search experiments) are an order of a magnitude shorter than saccadic onsets. On average, scanning durations of 60 ms/item or above are usually considered to be long and yet, these durations are considerably shorter than even the fastest saccades which have an onset of about 120–180 ms (cf. Wolfe, 2003). Therefore, it must be concluded that covert shifts of spatial attention to the visual stimuli also go on prior to the saccades, in-between the saccades, or in the absence of any saccades (Helmholtz, 1896; Posner, 1980). In contrast, the saccade itself seems to be a convenient device to make several stimuli in the vicinity of fixation available to the more fine-grained top-down contingent deployment of spatial attention. In conclusion, the mechanisms and the effects of visuospatial attention are not exhaustively estimated in saccadic reaction tasks. In addition to the saccades, other reports about to-be-discriminated target features are necessary to get an exhaustive estimate of the attentional effects (see also Ludwig & Gilchrist, 2002).

With the outlined division of labor between (a) covert attention shifts and (b) overt saccades borne in mind, we are now equipped to better understand an apparent paradox in the interplay of the two. According to a widely held assumption, a successful saccade toward a target requires a prior shifting of attention to the location of the target (cf. Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995; Rizzolatti, Riggio, & Sheliga, 1994). Yet, according to a second assumption, a covert attention shift to a visual stimulus already makes attended-to stimulus information available to the processing system (cf. Helmholtz, 1896; Posner, 1980)—given that the extrafoveal acuity is sufficient to retrieve that information. If both the assumptions hold true, we are left with the apparent paradox that a covert shift of visuospatial attention prior to the saccade already fulfills the putative function of the saccade itself and, thus, makes it superfluous.

This seeming paradox is resolved, however, under the assumption put forward here that visuospatial attention is not exhaustively measured in saccadic response tasks. Visuospatial attention shifts that are made in the service of the saccades *are not necessarily contingent on the same top-down control settings* that are applied to achieve performance as reflected in a more exhaustive measure of visuospatial attention. A saccade could be made contingent on stimulus salience, for example, whereas the top-down contingent allocation of visuospatial attention could take place at any time prior to the saccades, in-between the saccades, or in the absence of the saccades. The results of [Van Zoest et al. \(2004\)](#) are in line with this notion: they observed a large number of saccades that were made contingent on visual salience instead of being made contingent on the target shape as it was instructed.

Third, participants might be more inclined to use visual salience to drive their saccades than to drive their manual choice responses. Using visual salience to drive saccades directs the light-sensitive receptor surfaces of the organism in the direction of exactly those inputs that can be processed by these receptors. Therefore, this strategy is beneficial in a number of everyday situations. Yet, what would be gained if hands would be driven by visual salience, too? Nothing at all, it seems, because hands are not sensitive to light. They are not suited to process the salient visual signal.

In contrast, hands are used for partly unrelated functions. In particular, hands are well suited to communicate arbitrary content, as it is the case, for example, in gesturing. This latter function is exactly the one that is pinpointed in the manual choice RT tasks in which the alternative manual responses are arbitrarily mapped to communicate the presence of different stimulus features. For this function of arbitrary communication to be accomplished, it is necessary to ignore irrelevant salient stimuli. Hence, the different results in saccadic and in manual choice reaction tasks may reflect this kind of strategic choices, with the consequence that saccadic responses appear to be more prone to visual salience than manual choice responses. In line with this argument, other researchers have found a much larger vulnerability of saccadic responses (as compared with manual responses) to salience-driven capture of spatial attention ([Ludwig & Gilchrist, 2002](#)).

Finally, if we want to study the influences of a particular top-down control setting on the amount of attentional capture exerted by a stimulus, we have to make sure that participants deploy their attention according to the instruction. However, among the faster responses of the investigation of [Van Zoest et al.](#), we have no evidence to confirm that participants deployed their attention as it was instructed. Actually, for the lower quintiles of the saccadic RT distribution, participants were on a chance performance level in discriminating between targets and nontargets. Chance performance might be an inevitable consequence of the structure of the fast operating salience-driven attentional system. However, it is also conceivable that participants did simply not follow the instructions in a large proportion of the trials of the lower quintiles. That is, without an above-chance performance level, we do have no evidence for the participants having implemented the instructed control settings. Accuracy (defined as correct performance in accordance with the instructions) can be traded for response speed. In general, guessing is most likely to show up among the fast responses (cf. [Gratton, Coles, Sirevaag, Eriksen, & Donchin, 1988](#)).

Correspondingly, in Van Zoest et al.'s study, the highest probability for saccade directions being based on a guess about which two equally salient stimuli might be the target should be evident among the fast saccades. The pattern of results that has been found in the saccadic response time study seems to be exactly in line with this prediction. Moreover, as argued above, using a “relaxed” set of searched-for stimulus features in saccadic responses is sufficient for a saccade to fulfill its purpose in the division of labor between covert attentional shifts and overt saccades. Some independent measure beyond the inconclusive saccadic responses is necessary in order to verify that participants indeed follow the instructions. Therefore, we conducted our test on the correct manual choice responses given to the target shapes. Among the correct responses, we have good reasons to assume that participants implemented the control settings according to the instruction.

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