Effects of task factors on selection by color in the rapid serial visual presentation (RSVP) task

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In five experiments, we examined task factors influencing selection by color in a rapid serial visual presentation (RSVP) task. Participants were required to respond to the presence or case of a target letter presented within an RSVP sequence, and they were cued as to the color in which that target was most likely to occur. The first two experiments explored the effect of task difficulty. It was found that a change from the discrimination of upper- versus lowercase targets to the detection of an exact shape had no influence on the color-cuing effect. In contrast, increasing letter set discriminability and decreasing color discriminability reduced the color-cuing effect considerably, although they did not eliminate it. In the third and fourth experiments, the frequency of valid trials was reduced, removing the incentive to use the color information. Again, a small benefit remained, indicating partially automatic and strategic color-processing components. Finally, the fifth experiment showed that an increase in perceptual load had no influence on the color-cuing effect. Together, these five experiments provide further evidence of the robustness of direct selection by color.

When participants are asked to select a target item out of a number of distractor items, advance information about the location of the target item enables them to select it more rapidly and accurately (e.g., Cheal & Gregory, 1997; Posner, Snyder, & Davidson, 1980; Theeuwes, 1989). For example, Theeuwes had participants judge the orientation of a line presented to either the left or the right of fixation. He provided advance spatial information by using a left or a right cue, which was either valid (75%) or invalid (25%). He also included blocks of trials without cues to determine the benefits and costs of location cues, relative to this baseline measure. The results showed that response times (RTs) were less than the baseline when the cue information was correct and greater than the baseline when the cue information was incorrect. Such findings are universally interpreted as evidence that advance spatial information is useful in guiding selective attention (e.g., Kinchla, 1992).

Whether and to what extent other visual features such as color can guide selective attention is less clear. Experiments in which advance color information has been investigated have often used precuing paradigms similar to those in studies in which advance location information has been investigated. In general, valid color cues have led to some advantage in performance, although to a lesser

extent than has been observed for location cues. In one study, for example, Kingstone (1992) provided color and shape cues in a design in which participants had to monitor several spatial locations for the presence of a target letter. Specifically, the participants were asked to judge the orientation of the target letter, either an A or a V, displayed together with three distractor letters. In addition, the color of the target letter was different from the color of the distractor letters; for example, the target letter was displayed in green, and the three distractor letters were displayed in red. Both target color (i.e., red or green) and target shape (i.e., A or V) were cued. The cues could be valid, neutral, or invalid, and the two cue types varied independently of each other. The results demonstrated the effectiveness of color cues. Responses were fastest in the valid color cue conditions and slowest after invalid color cues, indicating both benefits and costs of color cuing. For advance shape information (i.e., A or V), the same RT pattern was observed, but to a lesser degree. Similar benefits of advance color information have been reported for several different paradigms with stimuli appearing at multiple spatial locations (e.g., Carter, 1982; Geller, 1977; Green & Anderson, 1956; LaBerge & Brownston, 1974).

These results clearly demonstrate that advance color information has an impact on the selection process, but the cause of this influence is controversial. Some results seem to indicate that the advantage of advance color information is completely mediated by location (e.g., Tsal & Lavie, 1993). According to this view, color simply allows the allocation of attentional resources to the location of the item(s) of the cued color, and the benefit of color cuing is only to guide attention to the location of the correct item(s). In the experiment by Kingstone (1992), for example, the valid color cue might have enabled the selection process

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to select the correct item by using color to guide it to the target letter's location. Attention could then have been applied to this location, subsequently allowing further, more efficient processing of the selected letter. An alternative view, however, is that attention might be applied directly to items of the selected color, without any mediation by location. With regard to the effect described by Kingstone, this would mean that the participants were able to select the target more quickly in the valid cue condition because attention was applied directly to the item in the cued color, without any spatially defined attentional shift.

Attempts to decide between these possibilities, using paradigms with more than one potential target position, have led to contradictory results. Some studies seem to indicate that selection by color is completely mediated by location (e.g., Brawn & Snowden, 1999; Moore & Egeth, 1998; Tsai & Lavie, 1993). For example, Moore and Egeth used search displays consisting of blue and green letters. In half of the displays, a target digit was included. In addition, the participants were informed about the probability of the target's being in either blue or green. Moore and Egeth found evidence in favor of effective selection by color, because detection was faster for targets in the high-probability color. In another experiment, however, they presented the display only briefly and followed it by a mask. In this situation, color cues were ineffective. This was taken as evidence that direct selection by color is not possible. They concluded that the participants had to shift attention to the locations of the items in the cued color but that the time was not sufficient to complete the shift with the brief and masked displays. The authors interpreted this finding as evidence for a limited function of color—that is, to guide to a specific location. These conclusions have been supported by other findings, and their consistency over a number of different paradigms and visual attributes has led to the view that location has a special status in selection (Cave & Pashler, 1995; Garner, 1987; Kim & Cave, 2001; Lamy & Tsai, 2000; Nissen, 1985; Shih & Sperling, 1996; Tsai & Lamy, 2000; Tsai & Lavie, 1988, 1993). But this view is not shared uniformly (see Gold & Pratt, 2001; van der Heijden, Kurvink, de Lange, de Leeuw, & van der Geest, 1996).

Other studies looking at the effects of both location and color cues in selection, however, have shown some indication of an influence of color cues that is unmediated by location (e.g., Humphreys, 1981; Lambert & Corban, 1992). Humphreys used a two-item display, and participants were asked to judge the orientation of the item in a particular fixed location. The other item was close to the target item, and its orientation was either the same as or different from that of the target. In one condition, the distractor orientation changed on a trial-to-trial basis, whereas in another condition, it was constant across a whole block. Another manipulation was that the target and the distractor either shared the same color or were displayed in different colors. The results were that RTs and accuracy differed only when the target and the distractor shared the same color. When colors differed, performance was similar for both the constant and the random manipulations of the distractor form.

It seems that although the participants had clearly defined and valid location information, the additional knowledge of color made selection more successful. Humphreys concluded that attention can be allocated to either color or location when necessary to accomplish the task, which would support the hypothesis that direct selection by color is possible to some extent. Humphreys's findings can be interpreted differently, though. It might be that color is still used as an additional cue for selecting the appropriate location even when location information is provided. This strategy would be especially useful for displays in which locations are close together and, therefore, confusable. If that happened, the color-cuing effect could again be completely mediated by location, with color itself serving only a guiding function in selection.

All of the studies reviewed so far employed multiple-location designs in which item location varied. In the studies that reported a benefit of color, it is very difficult to determine whether this benefit of color cuing was mediated by location or whether selection by color was direct. In contrast, several early studies held location constant in order to disentangle the confounding of location and color. Specifically, they used superimposed stimuli of different colors, requiring the participants to process a target item of a given color, and they demonstrated that color information clearly could be used to guide the selection process (Goldstein & Fink, 1981; Rock & Gutman, 1981; Tipper & Cranston, 1985). Selection of stimuli defined by color was also successful when a large number of items were presented in a rapid sequence of superimposed stimuli (rapid serial visual presentation, or RSVP, task; Botella & Eriksen, 1992; Chun, 1997; Folk, Leber, & Egeth, 2002; McLean, Broadbent, & Broadbent, 1983). Together, these experiments suggest that direct selection by color is possible without mediation by location, but it is not clear whether this selection takes place at a perceptual level. When color information has to be used in order to fulfill task requirements, it is possible that selection effects arise postperceptually. In Goldstein and Fink's study, for example, the color information might have affected the level of memory rehearsal, because recognition of the relevant color-cued object was tested.

Designs in which color is provided as additional, but not necessary, information seem most promising for judging the value of color in perceptual selection, just as designs like this have been used to examine selection by location. For example, Shih and Sperling (1996) used color cues in a similar way in their experiment. Their paradigm consisted of an RSVP stream with six characters per frame. Participants were asked to find a single target digit among distractor letters and to report the target's identity, location within the frame, and color. In one condition, all of the frames were presented in the same color. In a second condition, two different colors of frames alternated, and the participants were informed of the color of the frame containing the target. Finally, in a third condition, alternating frames were blank. The authors argued that if direct selection by color were possible, the number of frames in the condition with the informative color cue would be

halved, and performance should, therefore, be similar to that in the condition with the blank frames, because the same number of frames would need processing in both conditions. On the other hand, if participants cannot select directly by color, performance in the color-cued condition should be similar to performance observed in the condition with all the frames in the same color. In fact, performance in the blank condition was best, and no difference was found between the alternating-colors condition and the same-color condition. These results thus suggest that direct selection by color is not possible. This conclusion was further supported by Pöder (2001), who replicated the main features of Shih and Sperling's study, using frames that contained only a single character. There was again no effect of whether color information could be used to select relevant frames, so Pöder also concluded that color is not useful for direct selection of items.

Although the results of Shih and Sperling (1996) and Pöder (2001) suggest that direct selection by color is not possible, both studies included a feature that is potentially problematic with regard to the assessment of cue efficiency. In both studies, even a 100% valid cue led to only a 50% reduction in the number of items that needed to be processed. In Shih and Sperling's experiment, 10–13 frames appeared in the cued color, depending on sequence length, and in Pöder's experiment, 8 frames appeared in the cued color. Thus, the color cues were far from isolating a single item for high-priority processing. With typical location-cuing paradigms, in contrast, the cue does indicate a single location for such processing (e.g., Posner et al., 1980; Treisman, 1985). Thus, the color cues used in these two experiments provided much less information than do typical location cues, making it less likely that they would be used by the participants and have an effect on performance. Indeed, location-cuing experiments cuing four or more locations have often shown no effect of valid location cues (e.g., Palmer, Ames, & Lindsey, 1993). Thus, participants might use cues only when the potential benefit is large. Consequently, although these two studies showed no evidence of direct selection by color, the evidence is not conclusive, because the color cues may have been insufficiently useful.

Vierck and Miller (2005) reported two RSVP experiments in which they employed color cues that were comparable in efficiency with standard location cues. Participants were asked to search for a specific letter and discriminate whether it was displayed in its upper- or lowercase version. Before each trial, the likely color of the target letter was cued. As in previous experiments in which the use of cues for direct selection was examined (Brawn & Snowden, 1999; Humphreys, 1981; Pöder, 2001; Posner et al., 1980), the color cue did not define the target but simply provided additional information about it. Most important, in valid trials, *only* the target letter was presented in the color indicated by the cue. Thus, this design differed from the previously described ones (Pöder, 2001; Shih & Sperling, 1996), in that the color cue singled out only one item of the sequence. This application of the color cue was similar to the way location cues have been

used and, therefore, allowed a better judgment of the role of color in the selection process. The results showed a clear benefit in accuracy and RTs for valid color cues over neutral cues, providing strong evidence in favor of direct selection by color.

To extend our understanding of selection by color, the present experiments were designed to examine what factors influence color-cuing effects, just as influences on location-cuing effects have been explored to gain a fuller picture of selection by location. The same basic RSVP paradigm as that used before was elaborated to address several questions. In the first experiment, we investigated whether color cuing would still be used when participants had to search only for a unique, predetermined target shape. In the second experiment, we investigated the influence of relative color versus letter discriminability on the color-cuing effect. In the third and fourth experiments, we examined whether color-cuing effects are found only when cues are informative, which would be indicative of their strategic use, or whether these effects would still be found when color cues were not informative, suggesting that they were used automatically. Finally, in the fifth experiment, we explored the effect of increased perceptual processing load on selection by color.

EXPERIMENT 1

The first experiment was designed to see whether selection by color is useful only when the task involves some uncertainty about the shape of the target. The participants in the experiments of Vierck and Miller (2005) could not search for a specific target shape; instead, they had to be prepared for either of two possible target shapes: an upper- or lowercase version of the target letter. It might be that the participants made use of the color cue only because of this ambiguity about the expected target shape, whereas they would not have used color cues if the target shape had been uniquely specified.

The basic design used in this experiment followed that of the RSVP tasks reported by Vierck and Miller (2005), but the participants were required to determine the presence or absence of a specific target letter shape specified by both identity and case, instead of discriminating between upper- and lowercase targets. Thus, the participants in this task were able to focus on a certain letter shape and to create an exact mental image of the target's shape. This change in the task might lead to a reduction or even elimination of the color-cuing effect, if color cues are not needed when participants have a unique target for shape processing. Thus, if the participants used the color cue in the previous experiments only because of the difficulty of monitoring for two possible target shapes, the color-cuing effect should be reduced or eliminated in this experiment. On the other hand, if color cues are useful even when participants know exactly what shape must be detected, the color-cuing effect in this experiment should be similar to the ones found previously.

Analogous effects of task have been found for location cues. Specifically, location cues produce slightly larger

benefits in detection tasks than in discrimination tasks (Posner et al., 1980), suggesting that task type has an effect on selection by location. Similarly, it is of interest to see whether a change of task requirements impacts on the color-cuing effect.

We sought to keep this experiment as comparable as possible to the previous experiments in which color-cuing benefits had been demonstrated (Vierck & Miller, 2005). As in our previous experiments, the sequence consisted of 15 colored letters presented in an RSVP stream. The stimulus set was also the same, consisting of 4 different letters in their upper- and lowercase versions. In each block, one of these 8-letter versions was selected as the target. At the beginning of each trial, a color cue was presented, indicating the likely color of the target. As before, trials could be valid, neutral, or invalid. In valid trials, only the target letter was presented in the color indicated by the cue. In neutral trials, the cued color did not appear anywhere in the RSVP sequence, so neither the target letter nor a distractor letter was presented in the color indicated by the cue. Finally, the same types of invalid trials as those used by Vierck and Miller were included. In these trials, the target letter did not appear in the cued color, but a distractor did appear in that color, so that use of the color cue would actually lead to selection of an incorrect item. Half of all trials were target-present trials.

Method

Participants. In this experiment, 24 undergraduates (5 of them male) at the University of Otago, New Zealand, took part. They were from 18 to 44 years of age. Their participation was part of a 1st-year course requirement. All of them reported that they had normal color vision.

Stimuli. The stimuli were the upper- and lowercase versions of the letters F, H, R, and T displayed in triplex font, a built-in font of Turbo Pascal 7.0. The color set consisted of six different colors; these were blue (RGB 5,14,63), yellow (RGB 63,63,0), red (RGB 63,9,1), green (RGB 5,63,8), gray (RGB 30,30,30), and white (RGB 63,63,63). The measurements of the letters were as follows: the lowercase form of the letter *r* had a height of 8 mm, whereas all the other letters had heights of 12 mm. The widths of the letters varied from 5 to 9 mm. The cue consisted of 14 horizontal colored lines, each 1 pixel wide; together, these lines created the image of a rectangle 14 mm high and 23 mm wide.

All the stimuli were presented in the center of the screen on a dark background and were viewed from a distance of approximately 59 cm. For the target detection task in this experiment, the slash (/) key was used for right index finger responses, and the Z key for left index finger responses. The assignment of the response keys to upper- or lowercase letters was counterbalanced across participants.

Procedure. The experiment took place in a semidarkened experimental chamber. Besides the computer monitor, a desk lamp was the only other light source. Each participant was tested in eight blocks in a single session lasting approximately 40 min. The first 4 of the 64 trials per block were warm-up trials and were not recorded.

Each block began with the presentation of the target letter in the center of the screen. The letter was displayed with a height of 30 mm and a width of 23 mm for 500 msec. Each of the eight letters in the letter set (four letters in their upper- and lowercase versions) was the target for one block. The order of these blocks was determined randomly. The participants were required to indicate whether the target was present or absent on any given trial. Half of the trials contained the target letter.

Both target-present and target-absent trials began with a plus sign presented for 800 msec, serving as a warning signal and a fixation point for the participant. It was immediately followed by the color

cue in the form of a rectangle. The cue remained on the screen for 1,000 msec. Its color was chosen randomly out of the color set. The RSVP sequence began 200 msec after the offset of the cue. The sequence was made up of 15 letters, each of which was presented for 55 msec. Each letter was immediately followed by the next one.

Each block contained 30 target-present trials and 30 target-absent trials. For the target-present trials, the target appeared equally often and in a random fashion in the following position ranges within the 15-item sequence: 1–3, 4–6, 7–9, 10–12, and 13–15. Within these categories, the position was chosen randomly. In addition, there were three different cue conditions, as used by Vierck and Miller (2005, Experiment 2). In the valid condition (20 trials per block), the color of the target letter was the same as the color of the cue, whereas the 14 other letters of the sequence consisted of upper- and lowercase versions of the 3 letters remaining in the letter set and the uppercase (or lowercase) version of the target letter, whichever was not the target shape in any given block. These letters were displayed in the five remaining colors of the color set. The distractor color, identity, and case were chosen randomly for each frame, with both case versions equally likely. In the neutral condition (5 trials per block), the target was displayed in a color different from the cue color, and none of the other letters was displayed in the cued color either, so this color was not used at all in the sequence. In invalid trials (5 trials per block), the target was presented in a color other than the cued color, and a randomly selected distractor letter was presented in the cued color.

For the target-absent trials, all aspects were the same as those in the target-present trials, apart from the fact that no target letter was presented. In order to match the target trials in terms of the occurrence of the cued color in the sequence, the cued color was presented once in the sequence for 25 of the target-absent trials, and it was not presented at all in the sequence for 5 target-absent trials.

A question mark was used to signal the end of the RSVP sequence. It remained on screen until a response key was pressed or 5,000 msec had passed, whichever came first. Visual feedback was provided for incorrect responses. If the participants used the wrong response keys or responded before the target frame was presented, a visual reminder of the task requirements was displayed. The next trial began after approximately 800 msec.

The participants were instructed to respond immediately after the detection of the target letter and not to wait for the question mark. In the target-present trials, RT was measured from the onset of the target frame; in the target-absent trials, it was measured from the onset of the question mark. The participants were also informed that the target's color was usually that of the cue, which was, therefore, potentially helpful, and that they were free to use this information to help them accomplish the task.

Results and Discussion

For the analysis of accuracy, all the trials were included, because exclusion of trials with outlying RTs would tend to eliminate responses to letters presented before the target letter and responses in trials in which the participant missed the target and had to guess after the presentation of the last frame. The analysis of RTs, however, included only trials with RTs in the range of 200–2,500 msec. In total, 4.18% of all the trials lay outside the RT boundaries. Of these, approximately 3.94% were early responses with RTs less than 200 msec and with responses at chance accuracy. The percentage of early responses also varied with target location, suggesting anticipations. All statistical tests were conducted using an ANOVA, and Greenhouse–Geisser corrections (Huynh, 1978) were performed and will be reported where appropriate.

Mean percentages correct and RTs were calculated and averaged across participants, and the average RTs and ac-

curacies for the valid, neutral, and invalid cue conditions are displayed in Table 1.

Analysis of accuracy. For accuracy, the effect of validity was significant [$F(2,46) = 7.16$, $MS_e = 621.87$, $p < .005$]. Pairwise comparisons among the different validity conditions showed, as was expected, a significant difference of 5.9% between valid and invalid trials [$F(1,23) = 8.56$, $MS_e = 497.66$, $p < .01$]. The surprising 2.4% advantage for invalid trials over neutral trials did not reach significance.

For a more sensitive comparison between invalid trial performance and neutral trial performance, the relation of the cued-color nontarget to the target was taken into consideration (cf. Vierck & Miller, 2005). Invalid trials with the misleading cued-color nontarget presented after the target are actually the same as neutral trials up to the presentation of the target, so the misleading nontarget may appear too late to interfere with the identification of the target. A stronger comparison between valid and neutral trials might, therefore, exclude these trials, including only trials in which the misleading cued-color nontarget appeared before the target. Accordingly, invalid trials were analyzed in terms of distance from the cued-color nontarget to the target. The results are displayed in Figure 1. It shows that when the nontarget in the cued color appeared one to two frames before the target frame, performance was significantly better than when it appeared earlier than that [$F(1,23) = 13.57$, $MS_e = 0.02$, $p < .002$]. This result confirms the alerting effect of nontargets in the cued color observed previously (Vierck & Miller, 2005). Accuracy also appears to be slightly better if the noncued nontarget appeared shortly after the target. It might be that a representation of the target letter was still available in working memory when the cue color appeared, and this residual representation may have allowed the participants to select the correct response more often from memory than in other trials, in which the cued color nontarget appeared after the target frame but later in the sequence.

The strong alerting effect can also account for the advantage of invalid trials over neutral trials. Performance in neutral trials was slightly better than performance in invalid trials when neutral trials were compared with trials in which the cued-color nontarget was presented more than three frames before the target frame, but this difference (4.2%) was not significant. This is in contrast to the previous finding that a cued-color nontarget presented more than three frames before the target led to considerable distraction (Vierck & Miller, 2005). It is not clear what caused this difference. This observed pattern

Figure 1. Accuracy of responses (in percentage correct [PC]) in invalid trials as a function of distance (number of frames) from the cued-color distractor to the target frame. Negative distances indicate that the cued-color distractor was presented before the target, and positive distances indicate that the cued-color distractor was presented after the target. For comparison, neutral trial performance across all target positions is also displayed.

of interference resembles the phenomenon of the attentional blink (AB), which occurs in RSVP designs when two targets have to be selected that are presented close to each other. If the second target follows the first one within 100–500 msec, the accuracy of responses to the second target is negatively affected (e.g., Chun, 1997). With a frame rate of 55 msec in this experiment, letters that appear more than three frames before the target frame fall in exactly this time slot. The speed of presentation in our experiments was also similar to that used in AB paradigms. Thus, it might be that the cued-color nontarget was somewhat comparable to the first target in an AB task and the real target was similar to the second target. This interpretation is, of course, fully consistent with the idea that selection by color occurred in our experiments.

For trials containing a target, the position of the target within the sequence had an effect on accuracy [$F(4,92) = 8.91$, $MS_e = 541.64$, $p < .001$], with responses becoming less accurate the later in the sequence the target was presented. Together with the analysis of the RT data presented below, this pattern probably represents a speed–accuracy trade-off.

A comparison of percentage correct for target-present trials with that for target-absent trials showed no significant differences.

Analysis of RT. For RTs, the differences between the three levels of validity were also significant [$F(2,46) = 7.50$, $MS_e = 17,679.3$, $p < .005$]. The pairwise comparisons between the different validity conditions also revealed a significant advantage for valid over invalid trials of 27 msec [$F(1,23) = 4.83$, $MS_e = 18,095.4$, $p < .05$]. The advantage of 47 msec for valid trials over neutral trials was also significant [$F(1,23) = 17.78$, $MS_e = 14,807.9$, $p < .001$]. As was the case for accuracy, the difference between neutral and invalid trials was not significant.

Table 1
Average Percentages Correct and Reaction Times
(in Milliseconds) As a Function of Cue Validity in Experiment 1

Trials	Dependent Variable	
	Percentage Correct	Reaction Time
Valid	73.7	747
Neutral	65.4	794
Invalid	67.8	774

The position of the target within the sequence also had an effect on RT, with response latencies decreasing significantly the later the target was presented in the sequence [$F(4,92) = 146.19$, $MS_e = 20,906.4$, $p < .001$]. As was mentioned above, given that accuracy also decreased toward the end of the sequence, this is presumably due to a speed-accuracy trade-off. In addition, there was an effect of practice [$F(1,23) = 11.35$, $MS_e = 53,793.1$, $p < .005$], with RTs tending to decrease across experimental blocks.

As was done for accuracy, the RT performance was analyzed for target-present versus target-absent trials. The participants responded more slowly in trials in which no target was presented than in trials with a target [$F(1,23) = 159.53$, $MS_e = 2,227.8$, $p < .001$]. This has been reported in previous RSVP tasks (e.g., Miller & Schröter, 2002). It seems that responses were faster when the target was present than when the participants had to search through all the stimuli without finding it.

In summary, the results of this experiment clearly demonstrate an effect of validity, replicating the findings of Vierck and Miller (2005). Although the participants in this experiment could focus on a specific target letter shape, instead of two possible letter shapes, color cues were still useful for selection, suggesting that the previously observed color-cuing effect was not caused by target case uncertainty. Somewhat surprisingly, no costs of invalid color cues were apparent. Rather, invalid trials led to better performance than did neutral trials. This finding might be caused by the alerting effect of the color cue when presented shortly before the target letter, leading to better performance in these trials, in comparison with other invalid trials. It seems that without these trials, accuracy might be slightly higher in neutral than in invalid trials. But in general, in comparison with the findings reported by Vierck and Miller, costs seem to be smaller in this experiment. It is possible, then, that the reduced effect of the misleading color cue reflects some influence of target case uncertainty on performance.

EXPERIMENT 2

This experiment provides a further test of the influence of task demands on the color-cuing effect by exploring the influence of relative color and shape discriminability. The similarities and dissimilarities among targets and nontargets are known to have an effect on search performance (Duncan & Humphreys, 1989). In addition, an increase in target-distractor similarity has been shown to increase the AB effect in RSVP tasks (Visser, Bischof, & Di Lollo, 2004). In the stimulus set used by Vierck and Miller (2005) and in the present Experiment 1, the color discrimination was easier than the letter discrimination, and the higher discriminability of the color attribute might have contributed strongly to the observed advantage for valid color cues found in these experiments.¹ That is, the relatively high color discriminability might have led the participants to make use of the color cue. With relatively high letter discriminability, however, the participants might only use letter identity to select the target letter.

To test this hypothesis, we developed a new stimulus set in which the letters were more discriminable than the colors.² Then the present experiment used this altered stimulus set in a replication of the experiment conducted by Vierck and Miller (2005, Experiment 2). If the greater discriminability of the colors, relative to the letters, was fully responsible for the color-cuing effect, color cues should have no effect on performance with this new stimulus set.

Method

Participants. Twenty-four undergraduates (4 of them male) at the University of Otago participated in this experiment. Their participation was part of a 1st-year course requirement, and their ages were from 18 to 21 years. All of them had normal color vision.

Stimuli and Procedure. The stimuli and procedure closely followed those used in Experiment 1, with only the differences described here. Instead of the letters F, H, R, and T in their upper- and lowercase versions, the letters B, G, L, and M were introduced. For this letter set, the width of the letters varied more, ranging from 5 to 14 mm. The height was again 12 mm, with the exception of the lowercase letter m, which had a height of 8 mm. In addition, the discriminability of the color set was diminished. The values used were as follows: blue (RGB 5,38,63), yellow (RGB 63,63,0), red (RGB 63,19,11), green (RGB 5,63,32), gray (RGB 16,16,16), and white (RGB 50,50,50).

Instead of the detection task used in the previous experiment, the same discrimination task as that used by Vierck and Miller (2005) was employed. The participants were asked to discriminate whether the target letter was presented in its upper- or lowercase version in each trial. As before, the target letter was randomly determined for each block, with the constraint that consecutive blocks always had different target letters. The other aspects of the trial were the same as those in the target-present trials in the previous experiment. Again, each block consisted of 60 trials: 40 with valid, 10 with neutral, and 10 with invalid cues. Each letter was presented for 70 msec to allow additional time for a discrimination, instead of a simple detection. Each session lasted for approximately 45 min.

Results and Discussion

In total, 3.72% of all the trials lay outside the same RT cutoff boundaries used in Experiment 1, and these were excluded from the analyses of RTs. Early responses represented the majority (approximately 3.35%) of these cases, and accuracy was at chance level for these RTs. Again, these early responses were presumably due to anticipation, because of the increased number of early responses for targets presented later in the sequence. Mean accuracies and RTs for the three levels of validity are displayed in Table 2.

Analysis of accuracy. The effect of validity on accuracy reached significance [$F(2,46) = 4.62$, $MS_e = 211.46$, $p < .02$]. A pairwise comparison showed that the 3.5% advantage for valid trials over invalid trials was significant [$F(1,23) = 7.73$, $MS_e = 188.01$, $p < .02$]. Responses in

Table 2
Average Percentages Correct and Reaction Times
(in Milliseconds) As a Function of Cue Validity in Experiment 2

Trials	Dependent Variable	
	Percentage Correct	Reaction Time
Valid	84.6	734
Neutral	81.0	792
Invalid	81.1	785

the valid condition were also 3.6% more accurate than responses in the neutral condition [$F(1,23) = 5.23$, $MS_e = 282.57$, $p < .05$]. The difference of 0.1% between neutral and invalid trials in favor of invalid trials did not approach significance.

As in Experiment 1, a further analysis was conducted comparing neutral trials against invalid trials in which the cued-color distractor was presented before the target, and a pattern similar to the one described in the previous experiment was found. To evaluate costs, accuracy for trials with the cued-color distractor presented more than two frames before the target were compared with neutral trials. The resulting difference of 2.4% in favor of neutral trials again resembles an AB pattern, but this effect was not significant, consistent with the generally smaller effect of validity in this experiment.

The position of the target within the sequence again had a strong effect on accuracy, with accuracy decreasing significantly the later the target was presented [$F(4,92) = 9.21$, $MS_e = 174.95$, $p < .001$]. Together with the results obtained for RTs, presented below, this could again reflect a speed-accuracy trade-off.

Analysis of RT. For RTs, the differences between the levels of validity were highly significant [$F(2,46) = 14.21$, $MS_e = 17,056.3$, $p < .001$]. Pairwise comparisons resulted in significant differences between valid and invalid trials [$F(1,23) = 17.40$, $MS_e = 18,033.1$, $p < .001$], with valid trials being 51 msec faster than invalid trials. The advantage of 58 msec for the valid condition over the neutral condition was also significant [$F(1,23) = 16.96$, $MS_e = 23,998.6$, $p < .001$], whereas the difference between neutral and invalid trials was small and not significant.

As was the case for accuracy, RT was affected by target position [$F(4,92) = 101.49$, $MS_e = 25,739.2$, $p < .001$], with RTs decreasing as the target was presented later in the sequence. This result, taken together with the decrease in accuracy, suggests a speed-accuracy trade-off. There was also a significant effect of practice on RT [$F(1,23) = 11.64$, $MS_e = 52,207.4$, $p < .005$].

The results of the second experiment showed that the participants made use of the color cue even when the letters were easier to discriminate from each other than the colors. Thus, use of color cues is not limited to cases in which the colors are extremely easy to discriminate. The observed cuing effect was weaker than that obtained by Vierck and Miller (2005, Experiment 2), and performance in general was better, presumably because of the altered stimulus set. As in Experiment 1 in the present article, only benefits, but no costs, were observed. The full pattern of results suggests that some costs might have been present, however, because accuracy seems to have decreased on trials in which the distractor color was presented three or more frames in advance of the target.

EXPERIMENT 3

A small color-cuing effect remained in the previous experiment, even though it might have been advantageous for the participants to focus solely on the shape of the target.

This result raises the question of whether some part of the color-cuing effect arises from automatic, rather than strategic, mechanisms of information processing. Automatic processing is thought to require neither processing resources nor attention, and it is sometimes described as being beyond the deliberate control of the participant (Schneider & Shiffrin, 1977), although it may still depend on the context of the overall task being performed (e.g., Folk, Remington, & Johnston, 1992). Strategic or controlled processing, in contrast, is defined both by a need for processing resources or attention and by being under the control of the participant. Strategic processing in the present task would mean that the participants were able to choose whether they wanted to use the color cue in any given trial; this choice would presumably be influenced by the perceived advantage and effort associated with using the color cue. The participants might even choose to use color cues in only some trials, perhaps influenced by the ease of finding the cued color, the target letter, or both. The previous results are consistent with this possibility. In contrast, the cue might be used automatically. The color cue presented in the previous experiments was relatively large and remained visible for 1,000 msec. Long cue presentation has been shown to be necessary to create a color repetition blindness effect (Fox & de Fockert, 2001). It therefore seems that a long presentation time can force some processing of the cue, and this might lead to automatic selection of items in the cued color.

To test between strategic and automatic processing of color-cued items, incentives to use the cues were removed from the present design. This was achieved by assigning the same likelihood (33%) to each of the three cue types: valid, neutral, and invalid. A similar procedure was used by Humphreys (1981), who tested whether color cues would be used in a controlled or automatic manner by introducing a condition in which the target was equally likely to be one of two colors. Thus, if the use of the color cue is strategic, participants would be likely to focus on letter shape alone and dismiss the color information, since its use would lead to a benefit in only one third of the trials. If, on the other hand, the use of the cue is automatic, a cuing effect should remain, despite the fact that the color cue provided little or no processing advantage.

Method

Participants. The participants in this experiment were 42 undergraduates (17 of them male) at the University of Otago, ranging in age from 18 to 57 years. As before, they reported normal color vision and participated to fulfill a 1st-year course requirement. Three of the original participants for this study were replaced, because their performance was close to chance level.

Stimuli and Procedure. Once again, the basic procedure was slightly modified. In this experiment, the colors and stimuli were the same as those in Experiment 1. Everything else followed the design of Experiment 2, with the exception of the number of trials per condition. Valid trials, which were more common in the previous experiments, were now equally as likely as neutral and invalid trials. Each of the eight blocks consisted of 60 trials: 20 valid, 20 neutral, and 20 invalid, presented in a random order. The experiment lasted approximately 50 min. The participants in this experiment were informed that the cue sometimes had the same color as the target and that it was their choice whether they wanted to make use of it.

Results and Discussion

As before, all the trials were included for the ANOVA of accuracy. For the analysis of RT, only trials with RTs within the range of 200–2,500 msec were considered, as in Experiments 1 and 2. A total of 5.29% of the trials were thus excluded; approximately 4.83% were early responses at chance accuracy. Again, early responses varied with target location in the RSVP sequence, suggesting anticipation. Average accuracies and RTs for the three levels of validity are presented in Table 3.

Analysis of accuracy. The effect of validity was significant for the accuracy data [$F(2,82) = 5.56$, $MS_e = 95.81$, $p < .01$]. Pairwise comparisons between the different validity conditions showed that the difference of 2.1% between valid and invalid trials was significant [$F(1,41) = 8.86$, $MS_e = 100.98$, $p < .01$], as was the 1.8% advantage for valid over neutral trials [$F(1,41) = 8.14$, $MS_e = 84.73$, $p < .01$]. The comparison between the neutral condition and the invalid condition showed no statistically reliable difference.

Surprisingly, no pattern that might suggest costs of invalid color cues was found when neutral trials were compared with invalid trials, even when the position of the color-cued distractor letter in relation to the target was taken into account. Accuracies for trials in which the cued color appeared before the target frame varied from 72% to 74.8%, but higher and lower accuracies alternated for successive distances. It is likely that the participants chose to pay less attention to items in the cued color because of the reduced perceived benefit of doing so. Accordingly, the cued-color nontarget might have less often been considered as a target, reducing any effects analogous to the AB.

The position of the target within the sequence had a strong effect on accuracy [$F(4,164) = 22.77$, $MS_e = 139.19$, $p < .001$], with accuracy decreasing the later the target was presented in the sequence. As before, taken together with the RT results, this pattern could be explained by a speed–accuracy trade-off.

Analysis of RT. For RT, the differences between the three levels of validity were also significant [$F(2,82) = 3.53$, $MS_e = 6,699.8$, $p < .05$]. Pairwise comparisons between the different validity conditions showed that only the 15-msec advantage of valid trials over neutral trials was significant [$F(1,41) = 5.12$, $MS_e = 9,195.7$, $p < .05$].

Target position had an effect not only on accuracy, but also on RT [$F(4,164) = 231.03$, $MS_e = 23,849.1$, $p < .001$], with RTs decreasing significantly the later the target was presented in the sequence. Together with the decrease

in accuracy, this suggests a speed–accuracy trade-off. As before, RTs also decreased over practice [$F(1,41) = 9.74$, $MS_e = 78,885.1$, $p < .005$]. In addition, there was a three-way interaction involving the factors of practice, validity, and target position [$F(8,328) = 2.17$, $MS_e = 5,094.3$, $p < .05$]. In invalid trials, performance varied strongly over target position only in the first blocks, whereas in later blocks, valid and neutral trial performance varied strongly over target position.

The main result of Experiment 3 is that a small but significant advantage of valid color cues remained even when the payoff for the participants to use the color cue was strongly reduced. This finding supports the hypothesis that an automatic-processing component contributes to the effects of color cues, because a significant color-cuing benefit remained, even without an obvious incentive to use the color cue. The observed cuing benefit appears, however, to be smaller than the benefits found in previous experiments. This reduction in cuing effect suggests that processing of the color cue also had a strategic component, because in a situation with no obvious incentive to use the cue, the participants apparently less often made use of it. Thus, the data suggest that processing is partially automatic and partially strategic. In contrast to cuing benefits, however, no sign of cost could be observed, even when the position of the distractor color in relation to the target in invalid trials was considered. This suggests that the presence of small costs may depend on strategic use of the color cues, although the experiment may simply have had insufficient statistical power to detect costs, which are consistently rather small.

These results are in line with findings reported by Laarni (2001). He asked his participants to discriminate the orientation of a certain stimulus in a multiple-item display. In addition, he provided color cues, which led to a validity effect. As in our experiment, in one of his experiments, he reduced the validity of the color cue to chance level. He also found an advantage of valid cues but no disadvantage of invalid cues.

EXPERIMENT 4

Although the results of Experiment 3 seem to suggest an automatic processing component, it can be argued, for two reasons, that the design of Experiment 3 might have encouraged the participants to make strategic use of the color cue. First, the cues were valid in 33% of all cases. Although this is a minority of all the trials, the cues were not completely uninformative, because 33% is still higher than the chance probability that a letter would be the target. Second, in the instructions, the participants were given a choice whether to use the color cue. Some participants might have chosen to use the cue because they interpreted the instructions to mean that this might be an effective strategy, in which case they might have produced cuing effects because of this strategic choice.

Experiment 4 was therefore conducted to test for automatic color processing in a more stringent design eliminating these two potential problems. The validity of the

Table 3
Average Percentages Correct and Reaction Times
(in Milliseconds) As a Function of Cue Validity in Experiment 3

Trials	Dependent Variable	
	Percentage Correct	Reaction Time
Valid	77.4	802
Neutral	75.6	817
Invalid	75.3	810

color cue was reduced to 6.67%; that is, only 1 out of 15 trials was valid. Since there were 15 letters in the sequence, the color cue was now completely uninformative. In addition, the instructions were changed. The participants were not informed about the significance of the color cue. They were told that each trial would start with a colored square and that they were to ignore this item. If color benefits remained under these conditions, the claim of a partly automatic processing would be even more strongly supported.

Method

Participants. In this experiment, 60 students (19 of them male) at the University of Otago took part. Their ages ranged from 18 to 29 years. All had normal color vision and were reimbursed with NZ\$9.50 for a session.

Stimuli and Procedure. The design was very similar to that in the previous experiment, with the following exceptions. Only valid and invalid trials were used in this experiment. The number of valid trials was drastically reduced. The target letter matched the color cue presented at the beginning of each trial in only 1 of 15 trials. In the other 14 trials, the target was displayed in one of the remaining five colors of the color set. Each block contained 10 valid trials and 140 invalid trials. Because of this large number of trials per block, only four blocks were run per participant. The experiment lasted approximately 50 min. The participants were told to ignore the colored squares used as cues.

Results and Discussion

The same RT range as that in Experiment 3 was chosen: 200–2,500 msec. This led to an exclusion of 4.86% of all the trials; approximately 4.23% of these were early responses, again at chance accuracy. As before, the percentage of early responses varied with target position, indicating anticipation. The average RTs and accuracies are displayed in Table 4.

Analysis of accuracy. Valid color cue trials led to a performance advantage of 1.5% over invalid color cue trials. This difference was significant [$F(1,59) = 4.22$, $MS_e = 152.99$, $p < .05$].

The only other effect concerned the position of the target. Performance decreased over target position [$F(4,236) = 11.75$, $MS_e = 218.12$, $p < .001$]. Taken together with the RT data reported next, this pattern seems to indicate a speed–accuracy trade-off.

Analysis of RT. There was no difference in RT between valid and invalid color cues ($p > .10$). As in the previous experiments, target position had an effect on RT [$F(4,236) = 176.46$, $MS_e = 24,608.3$, $p < .001$], with RTs decreasing strongly the later in the sequence the target was presented. Taken together with the effect described for accuracy, this suggests a speed–accuracy trade-off. In addition,

RTs also decreased over practice [$F(1,59) = 20.80$, $MS_e = 63,020.0$, $p < .001$].

In summary, the results of Experiment 4 replicated the findings of Experiment 3. A small benefit for valid color cue trials remained, confirming that the color-cuing effect partially involved an automatic-processing component and partially a strategic component.

EXPERIMENT 5

The previous experiments established a small but robust advantage of advance color information in RSVP tasks. In all of these experiments, the participants had to process only one letter per frame, so there was always a relatively small perceptual load. The effectiveness of the color cue might depend on perceptual load, so in our fifth experiment we explored the effect of an increase in perceptual load by presenting two slightly overlapping letters per frame.

There were three possible outcomes. First, the color-cuing effect might increase with more letters per frame. Lavie (1995) showed that an increase in perceptual load reduced distractor interference in a multiple-location design. Accordingly, the participants might focus more on the cued color under a higher perceptual load, and hence, larger benefits and costs of color cues could result. Second, the color-cuing effect might decrease. There is evidence that perceptual processes are more narrowly selective when perceptual load is large than when it is small (Lavie, Hirst, de Fockert, & Viding, 2004; Lavie & Tsai, 1994). Thus, if perceptual load is increased, the participants might focus more on the relevant attribute of target shape and, thus, process color less extensively. Similarly, if the use of the cue itself needs processing resources, an increase of the processing load might cause the participants to neglect the cue information. In that case, there should be no effect of cue validity. Third, the color-cuing effect might remain unchanged if the processes responsible for selection by color are insensitive to perceptual load.

To test among these possibilities, we used the same design as that in Experiment 2, but we used the original stimuli set described in Experiment 1. The only difference was that each frame in this experiment contained two slightly overlapping letters in two different colors. This increased the number of to-be-processed letters from 15 to 30 per trial. Both positions contained the target equally often. Because of the overlap between these two letters, it seems very unlikely that selection by location could have taken place.

Method

Participants. In this experiment, 24 undergraduates (7 of them male) at the University of Otago participated. As before, all of them reported that they had normal vision. They were from 17 to 36 years of age, and their participation was part of a 1st-year course requirement.

Stimuli and Procedure. For this experiment, the original stimuli and colors in Experiment 1 were used, whereas the procedure was similar to that in Experiment 2. The only exception was that a second letter was added to each frame. This second letter was always

Table 4
Average Percentages Correct and Reaction Times
(in Milliseconds) As a Function of Cue Validity in Experiment 4

Trials	Dependent Variable	
	Percentage Correct	Reaction Time
Valid	80.1	812
Invalid	78.6	821

presented in an uncued color and served as another distractor letter. The second letter partially overlapped with the first one. The first letter was presented, as before, in the center of the screen, and the second letter was presented approximately 2.5 mm higher and 3 mm to the right. The two letters in each frame were always different, as were their colors. The position of the target within the frame was determined randomly with equal likelihood. The presentation time per frame was increased to 110 msec. Because of this increase in trial length, only seven blocks of 60 trials each were conducted.

Results and Discussion

As before, all the trials were included in the analysis of accuracy, but for RT, the boundaries were slightly changed. The upper limit of 2,500 msec was increased to 3,000 msec in order to accommodate the additional length of the sequence due to an increase of presentation time per frame. This led to an exclusion of 4.96% of all the trials for the analysis of RTs. Most of these trials were early responses (approximately 4.48%) with chance accuracy. Also, an inspection of these trials in terms of target position indicates anticipation. Early responses became more frequent the later in the sequence the target was presented. Table 5 displays average accuracies and RTs for all three levels of validity.

Analysis of accuracy. The effect of validity was again highly significant [$F(2,46) = 9.60$, $MS_e = 504.38$, $p < .001$]. Pairwise comparisons between the different validity conditions showed, as was expected, a significant advantage of 8.5% for valid trials over invalid trials [$F(1,23) = 11.12$, $MS_e = 769.13$, $p < .005$]. In addition, the 6.9% benefit for the valid condition over the neutral condition was also significant [$F(1,23) = 11.22$, $MS_e = 506.77$, $p < .005$]. Responses in neutral trials were only 1.6% more accurate than those in invalid trials, and this difference did not reach significance. No other effects were significant.

As in the previous experiments, invalid trials were further compared with neutral trials while taking into account the position of the cued-color nontarget in relation to the target. The pattern found in Experiments 1 and 2 again failed to emerge in this experiment. Accuracy seemed to be increased when the cued color appeared in the frame immediately preceding the target frame, but responses to trials in which the cued color appeared more than four frames before the target frame were similarly high in accuracy. In contrast, when the cued color was presented in between—for example, two or three frames before the target—accuracy rates were more than 3% lower than those for the cued color with the target distances just described. The lack of an AB pattern might be due to the longer frame duration. In this experiment, each frame was

presented for 110 msec. Thus, the frame directly before the target frame fell within the AB period of 100–500 msec, as did the other three frame positions investigated here. Accordingly, if the previously observed pattern relates to the AB phenomenon, no difference between the four frames before the target would be expected.

Analysis of RT. For RT, the effect of validity was highly significant [$F(2,46) = 26.67$, $MS_e = 112,201.6$, $p < .001$]. Pairwise comparisons between the different validity conditions showed a highly significant advantage of 148 msec for valid over invalid trials [$F(1,23) = 43.55$, $MS_e = 60,699.9$, $p < .001$]. As for accuracy, the 218-msec difference for the comparison between the valid and the neutral conditions was also highly significant [$F(1,23) = 28.81$, $MS_e = 199,314.5$, $p < .001$]. Responses were also 70 msec faster in the invalid condition than in the neutral condition [$F(1,23) = 7.75$, $MS_e = 76,590.4$, $p < .02$]. An examination of the RT frequency distribution showed that this difference was due mainly to the presence of more very slow responses ($>1,700$ msec) in neutral trials than in invalid trials, presumably due to missed targets. Responses in the range of 200–300 msec were also more frequent in invalid trials—especially in invalid error trials—than in neutral trials. This probably reflects responses to distractor letters in the cued color.

As in the previous experiments, the position of the target within the sequence affected RT [$F(4,92) = 168.14$, $MS_e = 43,047.3$, $p < .001$], with faster responses to targets later in the sequence. The analysis of RT also yielded a significant interaction of target position with validity [$F(8,184) = 5.64$, $MS_e = 24,010.5$, $p < .001$]. Differences between the three levels of validity diminished over target position, probably due to the overall decrease in RTs for targets late in the sequence. In addition, there was a practice effect [$F(1,23) = 17.51$, $MS_e = 102,868.7$, $p < .001$].

Apart from the second letter in the frame, this experiment was the same as the Experiment 2 reported by Vierck and Miller (2005). This enabled us to compare the results of these two experiments for the dependent variable of accuracy with an additional ANOVA. None of the main effects or interactions involving the between-subjects factor of experiment reached significance.

In summary, although the number of stimuli per frame was doubled, the color-cuing effect seemed to remain essentially unchanged. A between-subjects comparison between the results of this experiment and those reported by Vierck and Miller (2005) yielded comparable benefits of valid color cuing in the two experiments. In contrast to the previously reported experiment, however, the difference between neutral and invalid trials was not significant. In addition, the previously reported pattern in invalid trials of a processing advantage when the distractor color was presented just before the target frame and a decrease of accuracy when it was presented further away was absent. Together, these findings suggest that in the present experiment, no costs of misleading color information were present, despite the similar benefit of valid color cuing.

Table 5
Average Percentages Correct and Reaction Times
(in Milliseconds) As a Function of Cue Validity in Experiment 5

Trials	Dependent Variable	
	Percentage Correct	Reaction Time
Valid	78.0	889
Neutral	71.1	1,107
Invalid	69.5	1,037

GENERAL DISCUSSION

In the five experiments reported here, we investigated which factors influence direct selection by color in the RSVP paradigm. All five experiments showed a clear benefit of valid color cues, and it is unlikely that these benefits were mediated by location, because all the stimuli were presented at fixation point. These findings provide further evidence that advance color information does allow direct selection of items for processing. They thus replicate the color-cuing effect reported by Vierck and Miller (2005) and—given the various changes in the task parameters investigated here—provide strong evidence for the robustness of this effect.

In the first experiment, the participants were asked to detect a specific letter (i.e., identity and case), instead of discriminating which letter case was presented. This enabled the participants to focus on a unique letter shape, rather than preparing for two possible versions of the target letter. If color-cuing effects depend on the requirement to monitor for multiple possible target shapes, the cuing effects should have disappeared in this experiment. Valid color cues still aided performance, however, indicating that these cuing effects are not unique to situations with uncertainty as to target shape.

In Experiment 2, we further investigated the effects of color and shape discriminability, using a new stimulus set in which the colors were less discriminable than the letters. In this experiment, the color-cuing effect was still reliable, but it was much smaller than had been observed previously. Thus, the effectiveness of direct selection by color is reduced to some extent when the relevant target information is more discriminable than the ancillary color information. This finding is in line with Duncan and Humphreys's (1989) attentional engagement theory, which emphasizes the similarity and dissimilarity of nontargets and targets. In this theory, target detection is easier when the target is more dissimilar to the distractor items and when the distractor stimuli are more similar to each other. The decreased color-cuing effect with more discriminable letters and less discriminable colors is consistent with Duncan and Humphreys's theory, because increased discriminability for letters would make participants less dependent on the color cue. It is important to note, though, that a significant color-cuing effect remained even with these discriminabilities, so advance color information is used, to some extent, even when the irrelevant color dimension is less discriminable than the relevant shape dimension.

At first glance, the results of Experiments 1 and 2 seem to be slightly contradictory. Both manipulations reduced task difficulty, but only the introduction of an easier-to-discriminate letter set had an influence on the color-cuing effect. These results can be explained if one assumes that participants have a subjective threshold for the informativeness of the cue, below which the cue will produce only automatic effects, not controlled ones. Under this assumption, the cue was still perceived as being of above-threshold usefulness even when target shape was certain,

whereas reversing letter and color discriminability crossed the threshold and caused the participants to ignore the color cue. This possibility is supported by the postexperimental debriefing statements given by the participants, who mostly claimed to have used the cue in Experiment 1 but mostly denied its use in Experiment 2.

The fact that a small color-cuing effect remained even when letter discrimination was easier than color discrimination suggested that processing of color cues might be automatic to some extent. Experiment 3 tested this possibility by reducing the incentive for the participants to use the color cue drastically. Instead of providing valid cues in the majority of the trials, all the cue types were equally likely. Accordingly, using the color cue would be helpful only in one third of the trials, whereas in the majority (two thirds) of the trials, the cue was not useful—that is, either conveying no information or being misleading. In a situation such as that, focusing on the letter shape alone might have been a better strategy than taking any notice of the color cue. The results showed, however, a small but significant advantage for valid cues, suggesting that the processing of color cues is partially strategic and partially automatic, like the processing of peripheral location cues (Jonides, 1981). Experiment 4, in which cue validity was reduced even further to 1 in 15 trials and the participants were instructed to ignore the cue, replicated the findings of Experiment 3. The small but significant benefit of valid cue trials found under these circumstances strengthens the conclusions made for Experiment 3. The small automatic component observed in both of the experiments might have been responsible for the validity effect in Experiment 2, where a small advantage of valid color cues was found despite easier letter discrimination.

In the fifth experiment, we investigated the effect of perceptual load by presenting two overlapping letters per frame. This effectively doubled the amount of information to be processed in each frame. This manipulation did not seem to change the color-cuing effect significantly, as compared with only a single letter per frame (Vierck & Miller, 2005). Thus, the effect of color cuing on direct selection seems largely independent of perceptual load.

Although the benefits of valid color cues are remarkably consistent and robust across variations of the RSVP paradigm, these effects are not particularly large, and there might simply be a rather small maximum advantage that can be reached with valid color cues when stimuli do not vary in location. The benefit for Experiments 1 and 5, as well as the benefits reported by Vierck and Miller (2005), were all approximately 7%. In contrast, for valid location cues, a cuing benefit of more than 20% has been observed (Henderson, 1991). Studies in which both location and color cues have been used have reported a considerably larger benefit of location over color cues (e.g., Geller, 1977; Laarni, 1999). Together, these results suggest that although direct selection by color is possible—as is conceivable for other features—the attribute of location might play a dominant role in selection, since it seems to be the favored choice of participants and also seems to lead to the largest benefits.

In all the experiments reported here, RSVP paradigms were used. A characteristic of these tasks is that item presentations vary in time, rather than in location. It can be argued that color guided attention only to a certain frame presented at a certain time, similar to the argument of color guidance put forward in experiments with several possible target locations. It is possible that a part of the observed cuing benefit can be explained by guidance in time, but it seems unlikely that this explanation can account for all of the effect. In RSVP experiments with a similar number of frames and a similar presentation rate, in which participants were asked to search for a target letter defined by a certain color, many errors have been observed (e.g., Botella & Eriksen, 1992; McLean et al., 1983). Selection by color seems, therefore, not very effective. Thus, it seems that only some part of the color-cuing effect is due to selection of time but that at least some part is due to direct selection by color (Vierck & Miller, 2005).

All five RSVP experiments showed an advantage of advance color information in valid trials. In contrast, costs were not clearly observed in invalid trials. In this respect, the present results are different from the small but significant costs reported by Vierck and Miller (2005). Hints as to the resolution of the discrepant results concerning costs in invalid trials can be found in a more detailed examination of the data of both the earlier experiments and the present Experiments 1 and 2. Specifically, there is evidence in both the earlier results and the present ones that the presence of a distractor in the cued color can have both distracting effects, which would tend to produce costs, and alerting effects, which would tend to produce counteracting benefits. In all cases, the evidence of this was a non-monotonic effect of the location of the cued-color distractor within the RSVP sequence on performance. When the cued-color distractor appeared within approximately one to two frames of the target, performance tended to be better in the invalid condition than in the neutral condition; in contrast, when the cued-color distractor appeared farther from the target, performance tended to be worse in the invalid condition than in the neutral condition (cf. Figure 1; see also Figure 1 in Vierck & Miller, 2005). This pattern is very similar to the AB phenomenon. When the cued-color nontarget was presented close to the target frame, discrimination or detection accuracy for the target was less efficient. It might be that the cued-colored nontarget had the same effect as the first target in an AB task, leading to a blink for a limited time in which the discrimination or detection of the real target was more difficult. But this effect was not constant across our experiments. With counteracting effects contributing to the results in the invalid condition, it is not surprising that this condition would be rather inconsistently different from the neutral condition, and it is easy to imagine that small procedural differences would tip the subtle balance between the conflicting effects.

Another possible way to confirm costs is to compare RTs for trials in which the target letter and the color-cued nontarget matched in letter case with those for trials in which letter cases were nonmatching.³ If the cue color

led to the selection of the nontarget, one would expect to find shorter RTs when the target letter case was congruent with the selected nontarget—that is, when both asked for the same response key (Eriksen & Hoffman, 1973). It is likely that the letter case would, therefore, be known in some cases, and response execution might be initialized. This response preparation should be beneficial in trials in which the target letter had the same case, but it should lengthen RT in the case of a mismatch, because the other hand was the response hand. A post hoc examination of this effect was conducted for Experiments 2–5. Experiments 3–5 showed the expected speedup of RTs in the congruency condition ($p < .01$ for each experiment), indicating that invalid color cues led, indeed, to the selection of the cued nontarget. Only Experiment 2 yielded no difference in the congruency conditions, most likely because the changed letter set caused the participants to focus more on letter shape and less on color, since letter shape was easier to distinguish in this experiment.

With respect to our conclusion that there are both automatic and controlled components to color-cuing effects, it should be noted that somewhat similar conclusions have been reached for location cuing. Jonides (1981, Experiment 2) used peripherally and centrally presented location cues within a search task with a display of eight letters arranged in a circle. One of them was the target letter, either an R or an L; the participants were asked to indicate which one was presented on any given trial. A cue in the form of an arrowhead pointed toward the probable location of the target letter, either from a central position or from a position close to the target location. Cue validity was at chance level. In addition, one group of participants was told to ignore the cue, whereas the other was told to attend to it. The results showed an advantage for valid cues, regardless of cue position, for the participants who attended to the cues. For the group that ignored the cues, however, a significant difference between valid and invalid trials was found only for cues presented peripherally. Moreover, the RT differences in this chance validity condition were much smaller than those in a previous experiment with 70% validity. The author attributed the drop in the effect on RT to control exercised by the participants. The fact that, for peripheral cues, an advantage remained, although the participants were asked to ignore the cue, was interpreted as a sign of partially automatic processing of the cue. The present findings for color cues are most similar to those for peripheral cues reported by Jonides. As in his experiment, the cue effect in the chance validity condition was smaller than that in the two-thirds validity condition, but it was still present to some extent. Note that cues and letters were all presented centrally in our task, so the cues were near the targets, just like the peripheral cues used by Jonides. The finding of a strategic component also fits well with our explanation for the inconsistency between our results and those of Pöder (2001) and Shih and Sperling (1996). Like ours, both of these earlier experiments explored the effect of color cues in an RSVP task, but neither of them showed an advantage for valid color cues. One difference between their design and ours is that the color cues used

in both of their experiments only halved the number of relevant items in the stimulus display, whereas in our experiment, the color cue reduced the stimulus display to just one relevant item. Such a reduction would maximize the use of the color cue for strategic processing, because it would provide a substantial processing advantage. In Pöder's and Shih and Sperling's experiments, though, the payoff from cues might not have been large enough to warrant strategic processing. Even the automatic component might have been affected by the inefficiency of the cue in these experiments. If every frame in the cued color was selected automatically, initiating further processing, all but one of these color-cued frames would consist of misleading distractors even in the valid condition, similar to our invalid condition. Thus, processing of all the items appearing in the cued color would have a substantial distracting effect even in this condition, and this could well have a negative effect on performance. Thus, it is easy to see how the potential selection benefit would most likely be masked by the disadvantages associated with directing attention to every item in the cued color.

In conclusion, the experiments reported here suggest that selection by color is a very robust phenomenon even in search tasks in which location does not vary. The effect seems to depend on discrimination difficulty, but not on display size or shape-processing demands, and it seems to have both automatic and strategic components.

REFERENCES

- BOTELLA, J., & ERIKSEN, C. W. (1992). Filtering versus parallel processing in RSVP tasks. *Perception & Psychophysics*, **51**, 334-343.
- BRAWN, P., & SNOWDEN, R. J. (1999). Can one pay attention to a particular color? *Perception & Psychophysics*, **61**, 860-873.
- CARTER, R. C. (1982). Visual search with color. *Journal of Experimental Psychology: Human Perception & Performance*, **8**, 127-136.
- CAVE, K. R., & PASHLER, H. (1995). Visual selection mediated by location: Selecting successive visual objects. *Perception & Psychophysics*, **57**, 421-432.
- CHEAL, M., & GREGORY, M. (1997). Evidence of limited capacity and noise reduction with single-element displays in the location-cuing paradigm. *Journal of Experimental Psychology: Human Perception & Performance*, **23**, 51-71.
- CHUN, M. M. (1997). Temporal binding errors are redistributed by the attentional blink. *Perception & Psychophysics*, **59**, 1191-1199.
- DUNCAN, J., & HUMPHREYS, G. W. (1989). Visual search and stimulus similarity. *Psychological Review*, **96**, 433-458.
- ERIKSEN, C. W., & HOFFMAN, J. E. (1973). The extent of processing of noise elements during selective encoding from visual displays. *Perception & Psychophysics*, **14**, 155-160.
- FOLK, C. L., LEBER, A. B., & EGETH, H. E. (2002). Made you blink! Contingent attentional capture produces a spatial blink. *Perception & Psychophysics*, **64**, 741-753.
- FOLK, C. L., REMINGTON, R. W., & JOHNSTON, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception & Performance*, **18**, 1030-1044.
- FOX, E., & DE FOCKERT, J.-W. (2001). Inhibitory effects of repeating color and shape: Inhibition of return or repetition blindness? *Journal of Experimental Psychology: Human Perception & Performance*, **27**, 798-812.
- GARNER, W. R. (1987). Location and color as cuing dimensions in contingent classification. *Perception & Psychophysics*, **41**, 202-210.
- GELLER, E. S. (1977). Latencies to name one of three stimulus dimensions: A study of probability effects and dimension integrality. *Perception & Psychophysics*, **22**, 70-76.
- GOLD, J. M., & PRATT, J. (2001). Is position "special" in visual attention? Evidence that top-down processes guide visual selection. *Canadian Journal of Experimental Psychology*, **55**, 261-270.
- GOLDSTEIN, E. B., & FINK, S. I. (1981). Selective attention in vision: Recognition memory for superimposed line drawings. *Journal of Experimental Psychology: Human Perception & Performance*, **7**, 954-967.
- GREEN, B. F., & ANDERSON, L. K. (1956). Color coding in a visual search task. *Journal of Experimental Psychology*, **51**, 19-24.
- HENDERSON, J. M. (1991). Stimulus discrimination following covert attentional orienting to an exogenous cue. *Journal of Experimental Psychology: Human Perception & Performance*, **17**, 91-106.
- HUMPHREYS, G. W. (1981). Flexibility of attention between stimulus dimensions. *Perception & Psychophysics*, **30**, 291-302.
- HUYNH, H. (1978). Some approximate tests for repeated measurement designs. *Psychometrika*, **43**, 161-175.
- JONIDES, J. (1981). Voluntary versus automatic control over the mind's eye's movement. In J. Long & A. Baddeley (Eds.), *Attention and performance IX* (pp. 187-203). Hillsdale, NJ: Erlbaum.
- KIM, M.-S., & CAVE, K. R. (2001). Perceptual grouping via spatial selection in a focused-attention task. *Vision Research*, **41**, 611-624.
- KINCHLA, R. A. (1992). Attention. *Annual Review of Psychology*, **43**, 711-742.
- KINGSTONE, A. (1992). Combining expectancies. *Quarterly Journal of Experimental Psychology*, **44A**, 69-104.
- LAARNI, J. (1999). Allocating attention in the visual field: The effects of cue type and target-distractor confusability. *Acta Psychologica*, **103**, 281-294.
- LAARNI, J. (2001). Colour-cueing in visual search. *Scandinavian Journal of Psychology*, **42**, 71-78.
- LABERGE, D., & BROWNSTON, L. S. (1974). Control of visual processing by color cueing. *Bulletin of the Psychonomic Society*, **4**, 417-418.
- LAMBERT, A. J., & CORBAN, R. (1992). Spatial attention and expectancy for colour, category and location: Further evidence against the spotlight model. *Acta Psychologica*, **81**, 39-51.
- LAMY, D., & TSAL, Y. (2000). Object features, object locations, and object files: Which does selective attention activate and when? *Journal of Experimental Psychology: Human Perception & Performance*, **26**, 1387-1400.
- LAVIE, N. (1995). Perceptual load as a necessary condition for selective attention. *Journal of Experimental Psychology: Human Perception & Performance*, **21**, 451-468.
- LAVIE, N., HIRST, A., DE FOCKERT, J. W., & VIDING, E. (2004). Load theory of selective attention and cognitive control. *Journal of Experimental Psychology: General*, **133**, 339-354.
- LAVIE, N., & TSAL, Y. (1994). Perceptual load as a major determinant of the locus of selection in visual attention. *Perception & Psychophysics*, **56**, 183-197.
- MCLEAN, J. P., BROADBENT, D. E., & BROADBENT, M. H. P. (1983). Combining attributes in rapid serial visual presentation tasks. *Quarterly Journal of Experimental Psychology*, **35A**, 171-186.
- MILLER, J., & SCHRÖTER, H. (2002). Online response preparation in a rapid serial visual search task. *Journal of Experimental Psychology: Human Perception & Performance*, **28**, 1364-1390.
- MOORE, C. M., & EGETH, H. (1998). How does feature-based attention affect visual processing? *Journal of Experimental Psychology: Human Perception & Performance*, **24**, 1296-1310.
- NISSEN, M. J. (1985). Accessing features and objects: Is location special? In M. I. Posner & O. S. M. Marin (Eds.), *Attention and performance XI* (pp. 205-219). Hillsdale, NJ: Erlbaum.
- PALMER, J., AMES, C. T., & LINDSEY, D. T. (1993). Measuring the effect of attention on simple visual search. *Journal of Experimental Psychology: Human Perception & Performance*, **19**, 108-130.
- PÖDER, E. (2001). Size-based selection in rapid serial visual presentation. *Vision Research*, **41**, 2221-2234.
- POSNER, M. I., SNYDER, C. R. R., & DAVIDSON, B. J. (1980). Attention and the detection of signals. *Journal of Experimental Psychology: General*, **109**, 160-174.
- ROCK, I., & GUTMAN, D. (1981). The effect of inattention on form perception. *Journal of Experimental Psychology: Human Perception & Performance*, **7**, 275-285.
- SCHNEIDER, W., & SHIFFRIN, R. M. (1977). Controlled and automatic

- human information processing: I. Detection, search, and attention. *Psychological Review*, **84**, 1-66.
- SHIH, S.-I., & SPERLING, G. (1996). Is there feature-based attentional selection in visual search? *Journal of Experimental Psychology: Human Perception & Performance*, **22**, 758-779.
- THEEUWES, J. (1989). Effects of location and form cuing on the allocation of attention in the visual field. *Acta Psychologica*, **72**, 177-192.
- TIPPER, S. P., & CRANSTON, M. (1985). Selective attention and priming: Inhibitory and facilitatory effects of ignored primes. *Quarterly Journal of Experimental Psychology*, **37A**, 591-611.
- TREISMAN, A. (1985). Preattentive processing in vision. *Computer Vision, Graphics, & Image Processing*, **31**, 156-177.
- TSAL, Y., & LAMY, D. (2000). Attending to an object's color entails attending to its location: Support for location-special views of visual attention. *Perception & Psychophysics*, **62**, 960-968.
- TSAL, Y., & LAVIE, N. (1988). Attending to color and shape: The special role of location in selective visual processing. *Perception & Psychophysics*, **44**, 15-21.
- TSAL, Y., & LAVIE, N. (1993). Location dominance in attending to color and shape. *Journal of Experimental Psychology: Human Perception & Performance*, **19**, 131-139.
- VAN DER HEIJDEN, A. H. C., KURVINK, A. G., DE LANGE, L., DE LEEUW, F., & VAN DER GEEST, J. N. (1996). Attending to color with proper fixation. *Perception & Psychophysics*, **58**, 1224-1237.
- VIERCK, E., & MILLER, J. (2005). Direct selection of color for visual encoding. *Perception & Psychophysics*, **67**, 483-494.
- VISSER, T. A., BISCHOF, W. F., & DI LOLLO, V. (2004). Rapid serial visual distraction: Task-irrelevant items can produce an attentional blink. *Perception & Psychophysics*, **66**, 1418-1432.

NOTES

1. To compare the discriminabilities of letters and colors, a pilot study was conducted. Twelve participants were asked to perform a detection task in which the same stimuli and colors were used as those in Experiments 1 and 2 in Vierck and Miller (2005), and the conditions in that experiment were replicated as closely as possible. The major difference from the previous experiment was that for the color detection task, one color was defined as the target for each trial. In half of the trials, the target color was present, and the participant's task was to indicate its presence or absence. For the letter detection task, target letters were specified on a block-to-block basis, and the target letter, if present, could be presented in its upper- or lowercase version, as in the original experiment. Color and letter detection blocks alternated within one experimental session. The results showed that accuracy was significantly better in the color detection task than in the letter detection task [$F(1,10) = 15.15$, $MS_e = 43.2$, $p < .005$], indicating that specific colors were, indeed, easier to detect than specific letters.

2. The new set was tested in another pilot study, where it was confirmed that with these new sets, letters were easier to discriminate from each other than were colors [$F(1,10) = 19.73$, $MS_e = 177.28$, $p < .002$].

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