Cueing of object orientation facilitates attentional selection of relevant objects

PETER WÜHR *

Institut für Psychologie I, Friedrich-Alexander Universität, Kochstrasse 4, 91054 Erlangen, Germany

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Abstract—Three experiments investigated the effects of advance information about orientation on the processing of relevant and irrelevant objects, as indicated by Stroop effects from color words located in either object. Four results were obtained. First, participants showed the expected modulation of the Stroop effect: words in the relevant object produced much larger Stroop effects than words in the irrelevant object or words in the background. Second, blocking of object orientation had no effects. Third, informative orientation cues facilitated processing of the relevant object, but cueing did not affect processing of the irrelevant object. Fourth, effects of informative orientation cues were restricted to the first part of each experiment. Results suggest that observers can use advance information about object orientation for improving attentional selection of a visual object. In addition, the results revealed some constraints for the effective use of orientation cues, and discard possible explanations for the observed modulation of Stroop effects.

Keywords: Attention; orientation cueing; Stroop effect.

INTRODUCTION

In every moment human observers are confronted with a wealth of visual stimuli. Usually, however, only a subset of these stimuli is relevant for achieving our current behavioral goals. To solve this problem, the cognitive system is equipped with mechanisms that support the selection and processing of relevant stimuli, and these mechanisms are called selective attention. One way that cognitive scientists investigate selective attention involves filtering or interference tasks, in which the investigator determines the effects of irrelevant information on the processing of relevant information. One of the best-known tasks for studying selective attention is the Stroop task (Stroop, 1935).

*E-mail: Peter.Wuehr@psy.phil.uni-erlangen.de
In the Stroop task, color words are presented in different colors (e.g., the word RED in green ink color). If participants are required to report ink color, then irrelevant word meaning strongly influences color-naming performance. In particular, when compared with neutral conditions (e.g., the letter string xxx in any color), congruent color words improve color-naming performance, whereas incongruent words impair color-naming performance (for reviews, see MacLeod, 1991; MacLeod and MacDonald, 2000). A common explanation for the Stroop effect rests on the distinction between controlled and automatic operations of information processing (Jonides, 1981; Posner and Snyder, 1975; Shiffrin and Schneider, 1977). Controlled processes are initiated and maintained by will, they require limited processing resources (e.g., selective attention), and are prone to interference from concurrent mental operations. By contrast, automatic processes are initiated involuntarily, they do not require limited resources, and they are immune to interference from concurrent processing. The transition between controlled and automatic modes of information processing should be viewed as continuous (e.g. MacLeod and Dunbar, 1988). Many authors conceive of word reading as strongly automatic, whereas color naming is believed to rely on much less automatic (i.e., controlled) processing. Hence, irrelevant words are read involuntarily, therefore interfering with color naming, but not vice versa (Brown et al., 2002; MacLeod and MacDonald, 2002; Posner and Snyder, 1975).

The results of a recent study by Wühr and Waszak (2003) suggest that the robustness of the Stroop effect, especially with integrated Stroop tasks (i.e., presentation of colored color words), cannot be explained merely by the automaticity of word reading. At least in integrated tasks, word shape seems to be analyzed not only because word reading is so strongly automatic, but because word shape belongs to the attended perceptual object (cf. Kahneman and Henik, 1981). The participants in the study by Wühr and Waszak were required to name the color of a rectangle that partially occluded a second rectangle (cf. Fig. 1c). To provoke Stroop effects, displays also contained congruent, neutral, or incongruent color words. Importantly, these color words appeared alternatively in the relevant object (Fig. 1d), or in the irrelevant object, or in the background (Fig. 1c). Spatial separation between each word and the fixation point was the same in all conditions. Hence the notion of a spotlight of attention (e.g., Posner, 1980), when focused on the fixation point, does not predict any differences between the conditions.

Wühr and Waszak (2003) observed systematic differences between their conditions. In particular, both facilitation from congruent words and interference from incongruent words were much larger when the words were part of the relevant object. Moreover, Stroop effects did not differ according to whether words appeared in the irrelevant object or in the background. The same pattern of results occurred when participants were asked to name the color of the occluded rectangle. These results were explained in terms of object-based attentional selection (Kahneman and Henik, 1981; for a review see Scholl, 2001). According to this account, preattentive processes segment the visual field into figures (so-called candidate objects).
and ground, and attention selects one (or more) of the figures for further processing. Moreover, attentional selection of an object is assumed to amplify processing of all its features (Duncan, 1984; O’Craven et al., 1999). Words that are parts of the relevant object therefore produce larger Stroop effects than words in the irrelevant object or words in the background.

Basically, two ways of object-based selection have been distinguished. One possibility is that attentional selection operates on spatially invariant representations of candidate objects. According to this account, attention can select an object on the basis of the features other than location (Duncan, 1984; Vecera and Farah, 1994). Another possibility is that attention needs to select the location occupied by an object in order to select the object itself (Schendel et al., 2001; Vecera, 1994).
At present, it is unclear whether the larger effects of Stroop words in the relevant object, compared to the effects of words outside the relevant object, are the result of an attentional mechanism that operates on spatially invariant object representations or on object locations.

The task used by Wühr and Waszak (2003) requires several complex cognitive operations. First, the visual system has to segment the two objects from the background. Next, attention has to select the relevant object for further processing. Then, the observer has to determine the particular value on the relevant object dimension. Finally, he/she has to select the appropriate response to the relevant object feature.

The present study further investigates the mechanisms of object segmentation and object selection in the task used by Wühr and Waszak (2003). In particular, the present study investigates whether and how these mechanisms can use advance information regarding the orientation (or shape) of two-dimensional objects. If the cognitive system can use this information then it should affect the pattern of Stroop effects. One possibility is that the cognitive system can use advance information about orientation for improving figure–ground segmentation. If so, processing of both the relevant and the irrelevant object should be facilitated, and Stroop effects in the relevant and irrelevant object should be larger with advance information about shape than without this information. Another possibility is that the cognitive system can use advance information about orientation for improving selection of the relevant object. If so, processing of the relevant object should be facilitated, selectively increasing Stroop effects in the relevant object. Alternatively, processing of the irrelevant object could be inhibited, selectively decreasing Stroop effects in the irrelevant object.

The results of earlier studies appeared to suggest that human observers are not able to use advance information (i.e. cues) about the likely shape of a target stimulus for improving target processing, whereas observers are able to use cues about the likely location of the target (e.g. Posner et al., 1980). In contrast, the results of recent studies suggest that shape cues can also affect performance under the appropriate conditions. For example, a study by Schendel et al. (2001) compared the effects of location cues with the effects of object (shape) cues on the exogenous allocation of visual attention. Participants in that study had to detect a target stimulus that appeared in one of two locations, which were marked by placeholders (i.e. objects). At the beginning of each trial, two stars of David appeared as placeholders. One of the stars was briefly thickened to cue the object at this location. Importantly, after the cue, the cued and the un-cued object could remain the same or change their shapes. In doing this, the authors independently cued locations and objects. Schendel et al. observed the typical results of exogenous location cueing, that is, facilitation of cued locations at short SOAs (i.e. 125 ms), and inhibition of cued locations at long SOAs (i.e. >400 ms). Interestingly, a different result emerged for object cueing in that facilitation of cued objects was observed for the longest SOA (i.e. 725 ms) only. This result shows that shape cues can affect the processing
of objects, and that the processing of shape cues needs much more time than the processing of location cues. On the other hand, it remains unclear whether shape cues facilitated the segmentation and/or the selection of the cued object.

In the present experiments, the participants were shown two overlapping rectangles (Fig. 1c) and verbally reported the color of the occluding rectangle. Stroop effects were provoked by presenting congruent or incongruent color words in the relevant object, in the irrelevant object, or in the background. Most importantly, participants were either given information regarding the orientation of the two objects in the next trial, or they were not provided with this information. The information about object orientation was delivered in different ways. In Experiment 1, the orientation of the objects was constant and predictable, or the orientation of the objects varied unpredictably. In contrast, an informative cue told participants about the orientation of the objects in half of the trials of Experiments 2 and 3 (Fig. 1a); an uninformative cue preceded the stimulus display in the other half of the trials (Fig. 1b). Trials with informative cues and those with uninformative cues were randomly mixed in each block of Experiment 2. In contrast, trials with informative cues and trials with uninformative cues were blocked in Experiment 3.

**EXPERIMENT 1**

Experiment 1 investigated whether predictability of object orientation in a selective attention task could affect figure–ground segmentation and/or the selection of the relevant object for further processing. Participants were shown two overlapping rectangles and were required to name the color of the occluding rectangle. In order to provoke Stroop effects, congruent or incongruent color words were shown in the relevant object, in the irrelevant object, or in the background. Words in the relevant object were expected to produce larger Stroop effects than words in the other conditions (e.g. Wühr and Waszak, 2003). The most important manipulation concerned the predictability of the orientation of the objects. This factor was manipulated between two groups of participants. One group was not able to predict the orientation of the objects because orientation varied randomly from trial to trial, as in previous studies (Wühr and Waszak, 2003). The second group, by contrast, was able to predict the orientation of the objects because this factor remained constant throughout the experiment.

The question of interest was how predictability of object orientation would affect the pattern of Stroop effects. If the cognitive system can use the predictability of object orientation (or object shape) for improving the segmentation of figures from the background, then processing of the relevant and the irrelevant object should similarity benefit. As a result, we should observe larger Stroop effects in the relevant object and in the irrelevant object with predictable orientation than with unpredictable orientation. If the cognitive system can use the predictability of object orientation (or object shape) for attentional selection of the relevant object then processing of the relevant object and processing of the irrelevant object should
be differentially affected. In particular, predictability of object orientation might be used to direct attentional resources to the relevant shape in advance, which should selectively increase Stroop effects in the relevant object. Alternatively, predictability of object orientation might be used to inhibit the irrelevant shape in advance, which should selectively decrease Stroop effects in the irrelevant object.

**Method**

**Participants.** 32 students from Erlangen University (21 female, 11 male) with a mean age of 24 years participated in a single-session experiment. The experiment lasted for approximately 45 min, and participants were paid €6.00 or were given course credits. All participants in this and the following experiments were native German speakers with normal (or corrected-to-normal) visual acuity. Moreover, each participant’s color vision was tested with Ishihara’s (1960) ‘Tests for color blindness’.

**Apparatus and stimuli.** The experiment took place in a dimly lit room. Participants sat in front of a 17-inch color monitor with viewing distance being constrained to 50 cm by a head-and-chin rest. Participants responded by speaking into a microphone, which triggered a voice key measuring RTs to the nearest millisecond. An IBM-compatible computer controlled the presentation of stimuli and collected vocal RTs. Visual stimuli were shown on a colored background (see below). The fixation cross was a small ‘+’ sign, subtending 0.5° of visual angle. Each stimulus display consisted of two rectangles, which were superimposed upon each other and formed a cross, centered on the fixation cross (see Fig. 1). The short side of the rectangles subtended 1.5 cm (1.7°); the long side subtended 5.5 cm (6.3°).

In each stimulus display, the background, the irrelevant rectangle, and the relevant rectangle appeared in different colors. The four colors used were blue, green, red, and yellow. Moreover, in order to provoke Stroop effects, two identical words appeared at different locations in the displays. When the words appeared in the horizontally oriented rectangle, one word appeared to the left of fixation and the other to the right. When the words appeared in the vertically oriented rectangle, one word appeared above fixation and the other below. When the words appeared in the background, one word appeared above-left (or above-right) and the other one appeared below-right (or below-left) of fixation. The words subtended between 1.1 cm (1.3°; ‘rot’ [German for ‘red’]) and 1.4 cm (1.6°; ‘grün’ [German for ‘green’]). The spatial distance between the fixation point and the center of a word was 2.1 cm (2.4°) in each condition.

**Procedure.** At the beginning of the session, the instructions appeared on the screen, and participants were able to read them at leisure. The instructions first described the experimental displays and the participants’ task. The task was to report the color of the occluding rectangle, regardless of its orientation. Moreover,
instructions pointed out that the words presented in the display were irrelevant with respect to the task; the participants were told to ignore them. Finally, instructions encouraged participants to fixate the fixation cross, and to respond loudly and as quickly and accurately as possible. The instructions were followed by sixteen practice trials.

Participants were randomly assigned to one of two different conditions. Therefore, there were 16 participants in each condition (Group 1: mean age of 24.9 years, 9 females, 7 males; Group 2: mean age of 23.6 years, 12 females, 4 males). There was one main difference between the two conditions. In one condition, the orientation of the front and the rear rectangle varied randomly from trial to trial. In the other condition, the orientation of both rectangles remained constant across the entire experiment, and participants were informed about this fact before the experiment began. In the latter condition, the orientation of the relevant rectangle was balanced across participants.

The experiment was run in 19 blocks of trials. At the beginning of each block, the string ‘Press a key’ appeared. The key press started a block of twenty trials, each of which contained the following sequence of events: First, the fixation cross appeared on the screen for 500 ms. Then, after a brief blank interval of 50 ms, the stimulus display was presented for 250 ms, followed by an additional blank period of 1,000 ms. After the final stimulus display of a block, the string ‘Press a key’ appeared and the participant was able to take a break.

The participants’ performance was monitored online by the experimenter, who sat outside the experimental chamber. The experimenter was able to hear the participants’ responses via earphones and compared them with the correct answers that were shown on a second monitor. Each error was recorded in a list.

Design. The experiment used a $2 \times 3 \times 2$ mixed design. The first factor was Congruency. The irrelevant words were congruent or incongruent with respect to the correct color-naming response. Color words and object colors were not correlated. As a result, incongruent conditions were three times as frequent as congruent conditions. The second factor was Object Condition. The words were presented either as parts of the relevant object, as parts of the irrelevant object, or as parts of the background. The third factor was Orientation Condition. The orientation of the relevant object either varied randomly from trial to trial, or it remained constant throughout the entire experiment.

The factors Congruency and Object Condition varied within participants. The factor Orientation Condition varied between participants. Each group of participants was presented with 8 repetitions for each combination of color word (4), color of the relevant object (4), and object condition (3), resulting in a total of 384 experimental trials. The final block contained 24 trials instead of 20.
Table 1.
RTs (in ms) and error percentages (in parentheses) observed in Experiment 1

<table>
<thead>
<tr>
<th>Words appeared in…</th>
<th>Relevant object</th>
<th>Irrelevant object</th>
<th>Background</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orientation random</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Congruent</td>
<td>596 (0.8)</td>
<td>600 (1.4)</td>
<td>598 (0.6)</td>
</tr>
<tr>
<td>Incongruent</td>
<td>697 (6.8)</td>
<td>646 (3.1)</td>
<td>644 (2.6)</td>
</tr>
<tr>
<td>Stroop effect</td>
<td>101 (6.0)</td>
<td>46 (1.7)</td>
<td>46 (2.0)</td>
</tr>
<tr>
<td>Orientation blocked</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Congruent</td>
<td>595 (1.1)</td>
<td>602 (1.2)</td>
<td>604 (0.8)</td>
</tr>
<tr>
<td>Incongruent</td>
<td>697 (9.4)</td>
<td>635 (3.0)</td>
<td>644 (3.2)</td>
</tr>
<tr>
<td>Stroop effect</td>
<td>102 (8.3)</td>
<td>33 (1.8)</td>
<td>40 (2.4)</td>
</tr>
</tbody>
</table>

Note: Stroop effect = incongruent condition minus congruent condition.

Results

RTs. For each participant and condition, vocal RTs exceeding two standard deviations from the mean were removed. Across participants and conditions, this procedure eliminated 1.9% of trials with premature responses and 1.9% of trials with retarded responses. The mean RT values and error percentages for each condition are presented in Table 1.

Mean RTs from error-free trials were entered into a 2 (Congruency) × 3 (Object) × 2 (Orientation) analysis of variance (ANOVA) for mixed designs. The main effect of Orientation was not significant ($F < 1$). In fact, the group with variable orientation ($M = 630$ ms) and the group with constant orientation ($M = 631$ ms) showed almost identical overall RTs. However, the main effects of Congruency and Object condition were significant. The main effect of Congruency, $F(1, 30) = 219.41, p < 0.001$, indicated a Stroop effect, i.e. shorter RTs with congruent conditions ($599$ ms) than with incongruent conditions ($661$ ms). The main effect of Object condition, $F(2, 60) = 39.30, p < 0.001$, indicated longer RTs when the words appeared in the relevant object ($646$ ms) than when they appeared in the irrelevant object ($621$ ms), or in the background ($622$ ms).

The two-way interaction between Congruency and Object was also significant, $F(2, 60) = 88.14, p < 0.001$. To clarify the interaction, Stroop effect scores (incongruent RT minus congruent RT) were computed and compared. Comparisons revealed that words in the relevant object ($D = 102$ ms) produced larger Stroop effects than words in the irrelevant object ($D = 39$ ms), or words in the background ($D = 43$ ms), respectively. The two-way interactions involving the Orientation factor were not significant (both $F < 1$). Moreover, the three-way interaction was also not significant $F(2, 60) = 1.01, p = 0.37$.

Errors. Error percentages were also entered into a three-factorial ANOVA for mixed designs, and results closely paralleled those of the RT analysis. The main
Orientation cueing

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effect of Orientation was not significant \( (F < 1) \). However, a significant main effect of Congruency, \( F(1, 30) = 65.42, \ p < 0.001 \), indicated fewer errors with congruent conditions (1.0%) than with incongruent conditions (4.7%). The main effect of Object condition, \( F(2, 60) = 28.99, \ p < 0.001 \), indicated more errors when the words appeared in the relevant object (4.5%) than when they appeared in the irrelevant object (2.1%), or in the background (1.8%).

The two-way interaction between Congruency and Object was also significant, \( F(2, 60) = 42.07, \ p < 0.001 \). Comparisons of Stroop scores revealed that words in the relevant object \( (D = 7.2\%) \) produced larger Stroop effects than words in the irrelevant object \( (D = 1.7\%) \), or words in the background \( (D = 2.2\%) \), respectively. The two-way interactions between Object and Orientation, \( F(2, 60) = 2.35, \ p = 0.11 \), and between Congruency and Orientation \( (F < 1) \) were not significant. The three-way interaction was also not significant \( F(2, 60) = 1.55, \ p = 0.22 \).

Discussion

The predictability of object orientation did not affect the pattern of Stroop effects. As expected, irrelevant color words produced larger Stroop effects when they appeared in the relevant object than when the words appeared in the irrelevant object or in the background. Stroop effects did not differ in the two latter conditions. Most interestingly, the pattern of Stroop effects from words inside and outside the relevant object was virtually identical with predictable orientation and with unpredictable orientation of the objects. In other words, participants were not able to use this information for figure–ground segmentation and/or selection of the relevant object. However, it is possible that delivering information by blocking provides unfavorable conditions for the use of this information (e.g. Posner et al., 1980). Experiments 2 and 3 investigated whether a different way of delivering information regarding object orientation — by means of cues — might reveal similar or different results.

EXPERIMENT 2

In Experiment 1, predictability of object orientation had no effects on participants’ performance in a Stroop task in which the color of one of two rectangles had to be reported. However, it is possible that presenting the objects with constant orientation provides unfavorable conditions for the use of this information. For example, for constant object orientation to become effective requires that participants actively use this information by will, without any exogenous event further supporting or triggering its use. It is therefore possible that many participants simply forgot to endogenously initiate the use of their knowledge of object orientation without a further exogenous stimulus commanding this use. Such an exogenous stimulus was provided in Experiments 2 and 3 by means of a cue that preceded each stimulus display. In particular, the orientation of the two objects varied randomly from trial
to trial in Experiments 2 and 3. Each stimulus display was preceded by a cue that, in 50% of the trials, validly informed participants about the orientation of the relevant and the irrelevant object in the upcoming display (cf. Fig. 1a). In the remaining trials, participants saw an uninformative cue (Fig. 1b). The question of interest was whether informative cues would produce a different pattern of Stroop effects than uninformative cues.

To keep the design as simple as possible, I decided to only compare the effects of words in the relevant object with the effects of words in the irrelevant object, and to drop the condition with Stroop words in the background. Words in the irrelevant object and words in the background were consistently found to produce similar effects in our previous studies (and also in Experiment 1 of the present study), and therefore the background condition did not appear to be of additional value.

On the basis of the results of Schendel et al. (2001), a relatively long stimulus-onset asynchrony (SOA) was used in Experiment 2. These authors had observed facilitation in the processing of cued objects only with their longest cue–target SOA of 725 ms, suggesting that the processing of shape cues needs much more time than the processing of location cues (see also Panagopoulos et al., 2004). Therefore, a cue–target SOA of 1000 ms was used in Experiment 2. In contrast to the Schendel et al. study, in which non-predictive cues were used (50% valid, 50% invalid), we compared the effects of predictive cues (100% valid) with the effects of uninformative (neutral) cues.

Method

Participants. 22 new students from Erlangen University (18 female, 4 male; mean age: 23 years) participated in a single-session experiment. They were paid €5.00 or given course credit.

Apparatus and Stimuli. The apparatus from Experiment 1 was also used for Experiment 2. However, in contrast to Experiment 1, informative or uninformative orientation cues were used. Both cues consisted of the outline shapes of the two rectangles that would appear in the stimulus display. The informative cues consisted of one complete and one incomplete shape of the rectangles, indicating which rectangle would occlude (i.e. appear ‘in front of’) the other one (cf. Fig. 1a). In contrast, the uninformative cues consisted of two incomplete rectangular shapes that did not reveal which of the two rectangles in the stimulus display would be in front of the other (cf. Fig. 1b).

Procedure. The procedure of Experiment 2 was similar to that of Experiment 1, except for the following three changes: The first change concerned the fact that in Experiment 2, the orientation of the two rectangles varied randomly from trial to trial for each participant. The second change consisted in the fact that in Experiment 2 an orientation cue preceded each stimulus display. The cue was
informative in half of the trials and uninformative in the other half. Informative and uninformative cues appeared randomly intermixed in each block of trials. The third change was that in Experiment 2 words no longer appeared in the background; they appeared either in the relevant or in the irrelevant object.

An experimental trial in Experiment 2 looked as follows. First, the fixation point appeared at screen center for 500 ms. Next, an informative or an uninformative orientation cue was shown for 200 ms, also at screen center. After a further period of 800 ms, in which the fixation point was again present, the stimulus display appeared for 500 ms. The stimulus display was followed by a blank period of 1,000 ms. The SOA between the cue and the stimulus display was therefore constant at 1,000 ms.

**Design.** The experiment used a $2 \times 2 \times 2 \times 2$ within-subjects design. The first factor was Congruency (congruent vs incongruent). Incongruent conditions were three times as frequent as congruent conditions. The second factor was Object Condition. The words were either presented as parts of the relevant object, or as parts of the irrelevant object. The third factor was Cueing Condition. The cue was either informative or uninformative, with respect to the orientation of the two objects. The fourth factor was Part of the Experiment (first vs second).

The color of the relevant object (4), the identity of the word (4), object condition (2), cueing condition (2), and the orientation of the front rectangle (2) varied randomly from trial to trial. Participants were presented with 20 practice trials, and a total of 512 experimental trials. The experimental trials were administered in blocks of 20 trials; the final block contained 12 trials.

**Results**

**RTs.** For each participant and condition, all vocal RTs exceeding two standard deviations from the mean were removed. Across participants and conditions, this procedure eliminated 1.9% of trials with premature responses and 1.8% of trials with retarded responses. The mean RT values and error percentages for each condition are presented in Table 2.

Mean RTs from error-free trials were entered into a $2 \times 2 \times 2 \times 2$ (Part) $\times$ (Cueing) $\times$ (Object) $\times$ (Congruency) repeated measures ANOVA. Each of the main effects was significant. The main effect of part reflected longer RTs in the first part of the experiment (678 ms vs 655 ms), $F(1, 21) = 6.32, p < 0.05$. The main effect of cueing indicated shorter RTs with informative cues than with uninformative cues (656 ms vs 676 ms), $F(1, 21) = 19.71, p < 0.001$. The cueing effect was larger in the first part of the experiment than in the second (27 ms vs 14 ms), $F(1, 21) = 7.16, p < 0.05$. The main effect of object indicated longer RTs when the words appeared in the relevant object than when they appeared in the irrelevant object (651 ms vs 682 ms), $F(1, 21) = 29.20, p < 0.001$. The object effect was larger in the first part of the experiment than in the second (37 ms vs 26 ms), $F(1, 21) = 6.46, p < 0.05$. Finally, the main effect of congruency indicated shorter RTs with congruent than with incongruent words (628 ms vs 704 ms), $F(1, 21) = 107.05, p < 0.001$. The
Table 2. 
RTs and error percentages (in parentheses) observed in Experiment 2

<table>
<thead>
<tr>
<th></th>
<th>Words in relevant object</th>
<th>Words in irrelevant object</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Informative cues</td>
<td>Uninformative cues</td>
</tr>
<tr>
<td>Part 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Congruent</td>
<td>614 (0.3)</td>
<td>654 (0.3)</td>
</tr>
<tr>
<td>Incongruent</td>
<td>754 (7.0)</td>
<td>761 (6.0)</td>
</tr>
<tr>
<td>Stroop effect</td>
<td>140 (6.7)</td>
<td>107 (5.7)</td>
</tr>
<tr>
<td>Part 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Congruent</td>
<td>609 (0.0)</td>
<td>621 (0.4)</td>
</tr>
<tr>
<td>Incongruent</td>
<td>713 (5.3)</td>
<td>728 (2.7)</td>
</tr>
<tr>
<td>Stroop effect</td>
<td>104 (5.3)</td>
<td>107 (2.3)</td>
</tr>
</tbody>
</table>

Note: Stroop effect = incongruent condition minus congruent condition.

The congruency effect was larger in the first part of the experiment than in the second (81 ms vs 72 ms), $F(1, 21) = 4.99, p < 0.05$.

The significant two-way interaction between object condition and congruency indicated larger Stroop effects in the relevant object than in the irrelevant object (115 ms vs 39 ms), $F(1, 21) = 66.01, p < 0.001$. The significant three-way interaction between object condition, congruency, and part of the experiment indicated that Stroop effects in the relevant object decreased from the first part of the experiment to the second (from 124 ms to 105 ms), whereas Stroop effects in the irrelevant object did not (39 ms in both cases), $F(1, 21) = 5.86, p < 0.05$.

The significant two-way interaction between cueing and congruency referred to larger Stroop effects with informative cues than with uninformative cues (82 ms vs 71 ms), $F(1, 21) = 6.90, p < 0.05$. This effect, however, was further qualified by a significant three-way interaction with part of the experiment, and by a significant four-way interaction. The three-way interaction between cueing, congruency, and part of the experiment indicated that the increase of Stroop effects with informative cues was restricted to the first part of the experiment (part 1: 93 ms vs 70 ms; part 2: 73 ms vs 72 ms), $F(1, 21) = 7.83, p < 0.05$. Finally, the four-way interaction reflected the fact that the increase of Stroop effects with informative cues in the first part of the experiment was restricted to relevant objects, $F(1, 21) = 5.20, p < 0.05$. In fact, planned comparisons confirmed that informative cues increased Stroop effects in the relevant object in the first part of the experiment, $t(21) = 5.05, p < 0.001$, but not in the second, $t(21) = 0.36, p = 0.72$. In contrast, informative cues had no significant effects on Stroop effects in the irrelevant object, both $t(21) < 1.30$, both $p > 0.20$.

Errors. Overall error rate was small ($M = 2.10\%$). Therefore, error rates were not further analyzed.
Discussion

There was a significant effect of cueing both on overall RTs and on the magnitude of Stroop effects in the relevant object. Informative cues allowed for shorter RTs than uninformative cues. Moreover, informative cues produced larger Stroop effects than uninformative cues in the relevant object but not in the irrelevant object. This pattern of results suggests that informative orientation cues can in fact be used for facilitating attentional selection of the relevant object. However, the effects of informative cues on the processing of relevant objects were restricted to the first part of the experiment. A possible reason for this finding is that the use of informative orientation cues is exhausting. Experiment 3 tested whether these cueing effects can be replicated when informative and uninformative cues are presented in different blocks of trials.

EXPERIMENT 3

Experiment 3 attempted to replicate the results of Experiment 2, and further explored the conditions for the effective use of orientation cues. Basically, Experiment 3 was a replication of Experiment 2, with the exception that informative and uninformative cues were presented in different blocks of trials in Experiment 3.

Method

Participants. 22 new students from Erlangen University (18 female, 4 male; mean age: 23 years) participated in a single-session experiment. Participants were paid €5.00 or were given course credit.

Apparatus and stimuli. These were the same as in Experiment 2.

Procedure. The only difference between Experiments 2 and 3 was that the cueing factor was blocked in Experiment 3. In particular, in one half of Experiment 3 (i.e. 12 experimental blocks) the cues were always uninformative, whereas in the other half of the experiment (i.e. 12 experimental blocks) the cues were always informative. The order of cueing conditions was counterbalanced across participants.

Design. Experiment 3 rested on a four-factorial mixed design. The factors Cueing, Object Condition, and Congruency were varied within participants. The factor order (of cueing conditions) was varied between participants.

Results

RTs. For each participant and condition, all RTs exceeding two standard deviations from the mean were removed. Across participants and conditions, this procedure eliminated 1.5% of trials with premature responses and 3.1% of trials with
Table 3.
RTs and error percentages (in parentheses) observed in Experiment 3

<table>
<thead>
<tr>
<th></th>
<th>Words in relevant object</th>
<th>Words in irrelevant object</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Informative cues</td>
<td>Informative cues</td>
</tr>
<tr>
<td></td>
<td>Uninformative cues</td>
<td>Uninformative cues</td>
</tr>
<tr>
<td>Part 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Congruent</td>
<td>616 (0.0)</td>
<td>623 (1.6)</td>
</tr>
<tr>
<td>Incongruent</td>
<td>742 (4.7)</td>
<td>666 (1.7)</td>
</tr>
<tr>
<td>Stroop effect</td>
<td>126 (4.7)</td>
<td>43 (0.1)</td>
</tr>
<tr>
<td></td>
<td>593 (0.0)</td>
<td>602 (0.3)</td>
</tr>
<tr>
<td></td>
<td>696 (5.9)</td>
<td>642 (2.3)</td>
</tr>
<tr>
<td></td>
<td>103 (5.9)</td>
<td>40 (2.0)</td>
</tr>
<tr>
<td>Part 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Congruent</td>
<td>592 (0.8)</td>
<td>593 (0.3)</td>
</tr>
<tr>
<td>Incongruent</td>
<td>690 (4.5)</td>
<td>633 (1.6)</td>
</tr>
<tr>
<td>Stroop effect</td>
<td>98 (3.7)</td>
<td>40 (1.3)</td>
</tr>
<tr>
<td></td>
<td>629 (0.0)</td>
<td>624 (1.0)</td>
</tr>
<tr>
<td></td>
<td>719 (4.6)</td>
<td>663 (0.9)</td>
</tr>
<tr>
<td></td>
<td>90 (4.6)</td>
<td>39 (−0.1)</td>
</tr>
</tbody>
</table>

Note: Stroop effect = incongruent condition minus congruent condition.

retarded responses. The mean RT values and error percentages for each condition can be found in Table 3.

Mean RTs from error-free trials were entered into a 2 (Order) × 2 (Cueing) × 2 (Object) × 2 (Congruency) ANOVA for mixed designs. The main effect of order, \( F(1, 20) = 1.13, p = 0.30 \), and the main effect of cueing, \( F < 1 \), were not significant. Moreover the two-way interaction between cueing and order was not significant either, \( F(1, 20) = 1.19, p = 0.29 \). The significant main effect of object condition referred to longer RTs when words appeared in the relevant object than when they appeared in the irrelevant object (659 ms vs 631 ms), \( F(1, 20) = 72.03, p < 0.001 \). The significant main effect of congruency indicated shorter RTs with congruent words than with incongruent words (609 ms vs 681 ms), \( F(1, 20) = 170.94, p < 0.001 \). The two-way interactions of object condition and of congruency with order were not significant, both \( F(1, 20) < 1.30 \), both \( p > 0.25 \). However, the two-way interaction between object condition and congruency was significant, referring to larger Stroop effects in the relevant object than in the irrelevant object (104 ms vs 40 ms), \( F(1, 20) = 63.87, p < 0.001 \). The two-way interactions between cueing and object condition, \( F(1, 20) = 1.96, p = 0.18 \), and between cueing and congruency, \( F(1, 20) = 2.19, p = 0.16 \), were not significant.

Interestingly, the three-way interaction between cueing, congruency, and order of cueing conditions was marginally significant, \( F(1, 20) = 3.74, p = 0.07 \), reflecting larger Stroop effects with informative cues than with uninformative cues when informative cues were presented in the first part of the experiment (85 ms vs 65 ms), but not when informative cues were presented in the second part of the experiment (68 ms vs 71 ms). The three-way interaction was further qualified by the marginally significant four-way interaction, \( F(1, 20) = 3.43, p = 0.08 \). The four-way interaction referred to the finding that informative cues increased Stroop effects in the relevant object (126 ms vs 90 ms, \( t(9) = 2.28, p < 0.05 \)) but not in the irrelevant object (43 ms vs 39 ms, \( t(9) = 0.26 \)), when informative cues were
presented in the first part of the experiment. In contrast, when presented in the second part of the experiment, informative cues neither increased Stroop effects in the relevant object (98 ms vs 103 ms, \( t(11) = 0.73 \)) nor in the irrelevant object (40 ms both, \( t(11) = 0.03 \)).

**Errors.** Again, error rate was low (1.9%), and therefore not further analyzed.

**Discussion**

Basically, Experiment 3 replicated the results of Experiment 2 when informative and uninformative cues were given in separate blocks. Although there was no significant main effect of cueing, informative cues again selectively increased Stroop effects in the relevant object. Moreover, the latter effect was only observed for the group of participants that received informative cues in the first part of the experiment, and uninformative cues in the second part of the experiment. In contrast, informative cues did not affect Stroop effects in relevant and irrelevant objects differently when participants received uninformative cues in the first part of the experiment, and informative cues in the second part of the experiment. The dependence of cueing effects on the order of cueing conditions simply reflects the observation that informative cues exert their effects only during the first part of the experiment, replicating the results of Experiment 2. The results of Experiment 3 confirm the notion that informative orientation cues are useful for facilitating attentional selection of the relevant object. The observation of weaker results in Experiment 3 than in Experiment 2 can be attributed to the fact that, in each part of Experiment 3, the cueing condition was varied between participants.

**GENERAL DISCUSSION**

The present study investigated whether and how advance information about the orientation (or shape) of two-dimensional objects affects visual processing. Adapting a task from Wühr and Waszak (2003), participants were presented with two rectangular objects, arranged in a cross-like fashion. Participants had to verbally report the color of the occluding object as quickly as possible. Importantly, processing of different areas of the visual display was probed by presenting congruent or incongruent color words in the relevant object, in the irrelevant object, or in the background. Previous research has shown that color words in the relevant object produce larger Stroop effects than color words outside the relevant object. Wühr and Waszak attributed this modulation of the Stroop effect to object-based attentional selection that amplifies processing of relevant and irrelevant features of the attended object.

Three experiments investigated the effects of advance information about orientation on the processing of relevant and irrelevant objects, as indicated by Stroop effects from color words located in either object. Different methods for providing participants with information regarding the orientation of the objects were used. In
one condition of Experiment 1 the orientation of the objects remained constant and was therefore predictable, whereas in another condition the orientation of the objects varied unpredictably from trial to trial. In Experiments 2 and 3 an informative cue, which indicated the orientation of the two objects in the following display, or an uninformative cue preceded each stimulus display by one second. Informative and uninformative cues were randomly mixed in Experiment 2, whereas cue type was blocked in Experiment 3. The results of the experiments can be summarized as follows. First, participants showed the expected modulation of the Stroop effect: words in the relevant object produced much larger Stroop effects (difference $\sim 100$ ms) than words in the irrelevant object ($\sim 40$ ms) or words in the background ($\sim 40$ ms). Second, mere blocking of object orientation had no effects in Experiment 1. Third, informative orientation cues facilitated processing of the relevant object, but cueing did not affect processing of the irrelevant object. Fourth, effects of informative cues were restricted to the first parts of Experiments 2 and 3.

In accordance with previous studies (Panagopoulos et al., 2004; Schendel et al., 2001), the present results showed that advance information about object shape can affect subsequent visual processing of objects when there is enough time to process the cues (i.e. SOAs $> 700$ ms). Going beyond previous studies, the present experiments revealed further information about when advance information about object shape is used for subsequent processing. In particular, advance information about object orientation was effective when conveyed by informative cues (Experiments 2 and 3). In contrast, advance information about object orientation had no effect when object orientation was blocked and therefore predictable (Experiment 1), suggesting that an external trigger supports the use of this information. Moreover, the effects of informative orientation cues and performance were restricted to the first halves of Experiments 2 and 3. The most likely explanation for this observation is that participants did not judge the informative cues as very useful because selection of the relevant object was easy without cues, and participants stopped using the cues when they became practiced with the task.

The results of the present study also revealed information on how advance information about object shape is used for subsequent object processing. Basically, there are two possibilities how informative orientation cues might aid performance in the present task. One possibility is that informative cues support figure–ground segmentation; the other possibility is that informative cues support attentional selection of the relevant object. Results support the second possibility. In particular, informative orientation cues selectively increased Stroop effects in the relevant object in Experiments 2 and 3. This result suggests that the informative orientation cues facilitated attentional selection of the relevant object, which amplified processing of relevant (i.e. color) and irrelevant (i.e. words) object features.

An interesting question is whether the cueing effects observed in the present study were bottom-up or top-down controlled. On the one hand, the informative cues revealed physical characteristics of the subsequent target stimuli, enabling bottom-
up cueing of object orientation or shape. On the other hand, the informative cues were highly predictive, which is an important precondition for top-down controlled processing of visual cues. Most importantly, however, the fact that the effects of informative cues were restricted to the first halves of Experiments 2 and 3 strongly suggests that cueing effects were top-down controlled, instead of being stimulus driven.

It is also interesting to compare the results of the present study to the results of studies on the use of target cues in visual-search experiments (e.g. Vickery et al., 2005; Wolfe et al., 2004). In visual-search experiments, observers have to find a target stimulus among a set of similar non-target items. Wolfe and colleagues (2004) investigated how observers use cues about the identity of the target stimulus when the target changes unpredictably from trial to trial. They found that an exact copy of the target stimulus is the most effective cue, which facilitates search when it is shown 100–200 ms ahead of the search display. In contrast, word cues are never as effective as visual cues, even when the word is presented 500 ms ahead of the search display (see Vickery et al., 2005, for similar results). The results of the search studies show that participants can use advance information about visual features of a target stimulus for improving detection and localization of the target. The results of the present study complement these previous findings in showing that cueing object shape facilitates processing of relevant features (i.e. color) and of irrelevant features (i.e. words) of the target object.

The results of the present experiments also discard possible explanations of why Stroop words in the relevant object produce larger effects than Stroop words outside the relevant object. The results of Wühr and Waszak (2003) could be explained by a mechanism of spatial attention that is able to alter the shape of its attentional ‘window’. Such a mechanism explains the results as follows: Wühr and Waszak varied the orientation of the two objects randomly from trial to trial. Participants were therefore most likely to distribute attention almost equally across the area of the monitor in which the stimuli appeared. With stimulus onset, participants determined the orientation of the occluding object and then adjusted the shape of their attentional window to the orientation of the relevant object. As a result, words outside the relevant object produced weaker Stroop effects because they were attended to for a shorter period of time than words in the relevant object. This account predicts that Stroop effects outside the relevant object should be smaller with predictable orientations than with unpredictable orientations because predictable orientations allow participants to adjust the shape of their attentional window to the orientation of the relevant object in advance of stimulus presentation. This result was not observed in any of the present experiments. Thus, the present results discard the possibility that the time-consuming adaptation of an attentional window to the shape of the relevant object produces the increased Stroop effects in the relevant object.
In sum, the present study revealed evidence that human observers can use advance information about object orientation (or shape) for improving the efficiency of attentional selection of relevant objects from multi-object displays.

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