A Case for Inhibition: Visual Attention Suppresses the Processing of Irrelevant Objects

Peter Wühr
Friedrich-Alexander Universität

Christian Frings
Universität des Saarlandes

The present study investigated the ability to inhibit the processing of an irrelevant visual object while processing a relevant one. Participants were presented with 2 overlapping shapes (e.g., circle and square) in different colors. The task was to name the color of the relevant object designated by shape. Congruent or incongruent color words appeared in the relevant object, in the irrelevant object, or in the background. Stroop effects indicated how strong the respective area of the display was processed. The results of 4 experiments showed that words in the relevant object produced larger Stroop effects than words in the background, indicating amplification of relevant objects. In addition, words in the irrelevant object consistently produced smaller Stroop effects than words in the background, indicating inhibition of irrelevant objects. Control experiments replicated these findings with brief display durations (250 ms) and ruled out perceptual factors as a possible explanation. In summary, results support the notion of an inhibitory mechanism of object-based attention, which can be applied in addition to the amplification of relevant objects.

Keywords: facilitation, Stroop effect, object-based attention, inhibition

In every moment, an abundance of visual stimuli impinges on the retinas of our eyes, and each stimulus affords different actions. The efficient control of action, however, requires that only some features of particular stimuli are processed, thus guiding our actions (Allport, 1987). Selective attention is a cognitive tool that helps us find and selectively process relevant visual information at the expense of irrelevant information. Imagine you are hungry and open the door of your refrigerator. Most likely, the complete interior of the refrigerator is projected onto your retinas. To find your desired food, however, you may selectively process the central area of your fridge because you know that the middle shelf contains some fruit. Next, you may selectively attend to one of the apples and ignore the other objects in the shelf. Finally, when grasping the apple, you may selectively process the location and shape of the object while ignoring its color.

The example indicates that selective attention is not a unitary phenomenon but one that may comprise a set of different mechanisms. In particular, attention may be directed to locations (e.g., central area of the fridge), visual objects (e.g., apple), and stimulus dimensions or features (e.g., shape). Moreover, attention may support the processing of relevant information either through facilitating (or amplifying) the processing of relevant stimulation and/or by inhibiting the processing of irrelevant stimulation. When combining these two aspects of attention (content and strategy), we found six possible mechanisms of visual attention (cf. Table 1). Empirical studies appear to support the existence of each possible mechanism, but the amount of support differs considerably between the mechanisms. Indeed, there appears to be much stronger support for facilitatory than for inhibitory mechanisms of visual attention.

The present study is mainly concerned with the question of whether there is an inhibitory mechanism of object-based attention. We first review the evidence for inhibitory mechanisms of visual attention for locations, objects, and dimensions. The review reveals a lack of clear evidence for the inhibition of irrelevant visual objects as a mechanism of selective attention. The empirical part of the article attempts to provide such evidence.

Inhibitory Mechanisms of Selective Attention

The Concept of Attentional Inhibition

The idea that attention inhibits the processing of unwanted inputs is very intuitive. Despite that, researchers have disagreed about whether inhibitory mechanisms of selective attention working in addition to facilitatory mechanisms are adaptive or not. For example, Houghton and Tipper (1994) argued that a dual mechanism of selective attention is beneficial for at least two reasons. First, a mechanism that boosts a target signal while it suppresses a distractor signal should effectively double the rate at which target and distractor processing can be pulled apart. Second, a dual mechanism may be particularly useful when the target signal and the distractor signals are very strong and the ability to amplify the target signal is limited. On the other hand, Allport (1987) argued that it should be maladaptive for a biological system to restrict
processing to a small subset of sensory information at an early level of analysis or to actively suppress information that has already been encoded to a high level. In the following sections, we briefly review three empirical phenomena that might be viewed as evidence for attentional inhibition of irrelevant locations, irrelevant objects, and irrelevant dimensions.

**Location-Based Attention: Inhibition of Return**

Evidence in favor of an inhibitory mechanism of spatial attention has been obtained with the spatial-cuing paradigm. Posner and Cohen (1984) observed that participants were slower to detect targets at previously cued locations than at previously uncued locations when cue–target delays exceeded 250 ms, an observation called inhibition of return (IOR; Posner, Rafal, Choate, & Vaughan, 1985; see, Klein, 2000, for review). As the term suggests, Posner and colleagues assumed that IOR reflects a bias against reorienting attention to a previously attended location. Subsequent research suggested a motoric locus of IOR. For example, Posner et al. (1985) demonstrated that saccades made in response to a central arrow (pointing either left or right) were delayed in the direction of a previous peripheral cue. Because the participants’ task (making a saccade) did not involve the detection of peripheral stimulation, this finding supports a motoric basis for IOR. On the basis of similar findings, Klein and Taylor (1994) advanced the motor-bias view of IOR. According to this view, IOR is a “reluctance to respond to an event at the inhibited location” (Klein, 2000, p. 140).

Recently, several authors advanced alternative explanations for IOR that do not involve the notion of inhibition (e.g., Neill & Mathis, 1998; Pratt, Spalek, & Bradshaw, 1999). For example, Pratt et al. (1999) proposed an “attentional momentum account” of IOR, which states that attention is biased to continue moving in the direction in which it most recently traveled. To support their account, Pratt et al. (Experiment 1) examined the effects of peripheral cues on target detection latencies at four possible locations at the ends of an imaginary plus sign. As usual, targets at the cued location produced the longest response times (RTs). It is interesting, however, that targets at the uncued location that was opposite to the cued location produced shorter RTs than did targets at the two uncued locations that were orthogonal to the cued location. This observation confirmed a unique prediction of the attentional-momentum hypothesis, whereas the inhibitory account did not predict this result.

**Object-Based Attention: Negative Priming**

The probably best-known evidence for an inhibitory mechanism of object-based attention is negative priming (NP). In a typical NP task, participants are presented with two consecutive displays, the prime and the probe display, each consisting of a target and a distractor stimulus. For example, each display may contain one red and one green shape, and the participants may have to report the name of the green shape and ignore the red shape. The experimenter is interested in how the relationship between the stimuli in two consecutive displays affects performance in the second display (the probe display). There are two interesting results. First, repeating the target stimulus (while changing the distractor) produces performance benefits, compared with a neutral condition, in which both the target and the distractor change (e.g., Tipper, 1985; Tipper & Cranston, 1985). This result constitutes positive priming and is viewed as evidence for a facilitatory mechanism of object-based attention. Second, presenting the prime distractor as the probe target produces performance costs, compared with the neutral condition (e.g., Dalrymple-Alford & Budayr, 1966; Neill, 1977; Tipper, 1985). This result is called NP and has been found with different stimulus materials in different populations, as well (for reviews, see Fox, 1995; Tipper, 2001). The demonstration of NP when location could not be used to discriminate between target and distractor suggests that NP can be object-based (e.g., Tipper, 1985). According to a popular explanation, attentional inhibition of distractor representations during processing of the prime episode produces the NP effect (e.g., Frings & Wühr, 2007; Houghton & Tipper, 1994; Houghton, Tipper, Weaver, & Shore, 1996; Tipper, 2001).

There are several observations that are incompatible with an inhibition-based account of NP. For example, NP is not observed when the probe episode contains only a target stimulus (e.g.,

---

**Table 1**

*The Factorial Combination of Three Possible Targets of Attention and Two Possible Strategies of Attention Reveals Six Possible Mechanisms of Visual Attention*

<table>
<thead>
<tr>
<th>Target of attention</th>
<th>Facilitation of relevant information</th>
<th>Inhibition of irrelevant information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Locations</td>
<td>Location-cuing benefits (e.g., Jonides, 1981; Posner &amp; Cohen, 1984) Location-based modulation of congruency effects (e.g., Eriksen &amp; Eriksen, 1974)</td>
<td>Inhibition of return (e.g., Posner &amp; Cohen, 1984) Visual marking (e.g., Watson &amp; Humphreys, 1997)</td>
</tr>
<tr>
<td>Objects</td>
<td>Same-object advantage (e.g., Behrmann et al., 1998; Duncan, 1984) Object-based modulation of congruency effects (e.g., Wühr &amp; Waszak, 2003) Positive priming for objects (e.g., Tipper, 1985)</td>
<td>Negative priming for locations (e.g., Park &amp; Kanwisher, 1994) Negative priming for objects (e.g., Tipper, 1985) Tipper &amp; Cranston, 1985) Object-based inhibition of return (e.g., Tipper et al., 1991) Sequential modulation of Stroop and Simon effects (e.g., Kerns et al., 2004; Stürmer et al., 2002)</td>
</tr>
<tr>
<td>Dimensions</td>
<td>Dimension-repetition benefits (e.g., Found &amp; Müller, 1996)</td>
<td></td>
</tr>
</tbody>
</table>

**Note.** The cells contain experimental phenomena that provide suggestive evidence for the existence of the respective mechanism.
Lowe, 1979; Moore, 1994; Tipper & Cranston, 1985; but see Frings & Wentura, 2006b). If the cognitive representation of the ignored prime distractor was simply inhibited, one would expect NP for related probe targets regardless of whether they were accompanied by distractors or not. As a result, several alternative explanations for NP were proposed that do not involve the notion of inhibition (e.g., Milliken, Joordens, Merkle, & Seiffert, 1998; Rothermund, Wentura, & De Houwer, 2005). Here we consider only the episodic-retrieval theory of NP (e.g., Neill & Mathis, 1998; Neill & Valdes, 1992). According to this account, a target stimulus cues the retrieval of past processing episodes involving similar stimuli. It is further assumed that the most recent episode involving a stimulus similar to the target is the one most likely to be retrieved. If the retrieved episode includes response information that is compatible with the present task (e.g., “Respond to stimulus X”), then probe target processing will benefit from retrieval. Such benefits should occur when the target repeats. If, however, the retrieved episode includes incompatible response information (e.g., “Ignore stimulus X”), then probe target processing will suffer interference. Such interference should occur when the prime distractor becomes the probe target. The episodic-retrieval theory can easily explain the dependence of NP on the presence of a distractor in the probe episode, because contextual similarity between prime and probe conditions should affect episodic retrieval.

**Dimension-Based Attention: Sequential Modulation of Stroop and Simon Effects**

Several studies showed that interference from irrelevant stimulation is reduced (or eliminated) after incongruent trials. For example, the Stroop effect (i.e., the difference between congruent and incongruent RTs in trial N) is reduced after incongruent trials N − 1, compared with the effect after congruent trials N − 1 (e.g., Kerns et al., 2004; Notebaert, Gevers, Verbruggen, & Liefooghe, 2006). Similar observations have been made for the Simon effect, in which the location of a stimulus interferes with a spatial response to stimulus color or stimulus shape (e.g., Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002; Wühr & Ansorge, 2005).

Several authors have claimed that sequential modulations of congruency effects reflect the work of a cognitive mechanism devoted to the monitoring and regulation of response conflict (e.g., Botvinick, Cohen, & Carter, 2004; Kunde & Wühr, 2006; Stürmer et al., 2002). For example, Stürmer and Leuthold (2003) and Stürmer et al. (2002) proposed a mechanism that registers the amount of response conflict and regulates the access of irrelevant stimulation to the response system. In particular, these authors assumed that conflict regulation decreases the ability of irrelevant stimulation to access the response system after incongruent trials. In other words, Stürmer and colleagues proposed a mechanism of inhibitory attentional control because the conflict-regulation mechanism is assumed to inhibit the processing of an irrelevant stimulus dimension after conflict trials.

Some authors proposed alternative explanations for sequential modulations of congruency effects that do not involve the notion of top-down inhibition (e.g., Hommel, Proctor, & Vu, 2004). For example, Hommel et al. (2004) argued that the degree of feature overlap between consecutive trials in congruency tasks produces the modulation of congruency effects. At present, the issue of whether top-down inhibitory control mechanisms are involved in sequential modulations of congruency effects is still a matter of debate.

**Inhibitory Mechanisms of Attentional Selection: Summary and Conclusions**

Our review of the literature revealed three facts. First, and most important, the empirical evidence for inhibitory mechanisms of attention does often rest on sequential effects. This means that studies usually measure the aftereffects of inhibition. In particular, the observation of performance decrements for stimulus X at time T (or in trial N) is often used to infer that the processing or representation of stimulus X has been inhibited at time T − 1 (or in trial N − 1).

Second, each attempt to explain the empirical phenomena through inhibitory mechanisms of attention was countered by powerful, noninhibitory explanations. One reason for this fact is that sequential effects are obviously open to explanations in terms of memory retrieval or in terms of feature mismatch. The availability of alternative explanations has led authors to doubt the usefulness of cognitive inhibition as an explanatory concept in general (e.g., MacLeod, Dodd, Sheard, Wilson, & Bibi, 2003).

Third, if attentional inhibition of irrelevant information occurs at all, it is not clear whether inhibition can be applied online, that is, while the processing of relevant information takes place. Rather, sequential effects may result from inhibition being applied offline, that is, after a response to the relevant stimulus has been made. Although the purpose of such offline inhibition is not immediately clear, it remains a theoretical possibility.

**The Present Study**

The purpose of the present study is to investigate attentional inhibition of irrelevant objects within single trials. We used a variant of the paradigm that Wühr and Waszak (2003) used to study object-based mechanisms of attention. Originally, Wühr and Waszak were interested in the role of object-based attentional selection on the processing of irrelevant words in the Stroop task. In their experiments, participants were presented with two rectangles forming a cross. The two rectangles and the background appeared in different colors. The participants’ task was to name the color of the occluding rectangle (the relevant object) and to ignore the occluded rectangle (the irrelevant object). To provoke Stroop effects, we had the congruent or incongruent color words appear in the relevant object, in the irrelevant object, or in the background. It is important that the distance between the color words and the screen center (i.e., the focus of spatial attention) was the same in all conditions. The main result was that color words in the relevant object produced larger Stroop effects than words in the irrelevant object or in the background (see also Wühr, 2006; Wühr & Welle, 2005).

The results were explained in terms of object-based attentional selection (Kahneman & Henik, 1981; for a review, see Scholl, 2001). According to this account, pre-attentive processes segment the visual field into figures 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, Downing, & Kanwisher,
On this account, words in the relevant object produce larger Stroop effects than words outside the relevant object because attentional selection facilitates processing of relevant features (color) and irrelevant features (word) of the selected object.

The task developed by Wühr and Waszak (2003) is suited for investigating attentional inhibition of irrelevant objects. In particular, inhibition of irrelevant objects should lead to the reduction of Stroop effects from words in the irrelevant object when compared with Stroop effects from words in the background. The preceding studies, however, never found a difference between these two conditions, suggesting that the conditions used in these experiments were not appropriate for the application of attentional inhibition to irrelevant objects. For example, it is possible that selecting between identical shapes (in different orientations) on the basis of a spatial cue (i.e., occlusion) does not afford inhibition of the irrelevant object. Therefore, the purpose of the present study was to investigate whether selecting between different shapes affords the inhibition of the irrelevant object. In this case, Stroop effects from color words in irrelevant objects should be significantly smaller than Stroop effects from color words in the background. Most important, this technique for investigating attentional inhibition does not hinge on the analysis of sequential effects.

Although the main focus of the present study was on the within-trial effects of inhibition, we were also interested in the effects of attentional selection between consecutive trials. In particular, we assessed two types of sequential effects. First, we analyzed the effects of the correspondence between a color in the preceding trial and the “to-be-named” color in the present trial. This analysis may reveal evidence for NP on the relevant stimulus dimension (color) as a result of ignoring an irrelevant object. Second, we analyzed the effects of the correspondence between a color word in the preceding trial and the target color in the present trial. This analysis may reveal evidence for NP on an irrelevant stimulus dimension (word shape) as a result of ignoring an irrelevant object. We discuss the results of between-trials measures of attentional selection in the General Discussion.

Experiment 1

The main purpose of Experiment 1 was to produce evidence for the notion that selective attention inhibits the processing of an irrelevant object. Participants were presented with two different objects (e.g., a circle and a square) at overlapping locations (see Figure 1). For obvious reasons, the two shapes could not be centered at the screen center because then the object in front would have almost completely occluded the second object. The task was to select a relevant object according to shape (e.g., the square), and to vocally report the color of this object as quickly as possible. To garner the strengths of perceptual processing of different areas of the display, we presented congruent or incongruent color words in the relevant object, in the irrelevant object, or in the background. The irrelevant color words were expected to produce Stroop effects, and the size of these Stroop effects are a measure for the relative strength of processing of the objects and the background. We expected that Stroop words in the relevant object would produce larger Stroop effects than words outside the relevant object. This difference may indicate amplification of the processing of the relevant object, including its irrelevant parts (i.e., the word). Most important, we expected that Stroop words in the irrelevant object would produce smaller Stroop effects than words in the background. This difference may reflect inhibition of the processing of the irrelevant object.

Method

Participants

Twenty-three university students (17 women, 6 men) participated in the experiment for course credit or payment. Their average age was 23 years (ranging from 19 to 30 years). All participants in this and the following experiments were native German speakers and declared to have normal or corrected-to-normal vision.

Apparatus and Stimuli

The experiment took place in a dimly lit room. The participants sat in front of a 17-inch color monitor with viewing distance being constrained to 60 cm by a head-and-chin rest. Participants responded by speaking into a microphone, which triggered a voice key measuring RT to the nearest millisecond. An IBM-compatible computer controlled the presentation of stimuli and collected vocal RTs. The fixation cross was a small plus sign (0.2° of visual angle). Each stimulus display consisted of two overlapping shapes, one being presented to the left of fixation, the other one being presented to the right of fixation (see Figure 1). The shapes used were a circle (with an area of 11.3 cm²), a diamond (10.9 cm²), a square (10.9 cm²), and a triangle (10.6 cm²). The center of one object was located 10 mm (1.0°) to the left of the screen center, and the center of the second object was located 10 mm (1.0°) to the right of the screen center.

The background and the two shapes (i.e., objects) appeared in different colors (blue, green, red, or yellow). The colors varied randomly from trial to trial. Moreover, in each display, a single color word appeared in black color in one of the objects or in the background. The words used were the German words for blue (blau), green (grün), red (rot), or yellow (gelb), and they subtended between 7 × 3 mm (rot) and 12 × 4 mm (blau, gelb, grün).
Words were presented on an imaginary circle around the fixation point at 0°, 135°, or 270°. The spatial distance between the screen center and the center of a word was 20 mm (1.9°) in each condition.

Procedure

At the beginning of the experiment, the instructions appeared on the screen and participants read them at leisure. Participants were told to vocally report, as quickly and accurately as possible, the color of a relevant object, which was designated by shape. Moreover, participants were told that the location of the relevant object would vary unpredictably from trial to trial, and therefore participants should always attend to the screen center. Finally, instructions pointed out that the words presented in the display were irrelevant with respect to the task, and participants were told to ignore them. Then participants had 20 practice trials.

Each trial contained the following sequence of events. First, there was a blank screen for 500 ms. Then the fixation point was shown for 500 ms at the screen center. Next, the stimulus display was presented for 500 ms, followed by a blank period of 1,000 ms. Vocal RTs were measured from the onset of the stimulus display for a period of 2,000 ms. If the participant did not respond within this period, a corresponding error message (“Please respond more quickly. . .”) was shown for an additional 2,000 ms. There was no feedback regarding the correctness of the vocal response.

The experiment was run in blocks of 20 trials. Participants could take a rest after each block and started the next block by pressing the space key. The participants’ performance was monitored online by the experimenter, who sat outside the experimental chamber. She heard the participants’ responses through earphones and recorded each error in a list.

Design

The experiment used a 2 × 3 within-subjects design. The first variable was congruency. The irrelevant word was congruent or incongruent with respect to the color of the relevant object, thus also to the correct response. The color word was always incongruent to the color of the irrelevant object and to the color of the background. The second variable was object condition. The words were presented as part of the relevant object, as part of the irrelevant object, or in the background.

The two experimental variables, the position of the relevant object (left–right, front–rear) and the colors of the two objects, varied randomly from trial to trial. Each participant was presented with two repetitions for each combination of color word (4), color of relevant object (4), position of relevant object (4), and object condition (3), resulting in a total of 384 experimental trials. The last block contained 24 instead of 20 trials. Note that incongruent conditions were three times as frequent as congruent conditions, hence the color of the relevant object and the color word were not correlated. There was one relevant shape and one irrelevant shape for each participant. The pairs of shapes presented to each participant were counterbalanced across participants (4 shapes produce 12 possible pairs).

Results

Within-Trial Analysis

Response times. RTs below 200 ms (< 3.0%) and above 1,500 ms (< 1.0%) were considered outliers and not further analyzed.¹ The mean RT values and error percentages for each of the six conditions are presented in Figure 2. Results of the F tests were

¹ We are aware that fixed RT limits for identifying outliers are always arbitrary. Therefore, we analyzed the results of each experiment on the basis of different procedures for identifying RT outliers, including the elimination of RTs exceeding two (or three) standard deviations from the mean for each participant and condition. All these analyses revealed similar patterns of results. Therefore, we are convinced that our particular choice of RT limits for identifying outliers did not affect the pattern of results.

Figure 2. Response times (RTs; in ms) and error percentages (PEs) observed in Experiment 1. There was one relevant and one irrelevant shape. Error bars represent standard errors between participants.

Response Time (RT in ms)

Percentage of Errors (PE)

Words appeared in...

relevant object background irrelevant object

120 WÜHR AND FRINGS
corrected according to Greenhouse and Geisser (1959), when appropriate (i.e., when Mauchly’s test of sphericity was significant). Two-tailed t tests were used for planned comparisons in each experiment. Finally, for each pairwise comparison, we report Cohen’s d (Cohen, 1988) as a measure of effect size.2

RTs were entered into a 2 (congruency) × 3 (object condition) repeated-measures analysis of variance (ANOVA). Both main effects and the two-way interaction were significant. The main effect of object condition, F(2, 44) = 29.52, MSE = 726.95, p < .001, indicated longer RTs with words in the relevant object (728 ms) than with words in the irrelevant object (689 ms) or in the background (691 ms). The main effect of congruency, F(1, 22) = 67.37, MSE = 3,059.35, p < .001, indicated shorter RTs with congruent words (664 ms) than with incongruent words (741 ms). Finally, the two-way interaction indicated that the congruency effect varied between object conditions, F(1,46, 32.01) = 52.70, MSE = 932.61, p < .001. Planned comparisons showed that words in the relevant object produced larger Stroop effects (D = 139 ms) than words in the irrelevant object (D = 31 ms), t(22) = 8.08, p < .001, d = 1.72, and words in the background (D = 62 ms), t(22) = 7.06, p < .001, d = 1.51. Moreover, words in the irrelevant object produced smaller Stroop effects than words in the background, t(22) = 4.20, p < .001, d = 0.90.

Errors. For this and the following experiments, we report the correlations between RT effects and error effects. Positive correlations indicate a similar pattern of results in RTs and in error percentages, whereas negative correlations indicate contradictory results (this was, however, never observed). For each of the three object conditions in Experiment 1, Stroop effects in error percentages and Stroop effects in RTs were positively correlated (range from r = .23 to r = .27), although none of the correlations was significant (all ps > .20).

Between-Trials Analysis

Color-to-color sequence. We analyzed whether presenting the color of the relevant object, the irrelevant object, or the background in the preceding display as the color of the relevant object in the present display affected performance. The location of the corresponding color in the preceding trial significantly affected RTs, F(2, 44) = 62.21, MSE = 834.52, p < .001. Repeating the color of the relevant object produced shorter RTs than reappearance of the background color in the relevant object (649 ms vs. 727 ms), t(22) = 8.63, p < .001, d = 1.80. By contrast, RTs were similar when the color of the irrelevant object reappeared as the relevant color and when the background color reappeared as the relevant color (734 ms vs. 727 ms), t(22) = 1.42, p = .17, d = 0.30. The error analysis showed no effects.

Word-to-color sequence. We analyzed performance in trials in which the distractor word in the preceding trial corresponded to the relevant color in the present trial as a function of where the word had appeared in the preceding trial (relevant object, irrelevant object, background). The location of the corresponding word in the preceding trial significantly affected RTs, F(2, 44) = 5.26, MSE = 959.48, p < .01. Corresponding words in the relevant object of the preceding display produced slower responses than corresponding words in the background of the preceding display (736 ms vs. 706 ms), t(22) = 3.04, p < .01, d = 0.63. Corresponding words in the irrelevant object of the preceding display and corresponding words in the background of the preceding display produced similar RTs (720 ms vs. 706 ms), t(22) = 1.43, p = .17, d = 0.30. The error analysis showed the same pattern.

Discussion

The results of Experiment 1 revealed evidence for attentional amplification of relevant visual objects and for attentional inhibition of irrelevant visual objects. Stroop words in the relevant object produced larger effects than words in the background. Moreover, Stroop words in the irrelevant object produced smaller effects than words in the background. This pattern of results might be attributed to the impact of object-based attentional selection. In particular, increased Stroop effects in the relevant object might reflect amplification of the relevant object. Conversely, decreased Stroop effects in the irrelevant object might indicate inhibition of the irrelevant object.

Alternatively, a shift of spatial attention (or gaze) can also explain the pattern of Stroop effects observed in Experiment 1. The alternative explanation results from the fact that the two objects were not presented at the same location. Therefore, it is possible that participants in Experiment 1 shifted their focus of spatial attention from the center of the screen to the center of the relevant object in order to facilitate processing of this object. It is important, however, that words in the relevant object were located closer to the center of the relevant object than words in the background, which were again located closer to the center of the relevant object than words in the irrelevant object (cf. Figure 1). Thus, if participants had shifted their focus of spatial attention to the center of the relevant object, the results of Experiment 1 may be explained by the different distances between the center of the relevant object and the location of the words in the three conditions. Experiment 2 investigated whether Stroop words in the irrelevant object still produce smaller effects than Stroop words in the background when the effects of spatial attention shifts are eliminated.

Experiment 2

Experiment 2 investigated the role of spatial-attention shifts to the center of the relevant object in the present task. In Experiment 1, words in the background were located closer to the center of the relevant object than words in the irrelevant object. This difference might have decreased Stroop effects in the latter condition if participants had shifted their focus of spatial attention to (or shifted their gaze at) the center of the relevant object. Therefore, in Experiment 2, words in the background and words in the irrelevant object were presented equidistantly from the center of the relevant object, respectively (see Figure 3).

A comparison of the results of Experiments 1 and 2 should reveal the relative effects of space-based attention and of object-based attention on performance. Three different outcomes are conceivable. First, if shifts of spatial attention were the only modulator of processing, we should not observe any differences between Stroop effects in the irrelevant object and Stroop effects

---

2 By convention, d values around 0.20 are considered small (weak) effects, d values around 0.50 are considered intermediate effects, and d values around 0.80 (and larger) are considered large (strong) effects (Cohen, 1988).
in the background in Experiment 2. The reason is that Stroop words in these conditions were equidistant from the center of the relevant object in Experiment 2. Second, if object-based attention was the only modulator of processing, we should observe similar differences between Stroop effects in the irrelevant object and Stroop effects in the background in both experiments. This pattern of results would suggest that object-based attention is insensitive to the exact locations of the words, which were altered between experiments. Third, if spatial and object-based attention affected the processing of objects in the present experiments, we should expect the difference of Stroop effects in the irrelevant object and in the background to be smaller in Experiment 2 than in Experiment 1. The reason is that two variables (distance of words from the focus of spatial attention; inhibition of irrelevant objects) decreased the Stroop effect in the irrelevant object in Experiment 1, whereas only one mechanism (inhibition) decreased the effect in Experiment 2.

Method

Participants

Nineteen new students (10 women, 9 men) participated for course credit or payment. Their average age was 25 years (ranging from 20 to 47 years).

Apparatus and Stimuli

The same apparatus and stimuli were used as in Experiment 1, except for the following changes. Only the circle and the square were used as shapes. The words were presented on an imaginary circle around the center of an object at 0° or at 90° (cf. Figure 3). When the word appeared in the irrelevant object or in the background, the distance between the center of the relevant object and the center of the word was 30 mm (2.9°). When the word appeared in the relevant object, the distance between the center of the irrelevant object and the center of the word was 30 mm (2.9°).

Procedure and Design

The procedure and design were the same as in Experiment 1.

Results

Within-Trial Analysis

Response times. RTs below 200 ms (< 1.0%) and above 1,500 ms (< 1.0%) were considered outliers and not further analyzed. The mean RT values and error percentages for each of the six conditions are presented in Figure 4.

The two-way ANOVA (Congruency × Object Condition) revealed two significant main effects and a significant interaction. The main effect of object condition, $F(1.50, 27.04) = 16.59$, $MSE = 1.015.33, p < .001$, indicated longer RTs with words in the relevant object (704 ms) than with words in the irrelevant object (670 ms) or in the background (675 ms). The main effect of congruency, $F(1, 18) = 86.32$, $MSE = 1.272.07, p < .001$, indicated shorter RTs with congruent words (652 ms) than with incongruent words (714 ms). Finally, the two-way interaction indicated that the congruency effect varied between object conditions, $F(2, 36) = 28.17$, $MSE = 501.08, p < .001$. Planned comparisons showed that words in the relevant object produced larger Stroop effects ($D = 105$ ms) than words in the irrelevant object ($D = 29$ ms), $t(18) = 7.21, p < .001$, $d = 1.70$, and words in the background ($D = 53$ ms), $t(18) = 4.55, p < .001, d = 1.07$. Furthermore, words in the irrelevant object produced smaller Stroop effects than words in the background, $t(18) = 2.66, p < .05, d = 0.63$.

Errors. Stroop effects in error percentages and Stroop effects in RTs were positively correlated for the relevant object ($r = .50, p < .05$), and for the irrelevant object ($r = .66, p < .01$), whereas the effects were uncorrelated for the background ($r = -.03, p = .89$).

Between-Trials Analysis

Color-to-color sequence. The location of the corresponding color in the preceding trial significantly affected RTs, $F(2, 36) = 9.46$, $MSE = 615.87, p < .01$. Repeating the color of the relevant object produced faster responses than reappearance of the background color as the relevant color (660 ms vs. 690 ms), $t(18) = 3.91, p < .01, d = 0.90$. By contrast, reappearance of the irrelevant object color in the relevant object and reappearance of the background color in the relevant object produced equivalent performance (690 ms vs. 690 ms), $t(18) = 0.05, p = .96, d = 0.01$. The error analysis showed no effects.

---

The distances between the words and the center of the objects were chosen in such a way that only the distance between the word in the background and the screen center changed (i.e., increased) from Experiment 1 to Experiment 2. In contrast, the distance of a word in an object from the screen center was similar in both experiments (about 2.0 mm or 1.9°).
Word-to-color sequence. The location of the corresponding word in the preceding trial affected neither RTs nor errors (all $F$s $< 2$, all $p$s $>.15$).

Combined Analysis of Experiments 1 and 2

To compare the results of Experiments 1 and 2, we entered RTs from both experiments into a three-factorial ANOVA for mixed designs with experiment as a between-subjects variable and object condition and congruency as within-subjects variables. Neither the main effect of experiment ($F < 1$) nor any one of the interactions involving this variable approached significance (all $F$s $< 1.9$, all $p$s $>.15$).

Discussion

The main result of Experiment 2 was that Stroop words in the irrelevant object still had smaller effects than Stroop words in the background when the distance between the word and the center of the relevant object was equal in these conditions. In particular, the decrease of Stroop effects in the irrelevant object compared with the background was similar in Experiment 1 (Stroop effects of 31 and 62 ms) and in Experiment 2 (Stroop effects of 29 and 53 ms). This result suggests that object-based attention modulates the processing of relevant and irrelevant objects in the present task. In particular, object-based attention appears to amplify the processing of the relevant object and inhibit the processing of the irrelevant object. Moreover, the similarity between the results of Experiments 1 and 2 suggests that the object-based mechanism of attention is rather insensitive to the exact spatial locations of words inside and outside of the objects.

The following experiments further explored the conditions under which the processing of irrelevant objects is suppressed. Experiment 3 was a control experiment investigating whether perceptual factors affect word processing in our task. Experiments 4 and 5 tested whether predictability of relevant and irrelevant shapes affects the results. Finally, Experiment 6 replicated the results with shorter display durations.

Experiment 3

When participants reported the color of a relevant object in Experiments 1 and 2, Stroop words in the relevant object produced a large interference effect, Stroop words in the background produced an intermediate effect, and Stroop words in the irrelevant object produced a small effect. We attributed this pattern of results to the fact that attention amplified processing of the relevant object and inhibited processing of the irrelevant object. However, it is possible that the variation of interference effects between conditions is (also) related to variations in the perceptual discriminability of the words between conditions. In particular, it is possible that words in the background produced larger Stroop effects than words in the irrelevant object because words in the background are easier to discriminate than words in the irrelevant object, although the same amount of attention is devoted to the background and to the irrelevant object. This hypothesis was tested in Experiment 3, in which participants had to read the word as quickly as possible, regardless of where the word appeared in the display. If words in the background are easier to discriminate than words in the irrelevant object, word reading should be faster (and more accurate) in the former condition than in the latter.

Method

Participants

16 students (9 women, 7 men) participated for course credit or payment. Their average age was 24 years (ranging from 21 to 35 years). Five had already participated in one of the previous experiments.
Apparatus, Stimuli, Procedure, and Design

The same apparatus and stimuli were used as an Experiment 1. The procedure in Experiment 3 was the same as in Experiment 1, except for the following change: The participant’s task was to read aloud as quickly as possible the word that was shown in the display, regardless of where the word appeared. The only experimental variable was object condition, indicating the location of the word (relevant object, irrelevant object, or background, where relevance refers to the conditions of Experiment 1).

Results

Response Times

RTs below 200 ms (< 1.0%) and above 1,500 ms (< 1.0%) were considered outliers and not further analyzed. RTs were entered into a one-factorial ANOVA, which showed no significant effect of object condition on word-reading latencies, $F(2, 30) = 1.10, MSE = 100.95, p = .35$. In fact, word-reading RTs were highly consistent across conditions (relevant object, 559 ms; irrelevant object, 557 ms; background, 554 ms). Most important, the 3-ms difference between the effects of words in the background and words in the irrelevant object was not significant, $t(15) = .92, p = .37, d = 0.24$.

Errors

The ANOVA on error percentages showed no significant effects ($F < 1$).

Discussion

Word-reading latencies (and accuracy) were statistically equivalent for color words appearing in either an object or in the background. This result shows that the perceptual discriminability of the words does not depend on whether the words are presented within an object or in the background. Hence, we conclude that the modulation of Stroop effects in Experiments 1 and 2 was not related to perceptual factors but can be attributed to attentional factors.

Experiment 4

Experiments 1 and 2 revealed evidence for the notion that attention inhibits the processing of irrelevant objects, including their features (e.g., shape, color, word), in our selective-attention task. In both experiments, there was one relevant and one irrelevant shape, and therefore the shapes of both objects were predictable. The purpose of Experiments 4 and 5 was to explore the boundary conditions for the reduced interference from Stroop words in irrelevant objects compared with words in the background. In particular, these experiments investigated whether inhibition would still occur when the difficulty of the task was increased, and predictability of the irrelevant shape was eliminated. To achieve these goals, for each participant we used two relevant and two irrelevant shapes in Experiments 4 and 5. For example, for some participants the relevant shape was either a circle or a diamond, and the irrelevant shape was either a square or a triangle. Hence, the shapes of both objects varied unpredictably from trial to trial. In Experiment 4, words in the irrelevant object and in the background were equidistant from the screen center, as in Experiment 1. In Experiment 5, words in the irrelevant object and in the background were equidistant from the center of the relevant object, as in Experiment 2.

Method

Participants

Twenty-two new university students (20 women, 2 men) participated for course credit or payment. Their average age was 23 years (ranging from 18 to 41 years).

Apparatus and Stimuli

The same apparatus and stimuli were used as in Experiment 1. The spatial distance between the screen center and the center of a word was 20 mm (1.9°) in each condition.

Procedure and Design

The procedure and the experimental design were the same as for Experiment 1, except for the following change: There were two relevant shapes and two irrelevant shapes for each participant. The 12 possible sets of two relevant and two irrelevant shapes were almost equally distributed across participants.

Results

Within-Trial Analysis

Response times. The results of 1 participant were excluded because he or she showed an extreme error rate (18% vs. 3% of the whole sample; $SD = 4.1$) and an extreme RT (844 ms vs. 638 ms of the whole sample; $SD = 75$). Thus, only the results from 21 participants are reported. RTs below 200 ms (< 3.0%) and above 1,500 ms (< 1.0%) were considered outliers and not further analyzed. The mean RT values and error percentages for each of the six conditions are presented in Figure 5.

The two-way ANOVA (Congruency × Object Condition) revealed two significant main effects and a significant interaction. The main effect of object condition, $F(2, 40) = 18.27, MSE = 787.38, p < .001$, indicated longer RTs with words in the relevant object (769 ms) than with words in the irrelevant object (760 ms) or in the background (734 ms). The main effect of congruency, $F(1, 20) = 174.93, MSE = 847.10, p < .001$, indicated shorter RTs with congruent words (720 ms) than with incongruent words (789 ms). Finally, the two-way interaction indicated that the congruency effect varied between object conditions, $F(2, 40) = 44.24, MSE = 757.85, p < .001$. Planned comparisons showed that words in the relevant object produced larger Stroop effects ($D = 131$ ms) than words in the irrelevant object ($D = 22$ ms), $t(20) = 8.57, p < .001, d = 1.91$, and words in the background ($D = 53$ ms), $t(20) = 6.62, p < .001, d = 1.53$. Moreover, words in the irrelevant object produced smaller Stroop effects than words in the background, $t(20) = 2.69, p < .05, d = 0.60$.

Errors. Stroop effects in error percentages and Stroop effects in RTs were uncorrelated in each of the three object conditions (range: $r = -.24$ to $r = .01$; all ps > .25)
Between-Trials Analysis

Color-to-color sequence. The location of the corresponding color in the preceding trial significantly affected RTs, $F(2, 40) = 10.94, MSE = 866.59, p < .001$. Repeating the color of the relevant object produced faster responses than reappearance of the background color as the relevant color (734 ms vs. 760 ms), $t(20) = 2.56, p < .05, d = 0.56$. By contrast, reappearance of the color of the irrelevant object in the relevant object produced slower responses than reappearance of the background color in the relevant object (776 ms vs. 760 ms), $t(20) = 2.39, p < .05, d = 0.52$. Error analysis showed no effects.

Word-to-color sequence. The location of the corresponding word in the preceding trial affected neither RTs nor errors (all $F$s $< 2$, all $ps > .15$).

Discussion

The results from Experiment 4, with two relevant and two irrelevant shapes for each participant, replicated the results from Experiment 1, with one relevant and one irrelevant shape for each participant. Thus, the predictability of relevant and irrelevant shapes is not a necessary condition for the pattern of results to occur. Moreover, an increase in task difficulty, as reflected in longer overall RTs in Experiment 4 than in Experiment 1 (754 ms vs. 702 ms, $F(1, 42) = 4.52, p < .05$), also does not eliminate the pattern of results.

Experiment 5

To investigate the effects of spatial-attention shifts in Experiment 4, we designed Experiment 5 to attempt to replicate the results of Experiment 4 by placing words in the irrelevant object and in the background equidistant from the center of the relevant object (as in Experiment 2).

Method

Participants

Twenty-one new students (11 women, 10 men) participated for course credit or payment. Their average age was 25 years (ranging from 21 to 33 years).

Apparatus and Stimuli

The same apparatus and stimuli were used as in Experiment 4, except for the following changes: The location of the words was now determined in relation to the center of the relevant or irrelevant object, as in Experiment 2 (see Figure 3).

Procedure and Design

The procedure and the experimental design were the same as for Experiment 4. That is, for each participant there were two relevant shapes and two irrelevant shapes. The shape of the relevant object and the shape of the irrelevant object varied randomly from trial to trial.

Results

Within-Trial Analysis

Response times. RTs below 200 ms (< 3.0%) and above 1,500 ms (< 1.0%) were considered outliers and not further analyzed. The mean RT values and error percentages for each of the six conditions are presented in Figure 6.

The two-way ANOVA (Congruency × Object Condition) revealed two significant main effects and a significant interaction. The main effect of object condition, $F(2, 40) = 16.46, MSE = 620.06, p < .001$, indicated longer RTs with words in the relevant object (797 ms) than with words in the irrelevant object (785 ms).
or in the background (766 ms). The main effect of congruency, $F(1, 20) = 156.90, \text{MSE} = 834.63, p < .001$, indicated shorter RTs with congruent words (750 ms) than with incongruent words (815 ms). Finally, the two-way interaction indicated that the congruency effect varied between object conditions $F(2, 40) = 27.13, \text{MSE} = 462.59, p < .001$. Planned comparisons showed that words in the relevant object produced larger Stroop effects ($D = 100$ ms) than words in the irrelevant object ($D = 31$ ms), $t(20) = 8.17, p < .001, d = 1.83$, and words in the background ($D = 62$ ms), $t(20) = 3.95, p < .01, d = 0.88$. Moreover, words in the irrelevant object produced smaller Stroop effects than words in the background, $t(20) = 3.09, p < .01, d = 0.69$.

**Errors.** Stroop effects in error percentages and Stroop effects in RTs were not significantly correlated for each of the three object conditions (relevant object, $r = .01, p = .97$; irrelevant object, $r = .42, p = .06$; background, $r = -.29, p = .21$).

**Between-Trials Analysis**

**Color-to-color sequence.** The location of the corresponding color in the preceding trial significantly affected RTs, $F(2, 40) = 18.24, \text{MSE} = 611.63, p < .001$. Repeating the color of the relevant object produced faster responses than reappearance of the background color as the relevant color (753 ms vs. 783 ms), $t(20) = 3.31, p < .01, d = 0.72$. By contrast, reappearance of the color of the irrelevant object in the relevant object produced slower responses than reappearance of the background color in the relevant object (798 ms vs. 783 ms), $t(20) = 2.34, p < .05, d = 0.51$. Error analysis showed no effects.

**Word-to-color sequence.** The location of the corresponding word in the preceding trial affected neither RTs nor errors (all $F$s < 2.6, all $p$s > .08).

**Combined Analysis of Experiments 4 and 5**

To compare the results of Experiments 4 and 5, we entered RTs from both experiments into a three-factorial ANOVA for mixed designs with experiment as a between-subjects variable and object condition and congruency as within-subjects variables. Neither the main effect of experiment nor the two-way interactions were significant (all $F$s < 1). However, the three-way interaction was significant, $F(2, 82) = 5.26, \text{MSE} = 604.84, p < .01$. Further contrasts showed that words in the relevant object produced larger Stroop effects in Experiment 4 than in Experiment 5, $F(1, 41) = 6.28, \text{MSE} = 767.43, p < .05$, whereas words in the irrelevant object and in the background produced similar Stroop effects in the two experiments (both $F$s < 1.5, both $p$s > .20).

**Discussion**

The results of Experiment 5 replicated the pattern of Stroop effects from Experiment 4, although words in the irrelevant object and words in the background were presented equidistant from the center of the relevant object, rather than being equidistant from screen center (as in Experiment 4). Again, larger Stroop effects from words in the relevant object than from words in the background suggest that in our task, object-based attention amplifies the processing of the relevant object, regardless of whether the relevant shape is predictable or not. Moreover, smaller Stroop effects from words in the irrelevant object than from words in the background suggest that object-based attention inhibits processing of the irrelevant object, regardless of whether the irrelevant shape is predictable or not. It is interesting that the decrease of Stroop effects in the irrelevant object, compared with the background, was statistically equivalent in Experiment 4 (Stroop effects of 22 and 53 ms) and in Experiment 5 (Stroop effects of 31 and 62 ms), suggesting that shifts of spatial attention did not affect the results.

**Experiment 6**

The comparison between Experiments 1 and 2, as well as the comparison between Experiments 4 and 5, revealed no evidence for shifts of overt or covert attention, suggesting that object-based
attentional mechanisms caused the results. Nevertheless, in Experiments 1–5 display durations were long enough to allow for eye movements from the screen center to the center of the relevant object. Therefore, Experiment 6 tested whether the pattern of results would replicate when shorter display durations rendered eye movements ineffective.

**Method**

**Participants**

Sixteen new students (11 women, 5 men) participated for course credit or payment. Their average age was 26 years (ranging from 21 to 37 years).

**Apparatus and Stimuli**

The apparatus and stimuli from Experiment 1 were again used.

**Procedure and Design**

The procedure and the experimental design were the same as for Experiment 1, except for two changes. First, stimulus displays were presented for only 250 ms. Second, the relevant shape always appeared as the occluding object, and the irrelevant shape always appeared as the occluded object.

**Results**

**Response Times**

RTs below 200 ms (< 1.0%) and above 1,500 ms (< 1.0%) were considered outliers and not further analyzed. The mean RT values and error percentages for each of the six conditions are presented in Figure 7.

The two-way ANOVA (Congruency × Object Condition) revealed two significant main effects and a significant interaction. The main effect of object condition, \( F(1.46, 21.93) = 29.65, \) \( MSE = 316.08, p < .001 \), indicated longer RTs with words in the relevant object (665 ms) than with words in the irrelevant object (623 ms) or in the background (629 ms). The main effect of congruency, \( F(1, 15) = 183.56, MSE = 445.59, p < .001 \), indicated shorter RTs with congruent words (606 ms) than with incongruent words (665 ms). Finally, the two-way interaction of congruency and object condition was significant, \( F(2, 30) = 28.92, MSE = 442.85, p < .001 \). Planned comparisons showed that words in the relevant object produced larger Stroop effects (\( D = 104 \) ms) than words in the irrelevant object (\( D = 27 \) ms), \( t(15) = 5.92, p < .001, d = 1.48 \), and words in the background (\( D = 44 \) ms), \( t(15) = 5.61, p < .001, d = 1.40 \). Moreover, words in the irrelevant object produced smaller Stroop effects than words in the background, \( t(15) = 2.29, p < .05, d = 0.57 \).

**Errors**

Stroop effects in error percentages and Stroop effects in RTs were not significantly correlated for each of the three object conditions (relevant object, \( r = .36, p = .17 \); irrelevant object, \( r = -.11, p = .69 \); background, \( r = .40, p = .12 \)).

**Discussion**

Experiment 6 replicated the results from the preceding experiments with shorter display durations (250 ms vs. 500 ms). Because eye movements within the displays should be rather ineffective with short display durations, eye movements cannot explain the results.

**General Discussion**

The present study investigated the conditions under which object-based selective attention inhibits the processing of an irrel-

![Figure 7](image-url)
event visual object to support the processing of a relevant visual object. Participants were presented with two visual objects around fixation, and the objects differed in shape and in color. The task was to report the color of a relevant object that was indicated by shape (except for Experiment 3). Most important, color words presented in the relevant object, in the irrelevant object, or in the background produced Stroop effects reflecting the relative strength of processing of the area containing the word.

In Experiments 1 and 2, there was one relevant shape and one irrelevant shape for each participant. Results show that words in the relevant object produced larger Stroop effects than words in the background, whereas words in the irrelevant object produced smaller Stroop effects than words in the background. Moreover, presenting words in the relevant object and words in the background equidistantly from the center of the relevant object (Experiment 1) or equidistantly from the center of the irrelevant object (Experiment 2) did not affect the results, which suggests that shifts of spatial attention to the center of the relevant object were not important. In addition, word-reading performance in Experiment 3 showed that perceptual discriminability of the color words did not vary across conditions. Therefore, we conclude that object-based mechanisms of visual selective attention produced the modulation of Stroop effects. In particular, we conclude that visual attention amplified the processing of the relevant object and inhibited the processing of the irrelevant object but did not affect the processing of the background.

The results of Experiments 4 and 5 indicate that both amplification of the relevant object and inhibition of the irrelevant object can occur when neither the shape of the relevant object nor the shape of the irrelevant object is predictable, which significantly increases the difficulty of the task. Again, presenting words in the relevant object and words in the background equidistantly from the screen center (Experiment 4) or equidistantly from the center of the relevant object (Experiment 5) did not alter the results, which suggests that shifts of spatial attention to the center of the relevant object were not important. The results of Experiments 4 and 5 have two implications. First, predictability of object shape is not a necessary condition for the ability to inhibit the processing of the irrelevant object. Second, variations in the capacity demands of the task do not appear to affect the ability to inhibit irrelevant objects. Finally, the modulation of Stroop effects was also observed in Experiment 6 when short display durations of 250 ms rendered eye movements ineffective.

The increased Stroop effects in the relevant object and the decreased Stroop effects in the irrelevant object, when compared with the background condition, are attributed to an object-based mechanism of attention. Particularly the finding that words in the irrelevant object are treated differently from words in the background suggests that object-based attentional selection is involved. A space-based mechanism of attention could, in principle, facilitate processing within a window (or spotlight) of attention and inhibit the processing outside the window of attention. However, such a center–surround mechanism of spatial attention (e.g., Dagenbach & Carr, 1994) would not distinguish between areas inhabited by irrelevant objects and the empty background. By contrast, treating an irrelevant object differently from words in the background requires segmentation of the irrelevant object from the background and some binding between the different features of the irrelevant object (i.e., shape, word, color). Moreover, comparisons between experiments showed that spatial factors played only minor roles in the present experiments. This, however, does not mean that object-based attention operated on spatially invariant object representations in the present experiments. It is quite possible that object-based attention addressed the objects through their locations.

We assume that in the majority of trials, the irrelevant object was processed in parallel with the relevant object and then inhibited. A possible alternative explanation may be that reduced Stroop effects from words in the irrelevant object resulted from a subset of trials in which participants erroneously selected the irrelevant object before the relevant one. In particular, one could assume that when participants detect their error and shift attention from the irrelevant to the relevant object, IOR is produced for the irrelevant object. This explanation predicts that the probability of IOR should increase when the difficulty of selecting the relevant object is increased. The results do not support this prediction. Increasing the difficulty of selecting the relevant object from Experiment 1 to Experiment 4 did not increase the inhibitory effect. Pratt et al. (1999) proposed attentional momentum as an alternative explanation of IOR. According to this account, attention is biased to continue moving in the same direction in which it most recently traveled. Can the attentional-momentum hypothesis explain our results? We believe that the answer is negative for at least two reasons. First, the attentional-momentum account presumes attention shifts to the relevant object, yet we found no evidence for such shifts of attention. In particular, altering the location of the words within the displays did not affect the pattern of Stroop effects. Second, the attentional-momentum account assumes a bias against moving spatial attention toward the location of the irrelevant object in our task, which was never required. Thus, whereas attentional momentum may play a role in spatial-cuing tasks, it is not applicable to our paradigm.

Our account claims that object-based attention amplifies the processing of relevant objects and inhibits the processing of irrelevant objects. When compared with the background condition, amplification decreased RTs with congruent words in the relevant object and increased RTs with incongruent words in the relevant object, whereas inhibition increased RTs with congruent words in the irrelevant object and decreased RTs with incongruent words in the irrelevant object. If only amplification and inhibition affected behavior in our experiments, we should have observed symmetric effects of word position on performance with congruent and incongruent words, respectively. Inspection of Figures 2 and 4–6, however, reveals that other factors influenced behavior in our experiments, as well. The first factor was a main effect of word position. When compared with the background condition, the mere presence of a word in the irrelevant object increased RTs by 10 ms, on average, and the mere presence of a word in the relevant object increased RTs by 33 ms, on average. These main effects added to the effects of amplifying the processing of incongruent words in the relevant object and to the effects of suppressing the processing of congruent words in the irrelevant object. By contrast, the main effect counteracted the effects of amplifying the processing of congruent words in the relevant object and the effects of suppressing the processing of incongruent words in the irrelevant object.

---

4 We thank Friederike Schlaghecken for discussing this issue.
In addition, other factors might have also distorted symmetrical effects of object-based attention in congruent and incongruent conditions. These factors involve the possibility of ceiling effects in congruent conditions, or the presence of undetectable word-reading responses in congruent conditions (e.g., MacLeod & Macdonald, 2000).

Although the main focus of the present study was on within-trial measures of attentional selection, we assessed sequential effects that might also reflect the work of attentional mechanisms. In particular, we analyzed sequential effects with regard to a relevant stimulus dimension (i.e., color) and an irrelevant dimension (i.e., word meaning). With regard to the relevant stimulus dimension, we determined how color-naming performance in the present trial was affected by having seen the same color in the relevant object, in the irrelevant object, or in the background of the preceding display. In four experiments (Experiments 1, 2, 4, and 5), RTs were shorter when the color of the relevant object was repeated than when the background color reappeared as the color of the relevant object. This benefit reflects positive priming within the relevant color dimension. Moreover, in three experiments, RTs were longer when the color of the irrelevant object reappeared in the relevant object than when the background color reappeared in the relevant object. This effect was significant in Experiments 4 and 5. This RT cost represents NP within the relevant color dimension. With regard to the irrelevant stimulus dimension, we determined how color-naming performance in the present trial was affected by having seen a corresponding color word in the relevant object, in the irrelevant object, or in the background of the preceding display. These analyses produced no consistent effects. In particular, having seen a corresponding color word in the irrelevant object of the preceding trial and having seen a corresponding color word in the background of the preceding display did not affect color-naming performance differently. That is, we observed no evidence for NP from ignoring a color word in the preceding trial on naming the corresponding color in the present trial. The difference between the effects of color-to-color sequences and the effects of word-to-color sequences is noteworthy for three reasons. First, the pattern of results replicates the finding that NP is stronger on the relevant stimulus dimension than on an irrelevant stimulus dimension (e.g., Frings & Wentura, 2006a). Second, and more important, the failure to observe NP from previously ignored words strongly suggests that the reduced Stroop effects from words in irrelevant objects did not result from sequential effects but were produced online. Third, the failure to observe NP from previously ignored words also demonstrates that the effects of suppressing irrelevant objects were rather short-lived in the present experiments.

An interesting discrepancy occurred between the results of previous studies (e.g., Wühr & Waszak, 2003) and the results of the present experiments. In particular, object-based amplification occurred both in the previous studies and in the present experiments, whereas object-based inhibition only occurred in the present experiments. There were, however, at least two important differences between the task used in preceding experiments and the task used in the present experiments. First, in preceding studies, the two objects appeared at the same retinal location in 2D space, whereas in the present study the two objects appeared at different locations in 2D space. Second, in preceding studies participants selected between two objects of the same shape (though rotated in 2D space), whereas in the present study participants selected between two different shapes. It is an interesting question for future research to determine which of these factors is necessary for inhibition of irrelevant objects to occur. We have already started to investigate this issue.

In summary, the results of the present study provide strong evidence for the existence of an inhibitory mechanism of attentional control that is applied online. Moreover, the results of the present study indicate that our experimental task is suited for investigating facilitatory and inhibitory mechanisms of object-based attention simultaneously without having to infer attentional modulations of processing from sequential effects.

References


Houghton, G., & Tipper, S. P. (1994). A model of inhibitory mechanisms...


Received October 30, 2006
Revision received May 22, 2007
Accepted June 4, 2007

130 WÜHR AND FRINGS

131 WÜHR AND FRINGS