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A Stroop Effect for Spatial Orientation

PETER WÜHR
Erlangen University, Germany

ABSTRACT. The author investigated the conditions under which a congruent or incongruent orientation word affects processing of the orientation of visual objects. Participants named the orientation of a rectangle that partially occluded another rectangle. Congruent or incongruent orientation words appeared in the relevant object, in the irrelevant object, or in the background. There were two main results. First, congruent orientation words produced faster orientation-naming responses than incongruent orientation words. This finding constituted a new Stroop effect for spatial orientation. Second, only words in the relevant (i.e., attended) object produced Stroop effects, whereas words outside the relevant object had no significant effects. This object-dependent modulation of Stroop effects resembled previous findings with color-naming tasks, and hence indicated that these modulations are not restricted to a particular type of task. In summary, results suggested that object-based attention plays an important role in processing of irrelevant words.

Keywords: attention, orientation, Stroop effect

A PROMINENT EXPERIMENTAL PARADIGM for investigating visual selective attention in humans is the Stroop Color-Word Interference Test (1935). Stroop developed this paradigm to compare the associative strength between colors and vocal color naming responses with the associative strength between words and vocal word naming responses. In his first experiment, Stroop observed that reading words printed in an incongruent ink color (e.g., the word *red* printed in *blue* ink color) was only slightly slower than reading words printed in black ink. In his second experiment, Stroop found that naming the colors of incongruent color words took much more time than naming the colors of a list of nonword stimuli. From these findings, Stroop concluded that the associations between words and word-naming responses are much stronger than the associations between colors and color-naming responses.

In the late 1960s, psychologists rediscovered Stroop's paradigm, especially

Address correspondence to Peter Wühr, Friedrich-Alexander-Universität Erlangen-Nürnberg, Institut für Psychologie, Kochstrasse 4, 91052 Erlangen, Germany; peter.wuehr@psy.phil.uni-erlangen.de (e-mail).

his color-naming task, and used it for investigating cognitive processes (see Dyer, 1973 for an early review). Stroop's task appeared suitable for investigating the mechanisms of cognitive control in general and selective attention in particular. In the Stroop task, participants have to selectively attend to one particular stimulus dimension (e.g., word color), and to ignore another stimulus dimension (e.g., word shape associated with meaning). In his results, Stroop demonstrated an asymmetrical pattern of interference because interference from incongruent word shape on color-naming performance is much stronger than interference from incongruent ink color on word-reading performance. Two implications from Stroop's findings are noteworthy. First, there must be an attentional mechanism that selects between different features (or dimensions) of the same perceptual object. Second, irrelevant stimulation can achieve deep (late) levels of processing under appropriate conditions (e.g., Lavie, 2005).

In the past 40 years, Stroop's original paradigm has been modified in several ways (see MacLeod, 2005 for a review). The two most important changes of the original paradigm concerned the presentation of individual stimuli on a trial-by-trial basis, and the use of a congruent condition (Dalrymple-Alford & Budayr, 1966). In the congruent condition, color words are presented in the congruent color (e.g., the word *red* in red color). Typically, congruent conditions facilitate performance when compared with a neutral condition.

Researchers also developed new variants of the Stroop test. One variant is the spatial Stroop task in which location (or direction) words appear in congruent or incongruent locations (e.g., White, 1969), or move in congruent or incongruent directions (e.g., Dyer, 1972). Another variant is the picture-word task, in which words appear with pictures showing congruent or incongruent objects or scenes. This task produces an asymmetrical pattern of interference because incongruent words interfere with picture-naming performance more strongly than incongruent pictures interfere with word-reading performance (e.g., Rosinski, Golinkoff, & Kukish, 1975; Smith & Magee, 1980). There is one interesting difference between the Stroop color and spatial tasks and the picture-word task. In the former tests, which are called integrated Stroop tasks, the experimenter varies the relations between two features of the same perceptual object (e.g., shape and location). In the latter task, a separated version of the Stroop task, the experimenter varies the relation between features of two different objects (i.e., a picture and a word).

Researchers have proposed many different explanations to account for the Stroop effect (see MacLeod, 1991 for a review). The most widely accepted explanation is the *automaticity account*, which rests on the distinction between controlled and automatic operations of information processing (Posner & Snyder, 1975; Shiffrin & 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, do not require limited resources (e.g., attention), and are immune to interference from concurrent processing. Many researchers conceive word reading as strongly automatic, whereas color naming seems to rely on much less automatic (i.e., controlled) processing. Hence, irrelevant words are read involuntarily, interfering with color naming, but not vice versa (Brown, Gore, & Carr, 2002; Posner & Snyder; MacLeod & MacDonald, 2000).

The results of some recent studies by Wühr and colleagues (Wühr & Waszak, 2003; Wühr & Weltle, 2005) challenge the traditional automaticity account of the Stroop effect. In these studies, researchers presented participants with two overlapping rectangles—one oriented horizontally, the other oriented vertically. Participants named the color of the occluding rectangle (the relevant object), and ignored the color of the occluded rectangle (the irrelevant object). To provoke Stroop effects, displays also contained congruent or incongruent color words. Importantly, these color words appeared either in the relevant object, in the irrelevant object, or in the background. 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. However, Wühr et al. consistently found that words in the relevant object produced much larger Stroop effects than did words outside the relevant object. Stroop effects for words in the irrelevant object and for words in the background did not differ. The same pattern of results occurred when Wühr et al. asked participants to name the color of the occluded rectangle. These results are explicable in terms of object-based attentional selection (Kahneman & Henik, 1981; for a review see Scholl, 2001). According to this account, preattentive 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 presumably amplifies processing of all its features (Duncan, 1984; O'Craven, Downing, & Kanwisher, 1999). According to this account, words in the relevant object produce larger Stroop effects than do words outside the relevant object because attentional selection facilitates processing of relevant (color) and irrelevant (word) features of the selected object. This account implies that word shape in the traditional Stroop test is processed because attention spreads to irrelevant features (or parts) of the attended object, and not because word reading runs without attention.

I had two aims in the present study. The first aim was to establish a new kind of Stroop effect of irrelevant words denoting spatial orientation (e.g., horizontal, vertical) on the processing of spatial orientation of visual stimuli. The second aim was to replicate the object-based modulation of Stroop effects, as Wühr and colleagues have observed, with the new kind of Stroop test. In the present experiment, I presented participants with two overlapping rectangles in different orientations. In contrast to previous studies, participants' task was to name the orientation of the occluding rectangle (the relevant object), and to ignore the orientation of the occluded rectangle (the irrelevant object). Importantly, I presented congruent or incongruent orientation words as parts of the relevant object, as parts of the irrelevant object, or in the background. I had two predictions. First, congruent orientation words should produce faster and more accurate responses than incongruent orientation words. Second, this Stroop effect for spatial orientation should be larger for words presented in the relevant object than for words presented outside the relevant object.

Method

Participants

Twenty-two university students (19 women, 3 men), with a mean age of 21 years, participated in a single-session experiment. The experiment lasted about 30 min, and participants received 3 euros (€) or course credit. All participants were native German speakers, who identified themselves as having normal (or corrected-to-normal) visual acuity.

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 constrained to 60 cm by a head-and-chin rest. Participants responded by speaking into a microphone, which triggered a voice key measuring reaction times (RTs) 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 subtending 0.2° of visual angle. Each stimulus display consisted of two rectangles, which were superimposed upon each other and formed a cross, centered on the fixation point (see Figure 1). The short side of the rectangles measured 18 mm (1.7°); the long side measured 68 mm (6.5°).

The background, the rear rectangle, and the front rectangle appeared in different colors (green, red, or yellow). The colors varied randomly from trial to trial. Moreover, in each stimulus display, two identical words appeared in one of the objects, or in the background. When the rectangle containing the words was oriented horizontally, one word appeared to the left and the other to the right of fixation. When the rectangle containing the words was oriented vertically, one word appeared above and the other one below fixation. When the words appeared in the background, one word appeared to the upper left and the other to the lower right of the rectangles, or vice versa. Hence, words in an object were shown at different locations than were words in the background.

The words that I used were the German equivalents of the English words *horizontal* (*waagrecht*), or *vertical* (*senkrecht*). I presented words in two parts, one above the other (see Figure 1). Each word measured about 14 mm × 8 mm (1.3° × 0.8°). The spatial distance between the fixation point and the center of

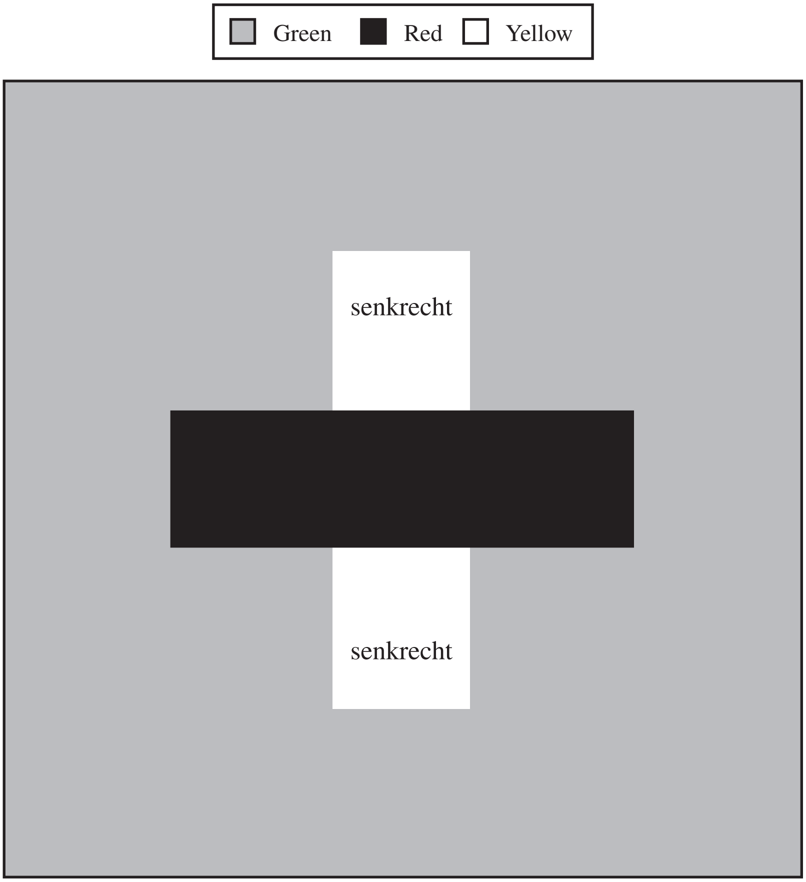

FIGURE 1. Example of a display used in the present experiment (*senkrecht* is the German equivalent of the English word *vertical*). Colors are represented as gray values (see legend). The example shows a trial in which incongruent words are shown in the irrelevant object. For purposes of illustration, the depicted sizes of stimuli are not proportional to the actual sizes used in the experiment (for actual sizes, refer to description of methods).

the words was 25 mm (2.4°) in each condition. I always presented the words in upright orientation.

Procedure

At the beginning of the experiment, the instructions appeared on the screen and participants could read them at leisure. Participants responded as fast and as accurately as possible to the orientation of the front rectangle, while maintaining fixation at the fixation point. Moreover, instructions pointed out that the words presented in the display were irrelevant with respect to the task; participants were told to ignore them. Participants had 20 practice trials.

Each experimental trial contained the following sequence of events. First, the fixation cross appeared on the screen for 500 ms in black color on a gray background. Next, the stimulus display appeared on the screen and remained until the participant responded. Last, there was a blank interval of 1000 ms. There was no error feedback.

I ran the experiment in blocks of 20 trials. Participants could take a rest after each block, and they started the next block at leisure by pressing the space key. The experimenter, who sat outside the lab room, monitored the participant's performance online, heard the participant's responses through earphones, and compared them with the correct answers that were shown on a second monitor. She recorded each error in a list.

Design

For the experiment, I used a 2 × 3 within-subjects design. The first factor was congruency. The irrelevant words were congruent or incongruent with respect to the orientation of the relevant object, and hence to the correct vocal response. The second factor was object condition. The words appeared as parts of the relevant object, as parts of the irrelevant object, or in the background. The two experimental factors, the orientation of the front rectangle, and the colors of the rectangles varied randomly from trial to trial. Participants worked through 48 repetitions for each of the six experimental conditions, resulting in a total of 288 experimental trials. The last block contained 28 instead of 20 trials.

Results

Response Times

For each participant, I first removed all vocal RTs that exceeded two standard deviations from the individual mean. Averaged across participants, I excluded RTs < 329 ms (1.3%) and RTs > 956 ms (4.4%) from further analyses. Table 1 shows the mean RT values and error percentages for each of the six conditions.

I entered RTs into a 2 (congruency) × 3 (object condition) repeated-measures analysis of variance (ANOVA). The main effect of object condition was not significant ($F < 1$). Yet the main effect of congruency was significant, $F(1, 21) = 14.39$, MSE = 397.71, $p < .01$, indicating a Stroop effect for object orientation. In fact, RTs were shorter in congruent conditions (624 ms) than in incongruent conditions (638 ms). Finally, the interaction was also significant, $F(2, 42) = 4.55$, MSE = 385.80, $p < .05$, indicating that Stroop effects varied across the different object conditions. Planned comparisons showed that orientation words in the relevant object produced a significant Stroop effect, $t(21) = 3.82$, $p < .01$. In contrast, words in the irrelevant object, $t(21) = 1.53$, $p = .14$, and words in the background, $t(21) = 0.79$, $p = .44$, had no significant effects. It may be noted that 15 of 22 participants showed the largest Stroop effect for the relevant object, whereas only 2 participants showed the smallest Stroop effect for the relevant object.

Errors

Error percentages, presented in Table 1, were also entered into a 2 × 3 repeated-measures ANOVA. There were no significant effects (all $F < 2.8$, all $p > .07$), but the numerical pattern was similar to the RT results.

Discussion

In the present study, I investigated the conditions under which a congruent or incongruent orientation word (i.e., horizontally vs. vertically) affects processing of the orientation of visual objects. Participants named the orientation of a rectangle that partially occluded another rectangle. Congruent or incongruent orientation words appeared in the relevant object, in the irrelevant object, or in the background. There were two main results. First, congruent orientation words produced faster orientation-naming responses than incongruent orientation words. This finding constitutes a new Stroop effect for spatial orientation. This Stroop effect for spatial orientation resembles previously described Stroop effects for other spatial features of visual stimuli, including spatial location and movement direction (e.g., Dyer, 1972; White, 1969). The second main result of

TABLE 1. Reaction Times (RT; in ms) and Error Percentages Observed in the Participants of the Present Study

	Words appeared in...					
	Relevant object		Irrelevant object		Background	
Variable	RT	% error	RT	% error	RT	% error
Congruent	620	1.7	626	1.6	627	1.6
Incongruent	648	3.4	634	1.9	632	1.1
Stroop effect	28*	1.7	8	0.3	5	–0.5

Note. Stroop effect = incongruent condition minus congruent condition.
*$p < .01$.

the present study was that only orientation words in the relevant (i.e., attended) object affected processing of the orientation of a perceptual object. In contrast, orientation words in the irrelevant object or in the background had no significant effects on behavior. This pattern of results resembles previous observations by Wühr and Waszak (2003) , and thus demonstrates that modulations of the Stroop effect are not restricted to tasks in which participants have to name the color of an object.

As previous researchers have noted, Stroop effects for spatial features of stimuli are typically smaller in size than the original Stroop effect for stimulus color (e.g., MacLeod, 1991). In particular, Stroop effects for spatial features are typically smaller than 50 ms, whereas Stroop effects for stimulus color are typically larger than 100 ms. At the time of this writing, the reason for this difference is unclear. A possible explanation is that color words are processed more effectively than orientation words. This hypothesis is supported by the fact that color words are more frequent in the German language than the orientation words that I used in the present study (absolute frequencies in the CELEX database: *blau* [blue]: 89, *gelb* [yellow]: 70, *grün* [green]: 95, *rot* [red]: 187, *senkrecht* [vertical]: 66, *waagrecht* [horizontal]: 6). Note that more efficient processing does not necessarily imply faster processing. In particular, it is possible that low-frequency words and high-frequency words are processed at similar rates, but activate their respective representations to different degrees. In fact, previous research has disproved speed-of-processing accounts of the Stroop phenomenon (e.g., Dunbar & MacLeod, 1984).

The modulations of Stroop effects that I observed can be explained in terms of object-based attentional selection. According to this account, preattentive processes segment the visual field into candidate objects (figures) and background, and attention selects a candidate object for further processing. Attentional selection of an object presumably amplifies the processing of all its features (e.g., Duncan, 1984; Kahneman & Henik, 1981), which explains why words in the relevant object typically produce the largest effects. Moreover, the object-based attentional selection account also may explain the observation of reduced but significant Stroop interference for the irrelevant object and for the background in the color-naming task (e.g., Wühr & Waszak, 2003), when assuming that selection of the relevant object fails occasionally. According to this hypothesis, if object-based selection works properly, the participant will select only the features of the relevant object, and words in the irrelevant object or in the background should have no effects at all. However, sometimes object-based selection fails, and the participant selects either the irrelevant object or no object (or the already selected object is lost). In these infrequent cases, the participant processes the words in the irrelevant object and words in the background (also or temporarily), and their features can affect the person's performance.

An interesting result of the present research was that words outside the relevant object produced small but significant interference effects in the color-naming task of the previous studies, whereas words outside the relevant object had no effects in the orientation-naming task. A possible explanation follows from the account of residual Stroop effects for words outside the relevant object that are in terms of failures of object-based selection. From this perspective, the object-based attention framework has to explain why object-based selection fails more frequently when participants process object color than when they process object orientation. A possible answer is that the processing of object orientation requires less resources than does the processing of object color. Thus, for color processing, less resources are available for maintaining attentional control settings than for orientation processing, and the risk for a slip of attention increases accordingly (e.g., Lavie, 2005).

The object-based attentional selection account of Stroop effects challenges the traditional automaticity account of these effects (e.g., MacLeod & MacDonald, 2000; Posner & Snyder, 1975). The major difference is that the object-based attentional selection account claims that word reading needs attention, whereas the automaticity account claims that word reading needs no attention. However, the object-based selection account does not exclude the possibility that some sort of automaticity promotes the processing of irrelevant word shape as part of an attended object. In particular, attentional selection of a perceptual object may trigger ballistic processing of relevant and of irrelevant object features (e.g., Kahneman & Henik, 1981). Attentional selection of a perceptual object may cause the automatic processing of irrelevant object features in the sense that this processing cannot be stopped as long as attention is deployed to the object. However, color words may not be truly task-irrelevant stimuli in a color-naming task. In a typical Stroop task, participants intend to process color information, and to say color words to visual stimuli, and these intentions may prime the processing of color words, compared with unrelated words. From this point of view, the processing of color words in the classic Stroop task may not be unintended. Future researchers should investigate whether object features that are neither related to relevant features nor to the participants task set, are processed.

The present results showed that the processing of irrelevant orientation words depends on the focus (or object) of attention. This observation challenges the view of word reading in the classic Stroop task requiring no attention, as assumed by the traditional automaticity account.

AUTHOR NOTE

Peter Wühr is an assistant professor at the Department of Psychology, University of Erlangen, Germany. His research interests include visual attention, action control, and executive functions.

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