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BRIEF REPORT

The spatial Stroop effect: A comparison of color-word and position-word interference

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Abstract The Stroop effect is one of the most famous examples of interference in human perception. The present study demonstrates that a position Stroop paradigm, comparable to the classical color-word interference paradigm, resulted in the same pattern of interference for the spatial dimension; however, the interference was significantly weaker. By exchanging the original oral response for a manual response in the spatial paradigm, we showed that the verbal component is crucial for the Stroop effect: Manual responses lead to a disappearance of the interference effect. Moreover, with manual responses word position was recognized at the same speed for the baseline condition and for words that were incongruent as well as congruent with the spatial position. The results indicate (1) that the Stoop effect depends heavily on verbal components and (2) that differing processing speeds between reading and position recognition do not serve as a proper explanation for the effect. In addition, the provided paradigm plausibly transfers the classical color-word interference to the spatial dimension.

Keywords Stroop effect · Interference · Spatial · Position

The Stroop effect

The famous article on attention and interference by John Riddley Stroop (1935) belongs, without doubt, among the most influential studies in experimental psychology until today. Stroop showed that it takes participants much longer to name the display color of a word if the word is the written name of another color, as compared either to words with identical meaning and display color or to colored bars. Stroop's experiments were based on the findings of Cattell (1886), who had demonstrated that it takes longer to name a seen object than to read the name of the object. Within the next 50 years after Cattell's article, a myriad of studies had been conducted to explain the phenomenon, yet Stroop was the first to combine the two functions of reading and color naming, forming incongruent cases and thereby creating the "Stroop effect." The effect describes the time difference between naming the colors of simple bars and the colors of words whose letters comprise the names of incongruent colors. The test created by Stroop, including these two conditions, has been named after its inventor: the "Stroop test."

Despite the considerable number of studies regarding the Stroop phenomenon, no universally accepted explanation has been found. However, two major candidates have been proposed: (1) relative processing speed and (2) voluntary versus automatic processes (see MacLeod, 1992). The latter theory assumes reading to be an automatized process that interferes with the voluntary process of color naming. Comalli, Wapner, and Werner (1962) argued that performance in the Stroop test reflects the ability to hold onto a course of action despite intrusions by other stimuli, calling the reading of color words a highly "automatized activity." Cattell (1886) also described his findings as a result of two different processes, one of which is automatized (reading) and the other one voluntary (object naming). Dyer (1973), along with Palef and Olson (1975), on the other hand, proposed different processing speeds for object naming and reading as the reason for the Stroop effect. However, Dunbar and MacLeod (1984) concluded their review by stating that—whether automaticity be a factor or not—relative speeds of processing do not provide an adequate

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explanation for the effect. The dispute has still not been conclusively resolved, and aspects including word order (Dalrymple-Alford & Budayr, 1966), masking of words (Gumenik & Glass, 1970), or the influence of individual phonemes continue to be subjects of investigation within a flourishing field of research (e.g., Bruchmann, Herper, Konrad, Pantev, & Huster, 2010; Conty, Gimmig, Belletier, George, & Huguet, 2010; M. E. Meier & Kane, 2012; Takeuchi et al., 2012).

In addition, the Stroop test is a commonly used test in the psychological assessment of cognitive inhibition (Swerdlow et al., 1995). It is used in clinical studies (e.g., Comalli et al., 1962; Dodrill & Troupin, 1977; Lezak, Howieson, & Loring, 2004) as well as for clinical assessments (Hilger & Kasper, 2002; Petermann & Toussaint, 2009).

Variations of the Stroop paradigm

Besides the classical color-word interference paradigm, various versions of Stroop tests have been designed—investigating, for example, emotional (B. P. Meier & Robinson, 2004), auditory (Cohen & Martin, 1975), or spatial (e.g., White, 1969) Stroop effects. In particular, the spatial Stroop effect, describing interference between word meaning and word position, has been analyzed in various settings (see Lu & Proctor, 1995, for an overview). White used a square with the words "north," south," "east," and "west" written next to the four respective sides of the figure. The participants had to verbally articulate the position of a word in the rectangle, regardless of its meaning. Even though geographic directions relate only indirectly to the four sides of a square, White found interference for words with incongruence between meaning and position. However, as compared to colors, the decrease in performance from baseline to the interference condition turned out to be much smaller. Taking into account the semantic proximity of a display color and the meaning of the written color name (as compared to the geographical directions and positions within a square), this discrepancy seems a little surprising. Shor (1970) used arrows as stimuli, within which the word "up, "down," "left," or "right" was written, in order to investigate the effect of interference between word naming and arrow direction, and vice versa. He could show that both dimensions showed interference with each other, but naming the arrow direction was impaired far more strongly than reading the word out loud. Palef and Olson (1975) investigated the spatial Stroop phenomenon by using varying font sizes, and they concluded that spatial position interfered with word meaning only when the latter was recognized faster (i.e., the font size was bigger), and thus (so they assumed) processed faster. In their experiment, however, the subjects had to indicate the position by pressing buttons. This way of responding to the stimuli made Palef and Olson's study only partly comparable to the classical Stroop paradigm, in which the subjects are required to respond verbally. Notably, White found interference only for verbal responses, whereas indicating the direction with a joystick did not lead to an interference effect. The same pattern appeared in the classical color-word interference paradigm: Interference was not apparent when the subjects were required to press buttons to indicate the display color.

Taken together, the aforementioned studies show the importance of the verbal component in the Stroop phenomenon, which—despite the considerable amount of research in this field—has rarely been discussed (however, a good analysis is given by Liotti, Woldorff, Perez, & Mayberg, 2000). None of the studies could conclusively solve the issue of the role of verbal processes, since White (1969) used inadequate stimuli, Shor (1970) investigated only verbal responses, and Palef and Olson (1975) used exclusively manual reactions. The question concerning the influence of a verbal component, therefore, requires further and more thorough analysis, particularly regarding the commonalities and differences of the dimensions involved, such as spatial position and color. Especially due to the broad application of the Stroop paradigm in clinical settings (e.g., Comalli et al., 1962; Dodrill & Troupin, 1977; Gold & Freshwater, 2002; Lezak et al., 2004) and the questions concerning the impact of verbal and nonverbal components, further investigation of the cognitive mechanisms involved and their interplay is also of practical importance.

In the present study, we used a comparison of the classical color-word paradigm and a position-word interference test (developed by the authors) for the investigation of the Stroop effect. In order to study the verbal factor of the effect, the spatial Stroop test was conducted using both a manual and a verbal response. It is expected that the effect of position-word interference would be observed, just as color-word interference is. Additionally, we hypothesized that no interference would show in the manual condition, since the verbal component is assumed to be essential for the effect.

Method

Sample

As is depicted in Table 1, $N = 75$ native German speakers took part in the study. For participation, the subjects received €15 and a signed certificate of participation, exchangeable for course credit.

Material

The computerized tests were conducted using a Dell E6510 personal computer with an Intel 2.53 GHz central processing unit, 4.00 GB random access memory, and an Nvidia NVS

Table 1 Descriptive statistics for the sample

Sex		Age		
Female	Male	Med (*SD*)	Min	Max
51	24	24.00 (5.4)	18	53

Med = median; *SD* = standard deviation; Min = minimum; Max = maximum

3100 M graphics adapter. Analog tests were presented to the subjects on white sheets of DIN-A4 size paper.

Color Stroop test For the assessment of color-word interference, the "Farbe-Wort-Interferenztest," a German version of the Stroop color-word interference test (Bäumler, 1985), was conducted: Sheets with colored bars, color words in black, and color words in an incongruent color were presented to the participants in sequential order. Every sheet showed 74 stimuli of one category, which had to be read or named (according to color) as quickly and accurately as possible in sequential order. The time taken to read or name all of the stimuli on one sheet was stopped with a stopwatch for every sheet individually.

Analog position Stroop test The analog position-word interference test was developed by the authors to mimic the classical color-word interference test for the spatial dimension. The stimuli consisted of crosses comprising the German words for "up," "down," "right," and "left" (i.e., *oben*, *unten*, *rechts*, and *links*) at incongruent positions within the crosses. A total of 24 crosses were depicted in black on a white sheet. A second sheet with the letters "XXXX" in one of the four possible positions within another 24 crosses served as the control condition. A third sheet consisted of only 24 position words, without crosses. Examples for both conditions are depicted in Fig. 1. The words or letters are written in black Calibri font (14-point). Subjects were required to name the position of the word or letters within the cross (i.e., "up," "down," "right," or "left"), or, in the condition without crosses, to read the position words out loud. As in the color-word interference test, the time to complete a whole sheet was measured by using a stopwatch in each condition.

Digital position Stroop test A digital version of the position-word interference test was developed in order to obtain exact reaction time measurements for the individual stimuli and was conducted on a computer. The participants had to react to the sequentially appearing stimuli: The letters "XXXX" or the German word for "up," "down," "right," or "left" appeared within one of the four possible positions within a cross (as in the analog version of the test, no stimuli appeared in the center of the cross). Each of the words appeared 120 times, uniformly distributed across the four positions, as did the "XXXX" stimulus. Since the words also appeared in congruent positions (i.e., identical spatial position and word meaning), a third ("congruent") condition resulted. The words/letters were presented in Calibri font at a visual angle of 3° vertically.

As in the analog version of the test, the task was to react to the position of the word (independent of the word meaning). The position had to be indicated by pressing one of four buttons, which were arranged in the same directions as the four possible positions. The index and middle finger of both hands were each placed on one of the buttons, and hand positions were switched for half of the participants to exclude effects of hand dominance.

Procedure

The tests were conducted in single sessions in a university laboratory under comparable conditions. Every participant was tested individually. The order of the tests, as well as the order of the conditions within the tests, was randomized between the subjects to avoid sequence effects (possible effects of test order were nevertheless tested for).

Analysis

Performance on both analogous tests was measured in words per second (WPS) for the sake of comparability (every "XXXX" stimulus was counted as one word):

$$WPS = \frac{words\ \ read{-}errors}{time\ \ in\ \ seconds}$$

WPS seems a reasonable measure of performance, due to the fact that it includes reading speed and accuracy in one parameter: "Words read" represents the fixed number of stimuli on a single sheet, whereas "errors" stands for the number of stimuli not correctly identified on this sheet. The parameter therefore increases with increasing reading speed and decreases with increasing numbers of incorrectly named stimuli.

Additionally, an index for the decrease in performance between the baseline condition and the respective interference condition was calculated. In the classical Stroop test, performance in color-bar naming is divided by the interference-condition performance. For the position Stroop test, performance in the "XXXX" condition was divided by performance in the interference condition. In the following discussion, this measure will be referred to as the "index."

Repeated measures analyses of variance (ANOVAs) were conducted to test for differences in performance between the three conditions. Possible effects of test order were analyzed using independent-samples ANOVAs. Violations of the sphericity assumption (tested by Mauchly's W test) were corrected by Greenhouse–Geißer ($\varepsilon_{\text{G-G}}$) adaptations to the degrees of freedom. Subsequent post-hoc tests were used to test for

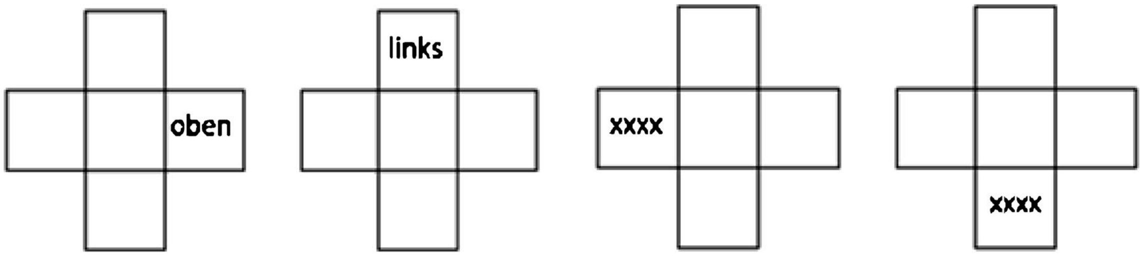

Fig. 1 Exemplary items position Stroop test: Two exemplary items from the interference condition (*oben* "up" and *links* "left") and the baseline condition ("XXXX")

differences between the conditions individually, and these underwent Bonferroni corrections to a total α level of .05. Additionally, Pearson product-moment correlations were calculated to investigate the relationships between the variables. All variables were tested for a normal distribution using Kolmogorov–Smirnoff tests, and all tests were run two-tailed, unless stated differently.

The sample size of 75 subjects was chosen to allow detection of even small effects ($g_{\text{Hedges}} = .35$) with manual stimuli with a probability of .849. The power was adjusted with regard to the manual response paradigm, because the difference in reaction times in this paradigm was expected to be, if apparent, the smallest one of the investigated effects.

All analyses were conducted using the open license software R (R Development Core Team, 2009).

Results

Test order

No significant effect of test order on performance was observed for any of the conditions (all *p*s > .83).

Color-word interference test

An overview of the performance in the classical Stroop test conditions is depicted in Table 2. As expected, the mean performance varied across the three conditions [$F(2, 148) = 90.74$, $p < .01$, corrected by $\varepsilon_{\text{G-G}}$; $\eta_p^2 = .89$]. The subjects showed faster mean performance in reading color words in black than in naming the colors of the bars [$t(74) = 17.92$, $p < .01$, one-tailed; $g_{\text{Hedges}} = 2.00$] and in the interference condition [$t(74) = 40.76$, $p < .01$, one-tailed; $g_{\text{Hedges}} = 4.38$]. Also, the subjects were slower to name the display color in the interference condition than to name the bar colors [$t(74) = 13.34$, $p < .01$, one-tailed; $g_{\text{Hedges}} = 1.63$].

Table 2 Response speed analog Stroop test results, in words per second

Condition	*M* (*SD*)	Min	Max
Color bars	1.80 (0.51)	1.01	5.29
Color words	2.71 (0.41)	1.61	3.66
Color interference	1.17 (0.20)	0.66	1.85
Color index	1.62 (0.33)	1.25	3.83
Position "XXXX"	1.77 (0.27)	0.74	2.53
Position words	1.92 (0.29)	1.19	2.50
Position interference	1.49 (0.29)	0.63	2.40
Position index	1.20 (0.13)	0.96	1.64

M = mean; *SD* = standard deviation; Min = minimum; Max = maximum; Index = ratio between baseline and interference conditions

Analog position-word interference test

Performance in the position Stroop test is also depicted in Table 2: The means differ significantly between the three conditions [$F(2, 148) = 354.53$, $p < .01$, corrected by $\varepsilon_{\text{G-G}}$; $\eta_p^2 = .65$]. Showing the same pattern as the color-word interference test, mean performance was better for reading the position words than for naming positions in the baseline [$t(74) = 5.18$, $p < .01$, one-tailed; $g_{\text{Hedges}} = .51$] and in the interference condition [$t(74) = 15.17$, $p < .01$, one-tailed; $g_{\text{Hedges}} = 1.52$]. Subjects were also slower at position naming in the interference than in the baseline condition.

Digital position-word interference test

Two subjects had to be removed from the analysis due to a random response pattern, which resulted in performance more than four *SD*s slower than average. Mean performance in the digital position Stroop test is shown in Table 3. The mean speeds did not differ significantly between the three conditions [$F(2, 144) = 3.96$, n.s., corrected by $\varepsilon_{\text{G-G}}$; $\eta_p^2 = .05$; condition $t(74) = 15.18$, $p < .01$, one-tailed; $g_{\text{Hedges}} = .95$].

Table 3 Response speeds (in milliseconds) on the digital Stroop test

Condition	*M* (*SD*)	Min	Max
"XXXX"	450 (62)	340	654
Congruent	468 (83)	345	724
Incongruent	467 (66)	353	677

M = mean; *SD* = standard deviation; Min = minimum; Max = maximum

Comparison between the analog position-word and color-word interference tests

The participants showed faster mean performance in reading color words than with position words [$t(74) = 30.10$, $p < .01$; $g_{\text{Hedges}} = 2.23$]. Between the two baseline conditions—naming of bar color and the position of the "XXXX" stimulus—no mean difference was observed [$t(74) = 0.42$, n.s.; $g_{\text{Hedges}} = .06$]. The interference condition, however, showed faster responses for color-word interference than for position-word interference [$t(74) = 14.18$, $p < .01$; $g_{\text{Hedges}} = 1.30$]. Consequently, the index of performance decrease between baseline and the interference condition was bigger in the classical Stroop test [$t(74) = 9.40$, $p < .01$; $g_{\text{Hedges}} = 1.55$].

Discussion

Color-word and position-word interference tests

The present study has shown that, for verbal responses, the color-word and position-word interference tests show the same pattern of results, with interference being stronger in the color-word interference paradigm. The application of manual responses in the position-word interference test led to the disappearance of the effect.

The pattern of results for the color-word interference test (i.e., fastest performance in reading, slower performance in color naming, and slowest performance in the interference condition) mimics the results of Stroop (1935) and of a series of replications of the original experiment in other studies (see MacLeod, 1991, for an overview).

Stroop interference in the spatial dimension has also been shown in various studies (e.g., Dyer, 1972; Palef & Olson, 1975; Shor, 1970; White, 1969); however, these differed greatly regarding their stimuli as well as their experimental setups. The present results are in line with the findings of Shor, who reported that naming of the orientation of an arrow took longer than reading the corresponding direction word out loud. However, regarding spatial attention, Shor's stimuli differed strongly from the stimuli used in the present investigation: Since arrow stimuli—and thus the relevant stimulus attributes—appeared in the center of the screen in every experimental condition, spatial shifting of attention was in no case necessary. Thus, it seems more appropriate to view Shor's task as object recognition rather than as spatial attention (see Posner, 1980). Since in the present study we used response-relevant stimulus attributes that appeared in different positions, the role of spatial attention could be interpreted more clearly. Furthermore, Shor's study did not include a baseline condition using pseudowords or "XXXX" stimuli, but solely included a condition with congruent word meaning and arrow orientation. It was therefore not possible to unambiguously quantify a spatial interference effect, which clearly appeared in the present study.

Taken together, the pattern of results presented here of the classical as well as the spatial Stroop task are perfectly in line with the literature, but they show a clearer and more differentiated pattern than do the aforementioned studies.

The performance decrease between baseline and interference conditions proved to be bigger for color-word than for position-word interference. This shows that, despite identical rank orders of the three conditions (i.e., reading is faster than recognition, which is faster than recognition with interference), differences persist between spatial and color-related interference. A possible explanation lies within the different neural processing streams of spatial and object-related processing, including color (Mishkin, Ungerleider, & Macko, 1983): Whereas spatial Stroop paradigms activate parietal cortical areas (Liu, Banich, Jacobson, & Tanabe, 2004), color-word interference correlates with activity in the left temporo-parietal cortex, which is also known to be related to word meaning (Liotti et al., 2000). Simultaneous processing in a single path leads to more interference than does processing in different paths (e.g., Wickens, Sandry, & Vidulich, 1983), and this is therefore a promising candidate for the reason behind the difference in the observed magnitudes of interference between the two Stroop tasks.

The difference in reaction speed between color and position words can be logically explained by the number of syllables: Whereas all of the tested color words had only one syllable in German, the German position words "up" and "down" comprise two syllables (*oben* and *unten*, respectively), and thus require more time when read or spoken.

Comparison of verbal and manual responses

The digital position Stroop test was conducted with manual responses, which led to the disappearance of the interference effect observed in the verbal paradigm. Also, a possible facilitation through congruent stimuli could not be observed, further highlighting the robustness of manual response speed against word meaning. This result is in accordance with White (1969), who reported stronger interference for verbal than for manual responses (however, White investigated only color and position interference taken together, instead of individual analyses).

Also, Palef and Olson (1975) showed that, with their paradigm, interference appeared only partially, and they concluded that different processing speeds of the relevant and the irrelevant stimulus dimensions were responsible for the interference. Yet, the paradigm used by Palef and Olson differed strongly from the position Stroop test in the present study: They used only two response possibilities ("beneath" and "above" with respect to a horizontal line), for which they could only demonstrate interference by varying font size and relative stimulus position. Although Palef and Olson concluded that differing processing speeds of reading and position recognition are responsible for the effect, the present study shows that the reaction times between the two baseline conditions—namely, naming bars and the position of the "XXXX" stimulus—did not differ. This finding clearly speaks against Palef and Olson's assumption: If processing speed were the relevant factor, interference should not be stronger in the classical Stroop paradigm, since the baseline conditions were processed at the same speed. Thus, the present study cannot provide support for the notion that different processing speeds are the main reason for the Stroop interference. This is in line with the results of Dunbar and MacLeod (1984), as well as the conclusion of MacLeod's (1991) extensive review.

Limitations and applications

In order to further investigate the reason for the discrepancy between the results of Palef and Olson (1975) and those of the present investigation, it would be necessary to vary the number of response possibilities. For a further analysis of the processes involved in the manual response paradigm, the influence of word position on reading speed would have needed to be investigated. Future studies should therefore examine whether a manual response shows interference if the nonverbal stimulus attribute (i.e., position in space) serves as a distractor.

Notably, the position Stroop test provides promising applications for clinical settings: A measurement of inhibition capability can be made possible for color-blind patients, or even blind patients, if the stimuli are written in Braille.

Conclusion

The present study shows that the Stroop effect is also present in the spatial dimension, but that it is smaller than in the classical color-word interference paradigm. This pattern could possibly be due to the common neural pathway of color and word meaning information, and casts further doubt on the theory of different processing speeds, which has been proposed as an explanation for the Stroop effect. Importantly, the present study does not provide evidence for concurring automatic and voluntary processes, yet it does not speak against this theory, either. An important finding, however, is the cruciality of a verbal response for the occurrence of interference. Taken together, the present study highlights the various facets and consistency of Stroop interference, even across dimensions.

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