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Brief article

Processing of color words activates color representations

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ABSTRACT

Two experiments were conducted to investigate whether color representations are routinely activated when color words are processed. Congruency effects of colors and color words were observed in both directions. Lexical decisions on color words were faster when preceding colors matched the color named by the word. Color-discrimination responses were slowed down when preceding color words mismatched the test color even if no task had to be performed on these words. These findings are consistent with the experiential view of language comprehension according to which color perception and the comprehension of color words are based on overlapping representational resources.

1. Introduction

The emerging experiential view of language comprehension assumes that the representations underlying language comprehension are of the same kind as the representations involved in sensory experiences and perceptions (e.g., Barsalou, 1999; MacWhinney, 1999; Zwaan, 2004) rather than amodal symbolic representations such as propositions. According to the experiential view, individuals understand language by engaging in a perceptual simulation of the objects and events described in a linguistic expression. In support of this general claim, a number of experiments have demonstrated that perceptual information such as shape (e.g., Zwaan, Stanfield, & Yaxley, 2002), motion (e.g., Meteyard, Bahrami, & Vigliocco, 2007; Zwaan, Madden, Yaxley, & Aveyard, 2004) or orientation (Stanfield & Zwaan, 2001) is routinely activated when words or sentences are processed that explicitly or implicitly convey this information (see Zwaan, 2004, for an overview). In contrast to spatial and shape characteristics, the role of color information in language comprehension has received little attention, with the exception of Connell (2007). The goal of the present research was to fill this gap by investigating the role of color representations in the comprehension of color words.

The experiential view implies that color representations are activated whenever specific colors or objects with typical colors are mentioned in a linguistic expression. For example, words that denote color-diagnostic objects (Tanaka, Weiskopf, & Williams, 2001) as well as color words themselves should routinely activate color representations akin or identical to those that are involved in color perception. Previous neuroimaging and behavioral studies on the relationship of color and word processing do not provide a clear picture on this issue. For example, a study by Chao and Martin (1999) based on positron emission tomography failed to provide evidence for the assumption that providing color names for achromatic objects – a task requiring conceptual processing of color information – involves the same cortical regions that subserve color perception. The regions activated by generating color names were located in the left parietal cortex (left inferior temporal, left frontal, and left posterior parietal cortex) and in the left fusiform gyrus but lateral to the occipital regions that are activated in color perception. In contrast, a recent fMRI study by Simmons and coworkers provided support for the assumption of the experiential view that color perception and

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conceptual processes involving color information are based on the same neural substrate (Simmons et al., 2007). In this study, a property-verification task with linguistic stimuli (object and color words) activated a region of the left fusiform gyrus that was also active in color perception. However, the property-verification task used by Simmons et al. likely involves strategic imagery-based responses. For this reason, it is not clear whether their results extend to routine language processing. The only previous study with behavioral data on the topic (Connell, 2007) yielded results are difficult to interpret theoretically. Connell presented sentences that implied a specific color and measured latencies in a subsequent object recognition task. In contrast to the present experiments and similar experiments on other perceptual properties (e.g., Zwaan et al., 2002), she observed faster responses for pictures in a color that *mismatched* the color implied by the sentence. Thus, to date, there is just one neuroimaging study providing evidence for overlapping representational resources of colors and color words whereas direct behavioral evidence is still lacking.

Even the extensive literature on the Stroop effect (Stroop, 1935) with hundreds of experiments on the relationship between color and word processing provides only sparse information on the issue. The reason is that most researchers have concentrated on response conflicts as the explanation for the Stroop effect (e.g., Cohen & Huston, 1994; Posner & Snyder, 1975). Accordingly, the vast majority of experiments in this area made no attempt to dissociate effects on the response level from those at the representational level, with the result that both potential sources of facilitation or interference are confounded. Nevertheless, some experiments provide indirect evidence for the assumptions of the experiential view. For example, not only color words but also words denoting color-diagnostic objects have been found to produce interference with color naming, with stronger interference effects for words that denote objects with higher color diagnosticity (e.g., Klein, 1964; Scheibe, Shaver, & Carrier, 1967). For color-related words, an explanation in terms of overlapping representational resources appears to be more plausible than the common explanation of Stroop effects in terms of response conflicts. Further support for this idea comes from recent research showing interference effects of color-related words not linked to colors in the response set (Risko, Schmidt, & Besner, 2006) and from attempts to dissociate stimulus and response conflicts in the Stroop task. DeHouwer (2003) and Schmidt and Cheesman (2005), for example, used a Stroop paradigm with manual responses. Color words and color-related words slowed down the identification of incongruent ink colors even when the color named or implied by the stimulus word and the ink color were assigned to the same response key. Here, interference effects are likely to be caused by stimulus conflicts since the responses required by the stimulus color and implied by the verbal stimulus were identical.

However, the findings by DeHouwer (2003) and Schmidt and Cheesman (2005) do not provide an unequivocal answer to the question of whether color representations are activated when color words are processed; participants in these experiments might have generated a covert verbal response before selecting the appropriate motor response (e.g., MacLeod, 1991; Sugg & McDonald, 1994). In this case, the interference would still be due to a hidden response conflict rather than a stimulus conflict. In terms of the nature of the representations involved, the conflict would take place exclusively among verbal representations: the verbal representation of the stimulus word would interfere with the verbal label assigned by the participants to the stimulus color. On this account, the findings by DeHouwer and by Schmidt and Cheesman would be fully compatible with the classical amodal view of language comprehension but not diagnostic with regard to the experiential view.

To provide a more diagnostic test, the present experiments investigated the effects of color words on a more indirect perceptual task. Rather than having participants identify distinct colors, we asked them to provide color-discrimination judgments on subsequently presented colored stimuli. When the two colors differed, the changes were so subtle that the same verbal label applied to both stimuli; for example, they were both highly similar shades of red. Accordingly, any interpretation of effects of colors on color words in terms of verbal representations or response effects was ruled out as participants were effectively forced to compare a mental image of the first color to the perception of the second color. In Experiment 1, participants also performed lexical decisions on color words. This allowed us to simultaneously investigate effects of colors on the processing of color words as well as reverse effects of color words on color processing. Experiment 2 tested whether color words routinely activate color representations. For this purpose, color words were presented without any task instructions.

2. Experiment 1

In Experiment 1, participants first saw a colored square, then performed a lexical decision task on a color word (or a filler word of another type), and finally judged for a second colored square whether or not it was identical in color to the first one. The color words either matched or mismatched the colors. Importantly, the first and the second colored square were identical in color or represented just barely distinguishable hues of the same color that were highly unlikely to be associated with different color terms. The rationale for this was to prevent participants from using a verbal encoding strategy in the color-discrimination task. Rather, they had to activate and maintain a perceptual representation of the first colored square to compare it to the color of the second square.

If the same color representations are involved in the comprehension of color words and color perception, match/mismatch effects should be obtained for both the lexical decision task and the color-discrimination task. Lexical decisions on color words should be faster after processing of a matching compared to a mismatching color. Color-discrimination judgments should be faster after processing of a matching compared to a mismatching color word. The experiential view does not make a specific prediction about whether matching color words facilitate color processing, mismatching color words interfere with color processing, or both. However, the literature on the Stroop effect suggests that interference effects might be more likely than facilitation effects. In particular, mismatching color words could interfere with maintaining the image of the to-be-remembered color in working memory or with perceptual encoding of the second color (e.g., Schmidt & Cheesman, 2005). In both cases, responses in the color-discrimination task would be slowed down relative to a condition with color-neutral stimulus words.

2.1. Method

2.1.1. Participants

Participants were 30 psychology undergraduates at Florida State University.

2.1.1.1. Color stimuli. As color stimuli, we used 30 monochrome squares (10 cm × 10 cm) with the colors red, green, blue, yellow, cyan, and magenta (for samples, see the supplemental material provided on-line at http://www.allg-psych.uni-koeln.de/color_discrimination). Six of the squares represented pure instances of these colors according to the RGB (Red–Green–Blue) color model. The red square, for example, had the values (255, 0, 0), while the yellow square had the values (255, 255, 0) in the 0–255 range of RGB coordinates. A second set of 12 stimuli was created by adding a small amount (75 U) of another color to the original color, e.g., red squares with the values (255, 75, 0) and (255, 0, 75), or by substracting a small amount (25 U) from one of the component colors of the original color, e.g., yellow squares with the values (230, 255, 0) and (255, 230, 0). In pilot tests, color stimuli with these values were difficult to distinguish from the original color stimuli (accuracy of responses near chance). A third set of 12 stimuli was created by adding a slightly greater amount (100 U) of another color, e.g., red squares with the values (255, 100, 0) or (255, 0, 100), or by substracting a slightly greater amount (50 units) of one of the component colors, e.g. yellow squares with the values (230, 205, 0) and (255, 205, 0). In pilot tests, color stimuli with these values turned out to be easily distinguishable from the original color despite differing from the original color only gradually.

We also conducted a web-based validation study (206 native speakers of English without vision problems) and a corresponding lab-based study (17 native speakers of German without vision problems) to ensure that a verbal encoding strategy was not a viable means to distinguish the color stimuli used in Experiment 1. In these studies, participants were asked to name the color stimuli as accurately and distinctively as possible by typing the name into a text box that was placed below the color. The color stimuli were presented one by one in a sequence similar to the one used in Experiment 1 (see Section 2.1.1.3). Related color patches (e.g., all color patches representing instances of blue) were presented in a row, starting with the pure color patch (the reference color in Experiment 1) followed by all other variations of the same color in random order. Each group of colors appeared twice during the study. The order in which the groups of colors were presented was randomized across participants. Participants applied different names to colors distinct from the pure instance of the color (e.g., *light blue* vs. *blue*) in 61% (*SD* = 21%) of all cases in the web-based study and in 54% (*SD* = 25%) in the lab-based study. However, a verbal encoding strategy could be regarded as effective only if participants were able to provide different names to distinct colors in consistent manner. For this reason, we computed the proportion of color naming responses in which participants assigned a verbal label distinct from the label assigned to the pure instance of the color and applied the same label in both appearances of the same color. The mean percentage across participants was 21% (*SD* = 10%) in the web-based study and 21% (*SD* = 10%) in the lab-based study as well. Thus, despite having time and opportunity to develop effective verbal encoding strategies and despite being explicitly instructed to apply accurate and distinct verbal labels to the experimental color stimuli, participants in the validation studies failed to do so in the majority of cases.

2.1.1.2. Verbal stimuli. As verbal stimuli, we used six color words (*red*, *green*, *blue*, *yellow*, *cyan*, and *magenta*) that corresponded to the colors of the visual stimuli. In addition, there were six non-color words (*raw*, *great*, *best*, *yeasty*, *cosy*, and *marital*) and 12 orthographically and phonologically plausible non-words (e.g., *rop*, *gruce*, and *besk*) selected from the ARC Non-word Database (Rastle, Harrington, & Coltheart, 2002). Each non-color word and pairs of the non-words matched one of the color words in starting letter and number of letters.

2.1.1.3. Procedure. Participants performed lexical decisions on the verbal and non-word stimuli and a color-discrimination task on the visual stimuli. In each trial, a colored square (the reference stimulus) was presented in the middle of a light-grey screen for 1500 ms. Following a blank screen (500 ms) and a fixation cross (250 ms), a color word, a non-color word or a non-word was shown in black letters (Arial, 20 pt) in a white rectangle in the middle of the screen until participants provided a lexical decision via key presses. Subsequently, a second colored square (the test stimulus) appeared whose color was identical to that of the reference stimulus or differed from it gradually. Participants' task was to indicate via key presses whether or not the color of the test stimulus was identical to that of the reference stimulus. After a blank screen (2500 ms) and a fixation cross (250 ms), the next trial started. Thirty-six trials were experimental trials that included a color word as the target stimulus of the lexical decision task. In half of these trials, the color word matched the verbal label of the colors of test and reference stimulus, in the other half, it named the complementary color (e.g., *yellow* if test and reference stimuli were blue). In 24 experimental trials, the color of both test and reference stimulus was the original pure color, requiring a yes-response in the color-discrimination task. In 12 experimental trials, the color of the test stimulus was the modified color that was easily distinguishable from the original color, requiring a no-response. In addition, there were three types of filler trials. (1) Twelve filler trials included color words, half of which matched or mismatched the color of the reference and test stimulus, and as test stimuli a modified color that was difficult to distinguish from the original color. This type of more demanding filler trials was included to keep participants' attention focused on the color-discrimination task. (2) Forty-eight filler trials included non-color words. These trials were yoked to the 48 experimental and filler trials with corresponding color words. They were incorporated to prevent participants from developing color-related response strategies. (3) Ninety-six filler trials included non-words. These trials were yoked to the trials with corresponding color or non-color words. Thus, each color word, non-color word, and non-word was presented eight times during the experiment, twice with the same pair of color stimuli. Filler and experimental trials were presented in random order.

2.1.1.4. Design. For the lexical decision latencies as dependent variable, the design was a repeated-measurements design with color/color-word match vs. mismatch as the only independent variable. For the color-discrimination latencies, the design was a 3(color/color-word match vs. color/color-word mismatch vs. non-color word) $\times$ 2(test and reference color identical vs. different) repeated-measurements design. All colors appeared in equal proportions in each cell.

2.2. Results and discussion

Response latencies deviating more than three standard deviations from the condition mean (4% of all latencies) were removed from the data.

2.2.1. Accuracy

The proportion of correct responses to color words in the lexical decision task was high ($M = .90$, $SD = .11$) and did not differ between experimental conditions, $F(1,29) = 0.8$, $p = .38$. Likewise, the proportion of correct color-discrimination responses in the experimental conditions was high ($M = .87$, $SD = .09$) and differed only between test colors that were identical to the reference color ($M = .94$, $SE_M = .01$) and those that were different ($M = .77$, $SE_M = .03$), $F(1,29) = 32.0$, $p < .001$, $\eta_p^2 = .53$. However, it did not depend on word type (matching vs. mismatching color words vs. non-color words), with $F(1,29) < 0.7$ for the main effect and $F(2,58) = 1.8$, $p = .17$ for the interaction effect. Thus, there was no indication that the latency data might be confounded by a speed-accuracy trade-off.

2.2.2. Lexical decision latencies

As predicted, the lexical decision latencies for correct responses were shorter for color words that matched the reference color ($M = 925$, $SE_M = 42$) compared to those that did not match ($M = 978$, $SE_M = 40$), $F(1,29) = 4.2$, $p < .05$, $\eta_p^2 = .13$. Apparently, access to the meanings of color words was facilitated when matching colors had been processed immediately before. Still, due to the fact that the lexical decision task is a verbal task, it cannot be ruled out completely that the match–mismatch effect is actually due to a conflict between verbal representations activated by the reference color and the target word.

2.2.3. Color-discrimination latencies

There was a main effect of matching color words vs. mismatching color words vs. non-color words on the color-discrimination latencies, $F(2,58) = 3.5$, $p < .05$, $\eta_p^2 = .10$ (Fig. 1a). As expected, responses were faster when the test color and the preceding color word matched ($M = 742$, $SE_M = 22$) compared to when they did not match ($M = 793$, $SE_M = 27$; $t(29) = -2.2$, $p < .017$, one-tailed). The color-discrimination latencies for colors preceded by non-color words ($M = 758$, $SE_M = 21$) showed a tendency to be shorter than latencies for colors preceded by mismatching color words ($t(29) = -1.8$, $p = .04$) but did not differ significantly from latencies for colors preceded by matching color words ($t(29) = 1.0$, $p = .17$, one-tailed; for all follow-up t-tests, the α-level was adjusted by Holm-Bonferroni correction for multiple comparisons). Given that the trials with non-color words may be regarded as a kind of neutral control condition, these results indicate that the color representations activated by mismatching color words interfered with color-discrimination judgments. In contrast, there was no clear indication of a facilitating effect of matching color words.

In addition, responses to test colors that were identical to the reference color (yes-responses) were faster ($M = 700$, $SE_M = 23$) than responses to test colors that were different from the reference color (no-responses, $M = 829$, $SE_M = 26$), $F(1,29) = 21.6$, $p < .001$, $\eta_p^2 = .43$. There was no interaction effect of the two independent variables, $F(2,58) = 0.1$. Thus, color-discrimination responses were slowed down by preceding words that mismatched the test color, regardless of whether the test color differed from the reference color and regardless of the required response.

It could be argued that the pattern of data reported here is due to a verbal labeling strategy. However, two findings militate against this interpretation: (1) if participants had used such a strategy, color-discrimination responses in the trials with non-color words would have been slowed down to the same extent as in the trials with mismatching color words. (2) As our validation studies showed, even when given ample time to label and when instructed to apply distinct color labels, participants were unable to provide distinct and consistent labels for the different shades within a color. Of course, the data from the validation study do not completely rule out the possibility that some participants might have used a verbal encoding strategy as an additional memory aid. Nevertheless, they show quite clearly that participants must have relied mainly on perceptual processes in order to provide reliable color-discrimination judgments.

In sum, the lexical decision and the color-discrimination latencies provide converging evidence for the assumption that color representations are activated in the processing of color words. While the match–mismatch effect in the lexical decision task might be interpreted as a conflict among a verbal label that participants have given to the reference color and the color word, such an explanation seems highly unlikely for the match–mismatch effect in the color-discrimination task. Still, the fact that a lexical decision task was used in Experiment 1 somewhat limits the interpretation of the color-discrimination data. Lexical decisions require semantic processing of the verbal stimuli.

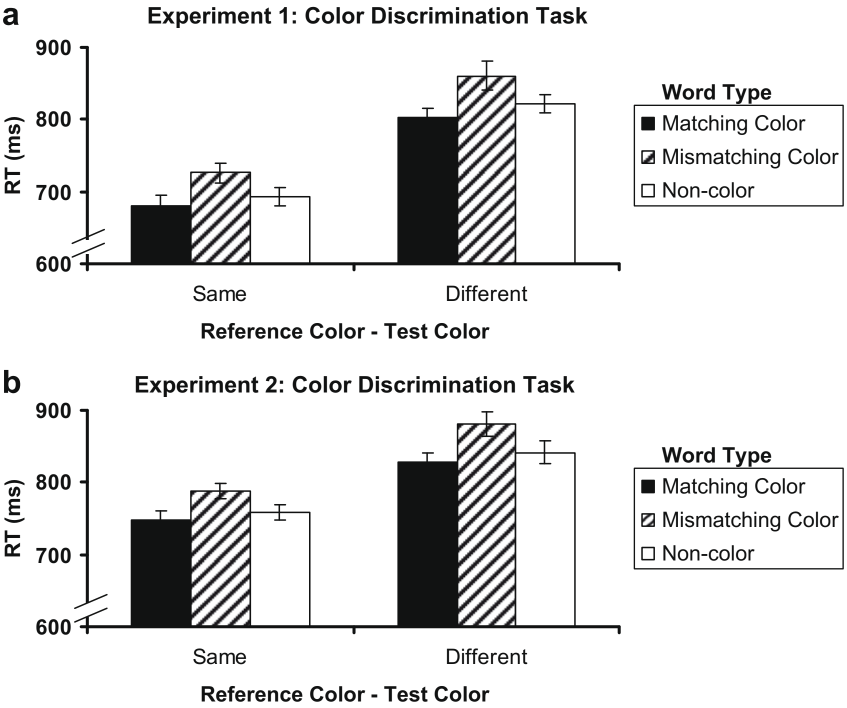

Fig. 1. Effects of matching color words, mismatching color words, and non-color words on color-discrimination latencies for yes-responses (reference and test color are the same) and no-responses (reference and test color are different) in Experiment 1 (a) and Experiment 2 (b).

Accordingly, the effects of matching vs. mismatching words on the color-discrimination latencies might reflect specific response strategies rather than the routine activation of color representations. We conducted a second experiment to rule out this possibility.

3. Experiment 2

Experiment 2 replicated Experiment 1 except for one important difference. The stimulus words were merely presented to the participants without any task instructions. This way, Experiment 2 was designed to detect the routine activation of color representations by color words. The predictions were identical to the predictions for the color-discrimination task in Experiment 1.

3.1. Method

3.1.1. Participants

Participants were 41 psychology undergraduates at Florida State University.

3.1.1.1. Stimuli and procedure. Stimuli and procedure were identical to Experiment 1 with the exceptions that the words and non-words were presented auditorily and participants did not perform any task on these stimuli. Each trial started with the reference stimulus (1500 ms) followed by a blank screen (500 ms). Subsequently, a color word, a non-color word, or a non-word was presented auditorily to the participants over headphones. The words and non-words were read by a standard computerized male voice. The test stimulus appeared 700 ms after the onset of the presentation of the word or non-word, and participants performed a color-discrimination judgment on this stimulus. After a blank screen (2500 ms) and a fixation cross (250 ms), the next trial started.

3.1.1.2. Design. The design was a 3(color/color-word match vs. color/color-word mismatch vs. non-color word) × 2(test and reference color identical vs. different) design with repeated measurements on both variables.

3.2. Results and discussion

Response latencies deviating more than three standard deviations from the condition mean (2.5% of all latencies) were removed from the data.

3.2.1. Color-discrimination accuracy

The proportion of correct color-discrimination responses in the experimental conditions was higher for test colors that were identical to the reference color ($M = .90$, $SE_M = .01$) compared to those that were different ($M = .85$, $SE_M = .01$), $F(1,40) = 10.5$, $p < .001$, $\eta_p^2 = .21$. Moreover, responses were more accurate when the test color was preceded by a matching color word ($M = .89$, $SE_M = .01$) or a mismatching color word ($M = .90$, $SE_M = .01$) compared to a non-color word ($M = .82$, $SE_M = .01$), $F(2,80) = 10.9$, $p < .001$, $\eta_p^2 = .21$. Importantly, none of the accuracy effects indicated that a speed-accuracy trade-off was present in our data.

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3.2.2. Color-discrimination latencies

An analysis of the color-discrimination latencies revealed a main effect of matching color words vs. mismatching color words vs. non-color words, $F(2,80) = 4.6$, $p < .05$, $\eta_p^2 = .10$ (Fig. 1b). As in Experiment 1 and in line with our predictions, responses were faster when the test color was preceded by a matching ($M = 788$, $SE_M = 23$) compared to a mismatching color word ($M = 835$, $SE_M = 29$; $t(40) = -3.0$, $p < .017$, one-tailed). In addition, color-discrimination responses to colors preceded by non-color words tended to be faster ($M = 800$, $SE_M = 23$) than responses to colors preceded by mismatching color words ($t(40) = -1.9$, $p = .03$, one-tailed) but their speed did not differ from responses to colors preceded by matching color words ($t(40) = 0.9$, $p = .20$, one-tailed; for all follow-up t-tests the α-level was adjusted by Holm-Bonferroni correction for multiple comparisons). Similar to Experiment 1, this pattern of effects suggests that the color representations activated by mismatching color words interfered with color-discrimination judgments.

Moreover, responses to test colors that were identical to the reference color were again faster ($M = 773$, $SE_M = 20$) than responses to test colors that were different ($M = 860$, $SE_M = 37$), $F(1,40) = 11.4$, $p < .01$, $\eta_p^2 = .22$. There was no interaction effect of the two independent variables, $F(2,80) = 0.7$.

In sum, Experiment 2 replicated the finding that color-discrimination responses were facilitated by preceding words that matched the test color. Even though the color words were merely presented to the participants without any specific task, they exerted an influence on perceptual judgments, suggesting that color representations are routinely activated when color words are processed.

4. General discussion

In two experiments, color-discrimination judgments were slowed down by the processing of color words that were incongruent with the target color. Experiment 1 provided additional evidence for an analogous reverse effect of color processing on lexical decisions. Experiment 2 established interference of incongruent color words with color-discrimination judgments even when no semantic task had to be performed on the color words. In both experiments, color-discrimination responses after processing mismatching color words were also slowed down relative to a neutral condition with non-color words whereas responses after matching color words did not differ from the neutral condition. This pattern of effects is inconsistent with an explanation in terms of verbal labeling.

Theoretically, these findings support the assumption that color representations are routinely activated when color words are processed. They are compatible with the idea that upon reading or hearing a color word, participants engage in a perceptual simulation that involves the same kind of representations that are also used in color perception. The effects that we found for color words run parallel to those obtained for linguistic expressions that convey shape, orientation, or motion information (Zwaan, 2004). However, they do not support the assumption that color representations in language comprehension are used in a way different from other types of perceptual information, as Connell (2007) has suggested. Most likely, the apparent contradictions between Connell's finding of a mismatch advantage and our findings are due to procedural differences, in particular the fact that Connell used color-implying sentences while we used color words as linguistic stimuli. It is conceivable, for example, that the simulation of color during comprehension is a local and short-lived phenomenon occurring as soon as the relevant information is encountered and dissipating quickly. To clarify this question, research on the time-course and the dynamics of color activation during sentence comprehension is needed.

Methodologically, the paradigm proposed here provides a new means to examine the role of perceptual representations in word processing independently from response effects. As such, it might be applied to investigations of Stroop effects as well as questions in the area of language comprehension. According to the experiential view, for instance, words denoting color-diagnostic objects should elicit a pattern of effects similar to the one that we found for color words. It also seems promising to expand the paradigm for studying the role of color in the comprehension of more comprehensive expressions such as compound nouns and sentences.

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