The Effect of the Color Red on Encoding and Retrieval of Declarative Knowledge

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Abstract

Studies on color psychology have demonstrated that the color red impairs cognitive performance in achievement situations. This study extends this line of research to the context of learning. One hundred and ninety students of a secondary school were instructed to memorize a short text (encoding phase). Subsequently, they were administered a knowledge test and a measure of cognitive load (retrieval phase). The experimental design manipulated the color (red versus gray) of the stimulus material during the encoding and the retrieval phase. For boys, repeated color exposure affected test performance more strongly than color presentation during a single phase. In contrast, for girls, a single color manipulation impaired knowledge retrieval, whereas repeated exposure to red had no effect. Descriptive analyses identified similar effects for cognitive load.

Keywords: color, red, learning, knowledge, cognitive load

The Effect of the Color Red on Encoding and Retrieval of Declarative Knowledge

Colors are omnipresent in our daily lives, including the places where we study and take our exams. Although colors are often used for mere esthetic reasons, they carry psychological meaning and have notable behavioral implications (for a current review, see Elliot & Maier, 2014). In educational settings, recent research has shown that the color red impairs cognitive performance in challenging tasks (e.g., Elliot, Maier, Moller, Friedman, & Meinhardt, 2007; Gnambs, Appel, & Batinic, 2010; Ioan et al., 2007; Shi, Zhang, & Jiang, 2015). These results are based on the idea that red evokes an avoidance motivation that, in turn, hampers performance in tasks that require intelligent thinking, creativity, or both (Elliot et al., 2007; Maier, Elliot, & Lichtenfeld, 2008; Mehta & Zhu, 2009; Tanaka & Tokuno, 2011). Extending prior research in color psychology, the present study examined color effects for learning outcomes in the context of a regular school lesson which involved a color manipulation at the stage of knowledge encoding and at the stage of knowledge retrieval. Moreover, potential gender differences in the effects of red color on learning and the role of cognitive load as a mediator of the color effect were taken into account.

The Color Red and Performance

Recent research has shown that red impedes performance in basic cognitive ability tasks (cf. Elliot & Maier, 2014). For example, when the participant number on an exam sheet was presented in red color (vs. green or black), participants performed worse in an anagram test. Moreover, participants performed worse in an intelligence subtest (analogies or number series) when an introductory test booklet sheet was colored red (vs. green or white, Elliot et al., 2007; see also Elliot, Payen, Brisswalter, Cury, & Thayer, 2011). Results further suggested that processes triggered by avoidance motivation (i.e., an initiation of behavior away from negative stimuli; Elliot, 2006), mediated this detrimental effect of red on cognitive performance. This assumption was supported in a subsequent series of experiments focusing on fluid intelligence measures (Maier et al., 2008). Although the effect of avoidance motivation induced by red color seems to depend on the specific task at hand—for example, red color facilitated performance on detail-oriented cognitive tasks such as proofreading (Mehta & Zhu, 2009)—most studies in the cognitive domain demonstrated poorer performance for respondents facing red (Elliot, Maier, Binser, Friedman, & Pekrun, 2009; Shi et al., 2015; Tanaka & Tokuno, 2011). Even simply reading the word 'red' resulted in lowered fluid intelligence test scores (Lichtenfeld, Maier, Elliot & Pekrun, 2009).

Despite ample evidence of the negative influence of red color on various measures of cognitive performance, research on the effects of red color has neglected a fundamental component of cognitive functioning: learning. In contrast to the performance in cognitive ability tests, learning consists of the encoding of new information into memory and the retrieval of information at a later point of time. Information encoding and retrieval are two distinct processes (Rutherford, Markopoulos, Bruno, & Brady-Van den Bos, 2012). Research within the framework of environmental context-dependent memory (cf. Smith & Vela, 2001) highlighted that the nature of the context during the encoding phase and during the retrieval phase can interact: Memory performance was better when the environment during encoding and the environment during information retrieval were similar, as compared to instances in which the environment changed. In this sense, colors as salient perceptual cues of the environment may differentially affect learning and later retrieval processes, depending on whether environmental colors change or do not change between learning and retrieval phases. Thus, the effects of the repeated use of the color red may not readily extrapolate from previous research, which involved red color cues at only one point of time. The present study aimed to fill this empirical gap regarding the effects of repeated color exposure.

Gender Differences in the Influence of the Color Red on Performance

Some of the previous studies found similar color effects for both genders (e.g., Maier et al., 2008; Mehta & Zhu, 2009), but others found a stronger effect of the color red on male than on female participants (Gnambs et al., 2010; Hill & Barton, 2005; Ioan et al., 2007;

Shibasaki & Masataka, 2014). For example, Gnambs and colleagues (2010) showed that men (but not women) scored significantly lower on a web-based general knowledge test when parts of the survey page were colored red as compared to green. Two lines of reasoning hint at potential gender differences in the effects of the color red:

On the one hand, red acts as a sign of danger and a trigger of avoidance motivation in achievement situations (Maier et al., 2008). On average, women score higher on avoidance motivation than men (Carver & White, 1994), and they have been found to perceive more danger in achievement situations than men, who perceive more danger in situations of affiliation (Pollak & Gilligan, 1982). Thus, one may suggest that women are more sensitive to red color as a warning signal in achievement contexts and, hence, have a lower threshold for reacting with avoidance motivation. In partial support of this assumption, some results on the detrimental effect of the color red were based on exclusively or predominantly female samples (cf. Elliot et al., 2007, 2009; Shi et al. 2015).

On the other hand, in many Western societies reddish colors are associated with girls, and dark colors (e.g., brown, black, gray, and blue) are associated with boys (cf. Boyatzis & Varghese, 1994). In line with these dominant cultural schemes, many parents raise their children accordingly (Shakin, Shakin, & Sternglan, 1985). Manufacturers of toys use gender-specific coloration (as can be impressively seen when googling images with the search terms “toys for girls”). Therefore, women likely associate many positive experiences with red and it may be a color with outstanding positive valence for them. Many objects colored red are desirable for girls (and women, e.g., a red rose or nail polish) and, hence, induce approach motivation (i.e., an impulse directed to go toward a positive goal; Elliot, 2006). In contrast to men, women are more likely to prefer red, purple, and pink (Cohen, 2013). Accordingly, Hurlbert and Ling (2007) found cross-cultural gender differences in participants’ color preferences indicating some biological origin. Women favored reddish colors, men preferred blue and green. The preference for red color could reduce the red color effect, particularly when women are exposed repeatedly to this favored color. This assumption is supported by a recent study showing that the repeated presentation of red distorts time perception in men but not in women (Shibasaki & Masataka, 2014), indicating “a sex difference in the emotional valence of red” (p. 3).

Consequently, there are two arguments to expect gender differences in color effects on learning: there is evidence for gender differences in red-sensitive avoidance motivation as well as evidence for gender differences in the preference for red on the behavioral and biological level. This possible gender by color interaction might yield important practical implications for the field of learning with respect to gender-fair learning materials at school.

Study Overview and Predictions

All previous studies on color red realized one-shot designs in which the color manipulation either preceded a task or was applied during task processing (e.g., Elliot et al., 2007; Gnambs et al., 2010; Maier et al., 2008). Whereas one-shot designs are appropriate for the study of cognitive performance investigated in these studies, the context of learning requires a repeated measures design, since learning paradigms comprise two processes: learning and retrieval. Hence, in the present study, color was independently manipulated during the encoding and during the retrieval phase of learning. In this context, we assumed a gender-specific effect of the color red: males who show a lower preference for red color should perceive it as the common warning signal for danger in achievement contexts (cf. Elliot et al., 2007). Due to a potential gender effect in the emotional valence of red, seeing red should induce avoidance but not approach motivation in males (Shibasaki & Masataka, 2014). However, as males perceive less danger in achievement situations than females (Carver & White, 1994; Pollak & Gilligan, 1982) the effect of red should be smaller when presented only at one time, that is, either in the learning phase or in the retrieval phase. Consequently, a red color treatment during a learning phase as well as during a later retrieval phase should reduce males’ performance more than color exposure exclusively during learning or retrieval.

H1: For boys, red color during the encoding and retrieval phase impairs test performance more strongly than a control condition with gray color or conditions with red presented only in one of the two phases.

For females—having a stronger preference for red—two competitive mechanisms should occur: on the one hand, like males, they should initially perceive red as the common signal for danger (Elliot et al., 2007), and because they perceive more danger in achievement situations in general, avoidance motivation should be triggered faster in comparison to males. This is the process that has apparently driven results of previous studies in which the majority of participants were females (e.g., Elliot et al., 2007; Shi et al. 2015). On the other hand, red should also evoke approach motivation among females when presented in the same context later once again. Because of the identical content of the tasks in the learning and retrieval phase, the same color presented twice contributes to a familiar learning context (e.g., Brinegar, Lehman, & Malmberg, 2013). This should facilitate the positive effect of red on approach motivation in females, that is, red should lose its initially impeding nature in the retrieval phase and approach motivation should be the dominant mechanism, due to the generally positive valence of red for women (cf. Shibasaki & Masataka, 2014). Consequently, we expect that the presentation of red during learning and later retrieval will result in no performance difference compared to a control condition in which gray is used.

H2: For girls, red color cues during the encoding and retrieval phase do not impair test performance as compared to a control condition with gray color.

Finally, several studies (e.g., Maier et al., 2008; Mehta & Zhu, 2009) have demonstrated that the detrimental effect of red color in performance settings is triggered by avoidance motivations. Avoidance motivation has several negative consequences, such as affective reactions (e.g., worries, self-doubts), a shift of attention toward potential threatening cues, and the initiation of various self-protecting behaviors (Roskes, Elliot, & De Dreu, 2014). All these processes are effortful and strain the cognitive system (Elliot, Schüler, Roskes, & De

Dreu, 2014). The concept of cognitive load represents the amount of cognitive processing in which a subject is engaged (Paas & van Merrienboer, 1993). Since cognitive resources are limited, avoidance motivations increase cognitive load, with detrimental effects for the specific task at hand. Thus, red might inhibit task performance by increasing people's cognitive load. One previous study provided initial evidence for this view and demonstrated that red enhanced cognitive load in males (Ioan et al., 2007). Accordingly, in line with the previous hypotheses, we expected red color cues to increase cognitive load and thus lead to differences in test performance for girls and boys:

H3: (a) For boys, cognitive load should be higher when red is presented during the encoding as well as retrieval phase in comparison to conditions with gray color or red presented only in one of the two phases. (b) For girls, a single presentation of the color red, either in the encoding or in the retrieval phase, will result in increased cognitive load in comparison to a repeated color exposure or a gray control condition.

Method

Participants

The sample included 191 students (126 girls) aged M=16.55 years (SD=1.49). All students attended an Austrian secondary school: 48% attended grade 9, 34% were in grade 10, 10% attended grade 11, and 8% were in grade 12. The testing was conducted in 13 groups of seven to 26 students by a trained research assistant. One student was excluded from analyses because he failed the test for color blindness (Ishihara, 1985).

Procedure

After arrival in class, students were seated at their computer terminals and informed that they were about to begin a study on the "Learning of Historical Facts". The entire experimental procedure followed five steps:

First, all students received an initial computer-based questionnaire assessing general demographic information, subjective knowledge on medieval dining customs, and general memory ability. Second, the participants worked on a paper-based learning task for 14min. Third, after finishing the learning phase, the students were allowed to individually engage in playing computer games unrelated to this research for 20min. Fourth, the students were given 8min to finish the paper-based knowledge test. Fifth, all students were administered a computerized Stroop test and Ishihara's (1985) test for color blindness. Finally, the participants were asked about the putative purpose of the study and debriefed. None of the students guessed the purpose of the experiment.

The presented procedure allocated each student randomly to one of four experimental conditions created by manipulating color cues of the learning text and of the knowledge test. Taking into account the gender of the participants, the experiment followed a 2 (learning text: gray or red color cue) x 2 (knowledge test: gray or red color cue) x 2 (gender) between-subject design. By random assignment, 50 participants (32 girls) received a gray learning text and a gray knowledge test whereas 48 students (34 girls) were administered both materials with red color cues. In contrast, 45 (30 girls) participants received only the learning text and 47 participants (29 girls) received only the knowledge test in red. The four conditions did not significantly vary with regard to sex or grade level, *p*s > .60.

Material and Experimental Manipulations

Learning material and color manipulation. Each student received a booklet containing the learning text on medieval dining customs adapted from previous research (Poekl, 2005). The booklet included eight pages (a title page and seven pages with learning text) and described typical food, beverages, and table manners in medieval times. The booklet was designed to mimic a contemporary learning text as used in school; for example, it was divided into several chapters, included pictures to support the text, and highlighted important passages visually. Using the cover page procedure from Elliot and colleagues (2007; see also Elliot et al., 2011; Maier et al., 2008), each student was randomly allocated to one of two experimental color conditions by either including a gray or a red color cue in the booklet.

Prior studies have demonstrated that in achievement situations, other control colors (e.g., green or blue) evoke identical effects as gray (e.g., Elliott et al., 2007, 2009). In the red color condition, the first page of the booklet contained the title "The Medievals" in a red rectangle (1 x 7.3 in.). In terms of the hue-saturation-luminosity (HSL) scheme used to represent colors, we specified a "pure" red color (HSL: 0/100/50). In the control group, the title was colored in gray (HSL: 0/0/50); thus, the two colors were matched on luminosity. On each of the subsequent pages of the booklet, the same title was included at the top of the page in a similar rectangle (0.6 x 2.3 in. in size) in the same color as on the first page. Other than the color manipulation, the booklets in both conditions were identically black and white.

Declarative knowledge test and color manipulation. Based on the learning material, a knowledge test containing 20 open-ended questions on medieval dining customs (e.g., *"Which vegetable was despised by nobility as 'peasant food'?"*) was constructed. The items were handed out in a booklet of three pages (a title page and two test pages). Here, our second color manipulation took place. For about half the students (random assignment), a red color cue was added to the knowledge test. The color manipulation for the knowledge test closely followed the procedure for the learning text. Thus, in the experimental condition, the title "The Medievals" was printed in a red rectangle on the first page; the subsequent pages included a similar rectangle at the top of each page. The control group received the knowledge test with gray color cues. Other than this color manipulation, the knowledge test was identical in both conditions. The sum of correct answers represented our measure of declarative knowledge. The scale resulted in a mean of $M = 12.04$ ($SD = 4.66$) and a good coefficient alpha reliability of .92.

Cognitive load. Cognitive load was measured using a computerized, numeric stroop task (Girelli, Lucangeli, & Butterworth, 2000). At each trial, respondents were presented with two single-digit numbers (e.g., 3 and 4). For stimulus-congruent trials, the number with the larger value was printed in a larger font; whereas in stimulus-incongruent trials, the number with the smaller value was larger. For each trial, respondents had to indicate as quickly as possible which number had the larger value by pressing one of two keys on the keyboard; response time in milliseconds was the variable of interest. The test consisted of 32 trials (16 congruent and 16 incongruent) presented in random order for each respondent. Extreme response times were identified for each participant using the non-recursive outlier removal procedure proposed by Van Selst and Joliceur (1994). This removed less than 3% of the reaction times for correct trials. A separate score was created for the stimulus-congruent trials and for the stimulus-incongruent trials by calculating the means of the response times for the correctly solved trials. As expected, stimulus-congruent trials ($M = 670.64$, $SD = 150.26$) resulted in significantly lower scores than stimulus-incongruent trials ($M = 714.58$, $SD = 153.97$), $t(189) = -7.72$, $p < .001$, $d = -0.29$. Cognitive load was operationalized as the difference in scores for the stimulus-incongruent and -congruent tasks; thus, high values indicate stronger cognitive load. The scale resulted in a mean of $M = 43.94$ ($SD = 78.48$) and a good coefficient alpha reliability of .94.

Subjective knowledge (baseline). Subjective knowledge on medieval dining customs was measured with three items. The respondents indicated on four-point scales from 0 (very little) to 3 (very much) how much they knew about (a) food, (b) beverages, and (c) table manners in medieval times. The sum score of these items had a mean of $M = 2.14$ ($SD = 0.64$) and a good coefficient alpha reliability of .87.

General memory ability (baseline). Baseline memory ability was assessed with a subtest of the Berlin Intelligence Structure Test (Jäger, Süß, & Beauducel, 1997). Participants had one minute to memorize several facts regarding a fictitious event presented as a short 85-word text. Afterwards, the amount of information they were able to remember was captured with 22 open-ended questions. The sum of correct answers represented the measure of general memory ability. The scale resulted in a mean of $M = 6.63$ ($SD = 3.53$) and a good coefficient alpha reliability of .85. The correlations between all cognitive measures are summarized in Table 1.

Results

It was hypothesized that for male students, repeated exposure to the color red would result in poorer test performance than for boys in the other conditions, whereas female students would not show differences in test scores. To test this hypothesis, test performance was regressed on the dummy-coded indicators for the color of the learning test (0=gray, 1=red), the color of the knowledge test (0=gray, 1=red), the sex of the respondents (0=female, 1=male), and the respective interactions. To account for the dependencies resulting from students being grouped within different school classes, we specified a multilevel model and thus conducted mixed effects regression analyses using a robust full information maximum likelihood algorithm (Asparouhov & Muthén, 2003). These analyses model the data on two hierarchical levels: Level 1 refers to the $N_{\text{Level 1}} = 190$ students, whereas Level 2 comprises the $N_{\text{Level 2}} = 13$ classes. In line with our hypotheses, the mixed effects regression resulted in a significant, $p = .02$, interaction between the color of the learning text and the color of the knowledge test (Model 1 in Table 2), while this interaction was additionally moderated by the sex of the respondents, $p < .001$. This effect was robust and remained significant even after controlling for participants' age, subjective knowledge, and baseline memory abilities (Model 2).

Gender Differences

To examine the form of the interaction more closely, we repeated the regression analyses separately for boys and girls. For boys, the color cues on the learning text and the knowledge test had a significant, $p = .002$, interaction effect on test score performance (Model 3 in Table 2). This effect was robust and remained significant after including the control variables (Model 4). To study the form of the interaction in more detail, we estimated a linear contrast (Abelson & Prentice, 1997; Harrell, 2001). According to Hypothesis 1, boys receiving both booklets with red color cues were expected to have lower test scores than students receiving only one booklet with red cues or students in the control condition. The respective linear contrast with design weights of +1 [gray text - gray test], +0.5 [red text - gray test], +0.5 [gray text - red test], and -2 [red text - red test], *Contrast* = 5.03, *SE* = 2.02, $p = .01$, supported the hypothesis that repeated exposure to the color red results in lower test performance for boys than a single presentation of red, either during knowledge encoding or retrieval (right bar in Figure 1).

For girls, the color of the learning text and the color of the knowledge test also had a significant, $p = .02$, interaction effect on knowledge test scores (Model 5 in Table 2). Even after controlling for potentially confounding variables, the predicted effect was observable and significant (Model 6). In line with our expectations (H2), a linear contrast with design weights of +1 [gray text - gray test], -1 [red text - gray test], -1 [gray text - red test], and +1 [red text - red test] identified a significant decline in knowledge test performance for female students receiving only one booklet with a red color cue (see middle bars in Figure 2) as compared to the other two conditions, *Contrast* = 2.82, *SE* = 1.18, $p = .02$. This significant effect indicates that the color red—either during the knowledge encoding or the retrieval phase—resulted in lower test performance, whereas repeated exposure to the color red did not have an effect compared to the control condition (gray color during encoding and retrieval phase).

Differences in Cognitive Load

It was hypothesized that the effect of the color red would be the consequence of differences in cognitive load (H3); red color was expected to increase cognitive load for male students and, thus, to lead to poorer test performance. Descriptive analyses supported the influence of red color on cognitive load: Boys had higher scores on the Stroop test and, thus, exhibited higher cognitive load after receiving booklets with red color on the learning text and the knowledge test ($M = 61.90$, $SD = 67.08$), as compared to the condition without any red color (*M* = 27.74, *SD* = 86.18), or the conditions with a red color cue on the learning text only (*M* = 47.87, *SD* = 65.56) or the knowledge test only (*M* = 40.36, *SD* = 55.35). However, a linear contrast with design weights of +1 [gray text - gray test], +0.5 [red text - gray test], +0.5 [gray text - red test], and -2 [red text - red test] could not confirm the descriptive trend, *Contrast* = 49.91, *SE* = 44.97, *p* = .27.

For girls, we expected that a single presentation of the color red, either on the learning text or on the knowledge test, would result in increased cognitive load. Descriptive analyses partially confirmed the expected pattern of effects. Girls exhibited stronger cognitive load after receiving only the learning text with a red color cue (*M* = 56.22, *SD* = 93.36) as compared to the conditions with no color cues (*M* = 47.78, *SD* = 73.95) or repeated color presentation (*M* = 33.04, *SD* = 81.30). Contrary to expectations, participants receiving only the knowledge test with a red color cue (*M* = 38.90, *SD* = 88.65) also exhibited similar cognitive load to the latter conditions. As a consequence, the respective linear contrast (design weights: +1 [gray text - gray test], -1 [red text - gray test], -1 [gray text - red test], +1 [red text - red test]), *Contrast* = 15.25, *SE* = 43.45, *p* = .73, did not reveal a significant effect.

Thus, although the effect sizes showed meaningful trends in the expected direction for boys and partially for girls, indicating that the color red increased cognitive load, the respective effects could not be confirmed statistically due to substantial between-subject variance within the different color conditions.

Discussion

A number of studies in recent years have demonstrated that the color red impairs performance in intellectual tasks (see Elliot & Maier, 2014). So far, all studies were limited to tasks with a single color manipulation. Little was known about repeated color exposure and potential habituation or amplification effects of red color. Research on environmental context-dependent memory suggests that the repeated use of the same color can contribute to better memory; thus, color manipulations at the stages of encoding and retrieval might have an interactive influence on learning. Therefore, this study examined the interdependent effects of color exposure during the encoding of new information and at the stage of knowledge retrieval. In line with previous research (e.g., Gnambs et al., 2010; Ioan et al., 2007; Shibasaki & Masataka, 2014), we identified pronounced gender differences in the effect of red color. For boys, repeated presentation of the color red had a negative influence of red on knowledge test scores. In contrast, for girls, repeated red color exposure had no negative effect, whereas a single color manipulation—either during information encoding or knowledge retrieval—had the expected detrimental effect.

Extending research on motivational mediators of the color red effect (cf. Maier et al., 2008), we examined whether red might also affect performance through increased cognitive load. Our results could not clearly confirm this hypothesis: whereas descriptive means showed a similar gender-specific pattern, these differences were not supported statistically. The observed color effect on cognitive load was considerably smaller than the respective effect on test performance. Therefore, differences in the current amount of cognitive processing seem to represent only a partial route through which red affects cognitive performance. Moreover, unaccounted individual differences in, for example, trait motivation or self-control strength might further moderate this effect (Baumeister, Muraven, & Tice, 2000; Roskes, Elliot, Nijstad, & De Dreu, 2013). In light of the unclear findings, this process should be explored in future research.

Nevertheless, these results carry intriguing implications for the design of learning material. For example, many educational specialists recommend the “pedagogical use of color” (Ogan-Bekiroglu, 2007, p. 627) to highlight important passages in textbooks. Moreover, creators of digital learning environments frequently adopt various color schemes merely for esthetic reasons (Lim, Song, & Lee, 2012). However, in light of the presented results, the indiscriminate use of the color red should be re-evaluated in these contexts. Although red might be used to focus students’ attention on certain content, it also seems to impair learning effectiveness. Moreover, the gender by color condition interaction shows that gender-fair learning material needs to consider gender-specific color effects.

Despite the contributions of the presented study, some limitations need to be noted. The color manipulation was limited to a chromatic color (red) and an achromatic control color (gray). This procedure was adapted from previous studies (Maier et al., 2008; Gerend & Sias, 2009). However, we were not able to compare red on the basis of specific color dimensions, such as hue. Future research would benefit by including additional chromatic colors such as blue or green. Second, the interval between the encoding and retrieval phase was rather short (20min), which seems rather uncommon for most real-life situations in educational settings. The observed amplification effect of the color red for boys could possibly decrease during a longer interval between learning and knowledge retrieval phase. Third, one explanation underlying the differential effect of red color on performance for boys and girls might be derived from gender-specific differences in color preferences (cf. Cohen, 2013; Hurlbert & Ling, 2007; LaBue & DeLoach, 2011; Sorokowski, Sorokowska, & Witzel, 2014): reddish colors are typically favored by girls, whereas boys prefer blue and green. Thus, initially the color red acts as the common signal for danger (Elliot et al., 2007; Ioan et al., 2007) and activates avoidance motivation for both genders. However, subsequently, the identical task content during learning and knowledge retrieval increases task familiarity (e.g., Brinegar et al., 2013). Future research should assess color preferences empirically. Included in the present research design, these preferences might mediate the moderating influence of gender on the two-way interaction of the color red at times of encoding and retrieval (mediated moderation, cf. Edwards & Lambert, 2007). Finally, our study is the first to connect color psychology to the field of learning. Therefore, the list of limitations is not exhaustive but indicates fruitful venues for future research. For example, future studies could vary learning topics, students' age groups, the level of previous knowledge about a topic, the kind of knowledge investigated (here we tested declarative knowledge), or the mode of color presentation (e.g., using the word *red* rather than showing red-colored stimuli, cf. Lichtenfeld et al., 2009).

In sum, the present work extends the recent surge in color psychology by identifying differential effects of repeated exposure to the color red for boys and girls. These results highlight the need for future longitudinal research that examine habituation and amplification effects of the color red on cognitive performance in more detail.

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Table 1.

Means, Standard Deviations, and Correlations between Cognitive Measures

	M	*SD*	1.	2.	3.	4.
1. Declarative knowledge	12.04	4.66	*.92*			
2. Subjective knowledge	2.14	0.64	.15*	*.87*		
3. Memory	6.63	3.53	.41*	.00	*.85*	
4. Cognitive load	43.94	78.48	-.09	-.02	-.09	*.94*

Note. $N = 190$. Coefficient alpha reliabilities in diagonal.

$p < .05$

Table 2.

Parameter Estimates from Regression Analyses on Knowledge Test Scores

		Total Sample						Boys					
		Model 1			Model 2			Model 3			Model 4		
		B	*SE*	β	*B*	*SE*	β	*B*	*SE*	β	*B*	*SE*	β
	Intercept	11.77*	0.60		13.57*	3.34		12.58*	1.04		12.87	8.75	
1.	Color cue of learning text [a]	-1.09	0.68	-0.24	-0.46	0.65	-0.10	1.54	1.07	0.33	1.66*	0.67	0.35
2.	Color cue of knowledge test [a]	-1.33*	0.67	-0.29	-0.94	0.65	-0.20	1.36	1.18	0.29	1.29+	0.74	0.27
3.	Sex [b]	0.71	1.01	0.15	0.96	0.71	0.21						
4.	Interaction 1. x 2.	2.80*	1.22	0.60	1.91*	0.96	0.41	-4.69*	1.53	-1.00	-4.48*	1.23	-0.96
5.	Interaction 1. x 3.	2.24*	1.06	0.48	1.37	0.96	0.29						
6.	Interaction 2. x 3.	2.75*	1.37	0.59	1.77	1.30	0.38						
7.	Interaction 1. x 2. x 3.	-7.43*	1.42	-1.60	-6.00*	1.31	-1.28						
	Control variables												
8.	Subjective knowledge				0.96+	0.51	0.21				1.36	0.89	0.29
9.	Memory				0.46*	0.08	0.10				0.51*	0.05	0.11
10.	Age				-0.42*	0.19	-0.09				-0.43	0.49	-0.10
	Random variance	3.38*			1.75+			2.44			4.22		

Note. $N = 190$. [a] 0 = gray, 1 = red; [b] 0 = female, 1 = male

* $p < .05$; + $p < .10$

Table 2 (continued).

		Girls					
		Model 5			Model 6		
		B	*SE*	β	*B*	*SE*	β
	Intercept	11.80*	0.64		13.20*	4.75	
1.	Color cue of learning text [a]	-1.07	0.68	-0.23	-0.53	0.60	-0.11
2.	Color cue of knowledge test [a]	-1.31+	0.68	-0.28	-0.98	0.67	-0.21
3.	Sex [b]						
4.	Interaction 1. x 2.	2.82*	1.18	0.61	2.04*	0.90	0.44
5.	Interaction 1. x 3.						
6.	Interaction 2. x 3.						
7.	Interaction 1. x 2. x 3.						
	Control variables						
8.	Subjective knowledge				0.89	0.60	0.19
9.	Memory				0.46*	0.12	0.10
10.	Age				-0.39	0.24	-0.08
	Random variance	3.45+			1.41		

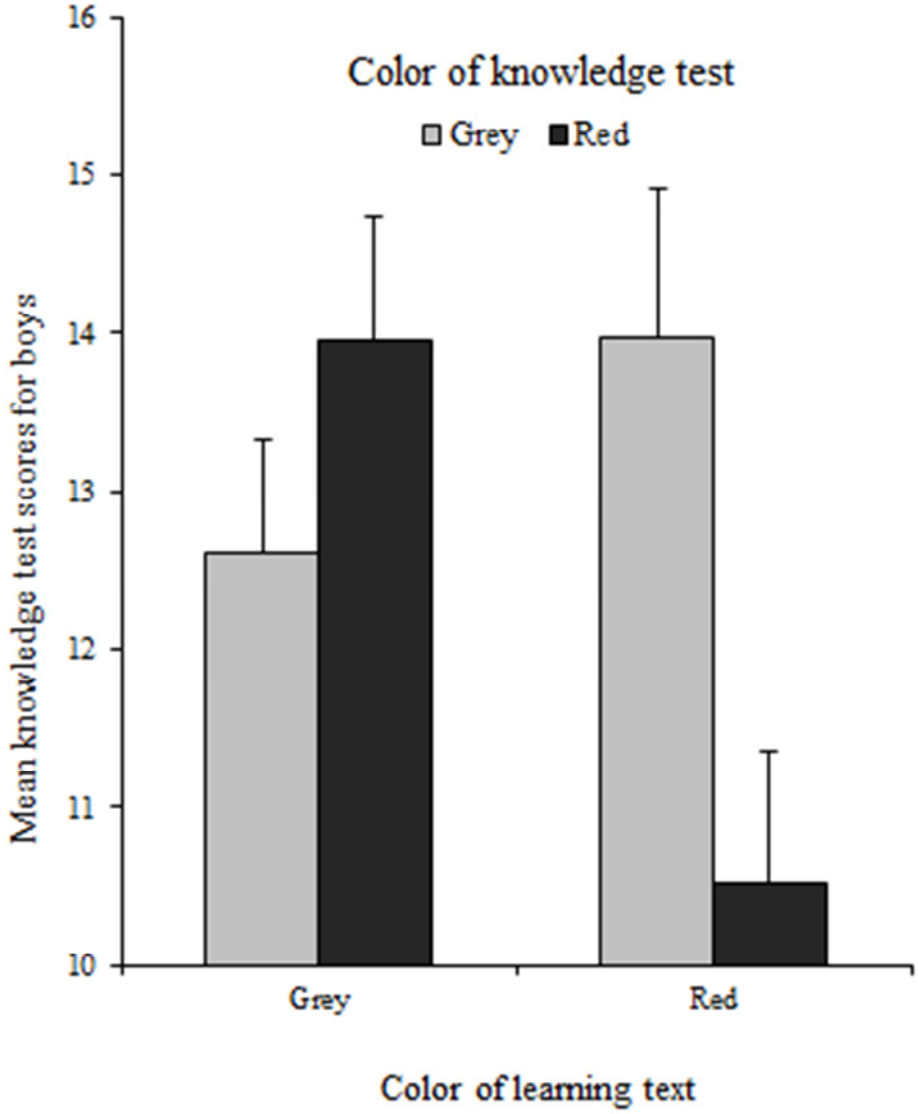

Figure 1. Mean knowledge test scores (with standard errors) for boys by experimental conditions

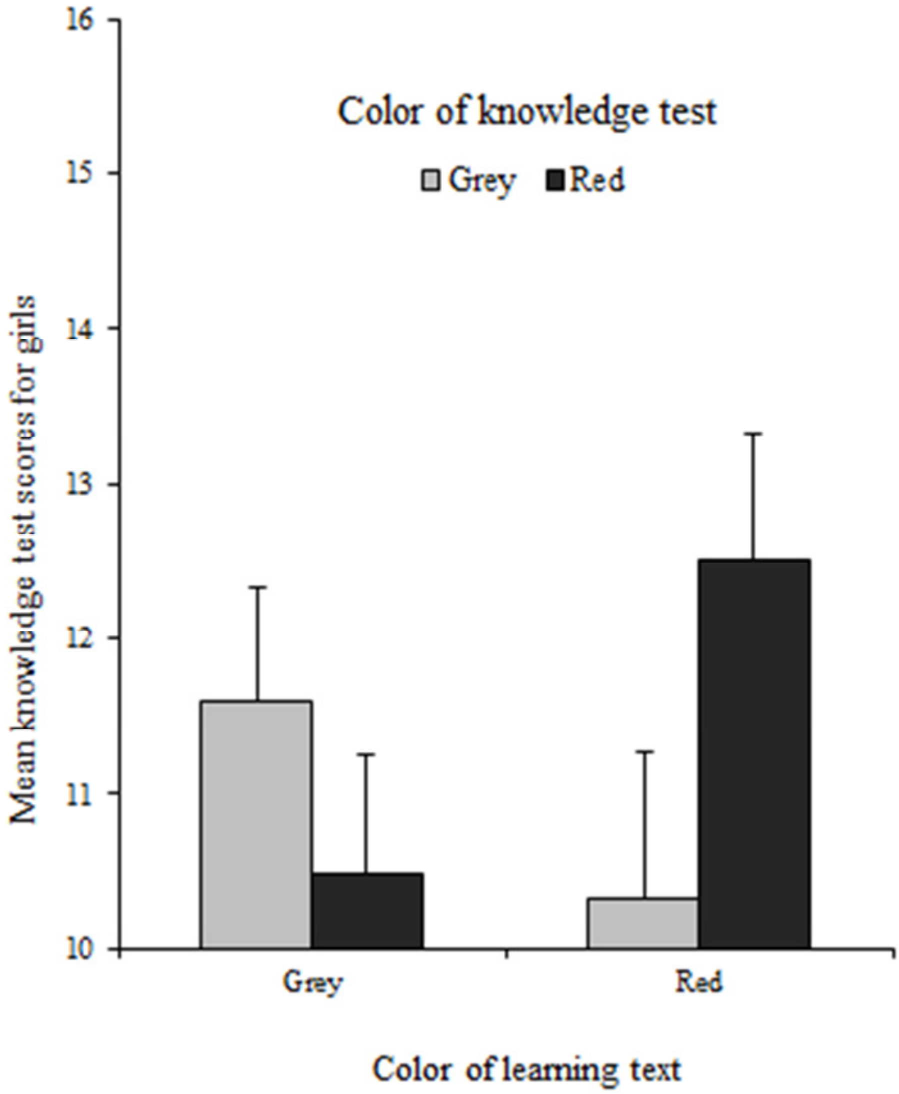

Figure 2. Mean knowledge test scores (with standard errors) for girls by experimental conditions