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Ego Depletion in Color Priming Research: Self-Control Strength Moderates the Detrimental Effect of Red on Cognitive Test Performance

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Abstract

Colors have been found to affect psychological functioning. Empirical evidence suggests that, in test situations, brief perceptions of the color red or even the word "red" printed in black ink prime implicit anxious responses and consequently impair cognitive performance. However, we propose that this red effect depends on people's momentary capacity to exert control over their prepotent responses (i.e., self-control). In three experiments (*N*s = 66, 78, and 130), first participants' self-control strength was manipulated. Participants were then primed with the color or word red versus gray prior to completing an arithmetic test or an intelligence test. As expected, self-control strength moderated the red effect. While red had a detrimental effect on performance of participants with depleted self-control strength (ego depletion), it did not affect performance of participants with intact self-control strength. We discuss implications of the present findings within the current debate on the robustness of priming results.

Keywords

color priming, ego depletion, self-control, self-regulation, test performance

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For most humans, the world is a colorful place. Colors have the power to affect us psychologically; for instance, a painting of Marc Chagall may instigate different feelings and cognitions depending on whether one views a colored or a black and white print of it. Beyond aesthetical experiences, colors have been considered to have an effect on psychological functioning via biologically engrained or learned associations they might carry (for a review, see Elliot & Maier, 2014). Folklore has long surmised that different colors elicit different psychological reactions, but thorough systematic research has only recently begun (Elliot & Maier, 2007; Fink & Matts, 2008; Guéguen, 2012; Hill & Barton, 2005; Mehta & Zhu, 2009; Spence, Levitan, Shankar, & Zampini, 2010; Stephen, Coetzee, Law Smith, & Perrett, 2009). To date, this research has mainly addressed the affective, cognitive, or behavioral effects of the color red (e.g., Franklin, Gibbons, Chittenden, Alvarez, & Taylor, 2012; Kuhbandner & Pekrun, 2013; Maier, Barchfeld, Elliot, & Pekrun, 2009; Young, Elliot, Feltman, & Ambady, 2013). The present research examined whether the negative effect of exposure to red on cognitive performance would be moderated by self-regulatory capacity (ego depletion).

Red as Color Prime in the Achievement Context

There is ample evidence that perceiving the color red in the context of an achievement situation undermines performance relative to other control colors (e.g., Gnambs, Appel, & Batinic, 2010; Greenlees, Eynon, & Thelwell, 2013; Hill & Barton, 2005; Houtman & Notebaert, 2013; Ioan et al., 2007; Shi, Zhang, & Jiang, in press; Sinclair, Soldat, & Mark, 1998). For example, several studies have demonstrated that brief exposure to the color red (or even the word "red" printed in black ink) caused decrements in cognitive test performance, relative to control groups who were exposed to other colors such as gray (Elliot, Maier, Moller, Friedman, &

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Meinhardt, 2007; Lichtenfeld, Maier, Elliot, & Pekrun, 2009; Maier, Elliot, & Lichtenfeld, 2008). The detrimental effect of the color or word red on cognitive performance has been explained by proposing that red activates (or primes) implicit anxious responses, such as avoidance, worrisome thoughts, and narrowing of attention, which typically interfere with intelligent thought (Elliot, Maier, Binser, Friedman, & Pekrun, 2009; Elliot et al., 2007; Lichtenfeld et al., 2009; Maier et al., 2008). Such theorizing and supporting findings are in line with the suggestion that the color red is associated with threat, failure, and avoidance (Genschow, Reutner, & Wänke, 2012; Gerend & Sias, 2009; Kliger & Gilad, 2012; Magee, 2012; Moller, Elliot, & Maier, 2009; Rutchick, Slepian, & Ferris, 2010; Shavit, Rosenboim, & Cohen, 2013; Tanaka & Tokuno, 2011; Ten Velden, Baas, Shalvi, Preenen, & De Dreu, 2012)—an association that may be based in evolutionarily ingrained predispositions (Elliot & Maier, 2007; Ellis, 1900; Hill & Barton, 2005; Humphrey, 1976).

As the detrimental effect of red on cognitive performance has reliably been shown over various studies from different labs, it can be considered as established. However, Elliot and Maier (2014) recently pointed out in their review of color effects on psychological functioning that further work is required to identify the boundary conditions (i.e., moderators) of the observed color effects. In following this call, we sought to determine one such moderator in the present work. Specifically, we investigated whether momentary self-control resources moderate the detrimental effect of red on cognitive performance. This corresponds to the step from what Zanna and Fazio (1982) called first-generation research questions (i.e., demonstrating the presence of an effect) to the second-generation research questions (i.e., identifying the conditions under which an established effect emerges). In the following, we first introduce our proposed moderator variable self-control strength and then discuss why and how it may moderate the red effect.

Self-Control and Ego Depletion

Self-control refers to human executive functioning and has been defined as the process of deliberately modifying or overriding one's prepotent responses (Baumeister, Muraven, & Tice, 2000; Muraven & Baumeister, 2000). It may be seen as one of human beings' most useful abilities as it allows people to overcome unfavorable response tendencies that would hinder them from attaining a valuable goal. Thus, evidence suggests that self-control is helpful in resisting unhealthy impulses to eat fattening food or drink alcohol (Crescioni et al., 2011; Friese, Hofmann, & Wänke, 2008; Hofmann, Rauch, & Gawronski, 2007), in resisting the impulse to quit working in the face of failures and setbacks (Baumeister, Bratslavsky, Muraven, & Tice, 1998; Burkley, 2008; Segerstrom & Nes, 2007; Webb & Sheeran, 2003), and in withstanding negative affects in anxiety- or anger-provoking situations (Bertrams, Englert, & Dickhäuser, 2010; Denson, Pederson, Friese, Hahm, & Roberts, 2011; DeWall, Baumeister, Stillman, & Gailliot, 2007; Englert & Bertrams, 2013; Stucke & Baumeister, 2006).

Numerous studies have found that after an initial act of self-control, subsequent self-control is impaired (e.g., Baumeister et al., 1998; Muraven, Tice, & Baumeister, 1998; for a meta-analysis, see Hagger, Wood, Stiff, & Chatzisarantis, 2010). The implication of this work—as formulated in the strength model of self-control (Baumeister, Vohs, & Tice, 2007; Muraven & Baumeister, 2000)—is that a limited resource akin to strength was depleted by exerting self-control in the first task, thereby leaving less resources for the second task. We refer to this limited resource as *self-control strength* in the following. Baumeister et al. (1998) coined the state of the relative depletion of self-control strength after an initial act of self-control *ego depletion*. Further research has revealed that self-control shares the limited strength resource with other forms of executive control such as decision making and effortful working memory processes (Baumeister et al., 1998; Masicampo & Baumeister, 2008; Pohl, Erdfelder, Hilbig, Liebke, & Stahlberg, 2013; Schmeichel, 2007; Vohs et al., 2008).

Self-Control Strength as Moderator of the Red Effect

Several studies demonstrated that behaviors and cognitions of people whose self-control strength had been depleted relied on their automatic and implicit response tendencies rather than on executive control, in comparison to nondepleted control groups. For instance, Hofmann et al. (2007) found that implicit preferences toward candies predicted casual consumption of candies only when the participants had just exerted self-control in an initial task. In a control condition that did not require initial self-control effort, the implicit tendencies failed to impact behavior. The implication is that when self-control is at full strength, it can override the automatic impulse to eat candy, but ego depletion reduces top-down control and allows the automatic preferences to guide behavior. Friese et al. (2008) replicated this finding with respect to alcohol consumption. Govorun and Payne (2006) found that after self-control exertion, participants were automatically guided by their stereotypes, but when no such depleting initial effort had been required, people were able to prevent stereotypes from influencing them. In sum, people may be more directed by their automatic response tendencies when their self-control strength is momentarily depleted than when it is intact.

We hypothesized that self-control strength would moderate the effect of red exposure on cognitive performance. Confrontation with red automatically activates implicit anxious responses that may be harmful to cognitive test performance (Elliot & Maier, 2014). However, when people can self-regulate effectively, they may be able to overcome the detrimental effects of anxious responses. Hence, we proposed that depleted individuals would find it difficult to draw on

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their executive control resources to override their anxious responses elicited by the color red. In contrast, nondepleted people would have sufficient executive resources to overcome their adverse response tendencies that would otherwise guide them automatically. This would be analogous to how implicit preferences mainly affected depleted people in Hofmann et al.'s (2007) as well as Friese et al.'s (2008) studies.

The *default interventionism* framework (Evans & Stanovich, 2013) offers a basis for our hypothesis that self-control strength would moderate the detrimental effect of the color red on cognitive performance. As this theory suggests (see Morewedge & Kahneman, 2010), a stimulus in the environment (a prime) can trigger a response, which affects behavior in a largely automatic way (default). However, if the triggered response is unwanted or inappropriate, it can principally be overridden by cognitive control mechanisms (intervention). Specifically, Morewedge and Kahneman (2010) proposed that the automatic and mostly unconscious operations of associative memory—which they referred to as System 1—generate response tendencies in a given situation. When it runs into difficulties, System 1 mobilizes the cognitive control operations of System 2. One important function of System 2 is thus to intervene and modify System 1 responses. The largely automatic guidance by System 1 has been considered to run effortlessly, in contrast to the effortful and resource-dependent operations of System 2 (Evans & Stanovich, 2013; Morewedge & Kahneman, 2010). Therefore, mobilization of System 2 may be less likely when the self-control strength resource is depleted than when it is intact (cf. Hofmann, Friese, & Strack, 2009).

The default interventionism account provided the overarching theoretical framework for the present research question, namely what are the boundary conditions of the red effect on cognitive performance? In the default response, red is assumed to automatically generate anxious responses via System 1. However, these undesirable responses can be stifled by activation of System 2. Whether System 2 intervenes should depend on momentary self-control strength. If self-control strength is relatively high, chances are good that the automatically activated anxious responses from System 1 will be overridden by self-control and would bring little or no damage to cognitive performance. If self-control strength has previously been depleted, however, the anxious responses will impair cognitive performance. Hence, we hypothesized that self-control strength would moderate the effect of red on cognitive performance.

The Present Research

We tested the hypothesis that implicit anxious responses elicited by the color red (Experiments 1 and 2) or the word red (Experiment 3) would impair cognitive performance more strongly when self-control strength was momentarily low rather than high. Specifically, we predicted that exposure to red (vs. gray) would impair cognitive test performance among people who had already exerted self-control and thus suffered from ego depletion, whereas the red priming effect would be reduced or eliminated among people who had not already expended self-control.

Our experiments began by manipulating self-control strength (depletion). Then followed a brief presentation of a color stimulus—either red or gray. Subsequently, participants completed a cognitive test (a mental arithmetic test or a standardized IQ test). Relative to existing studies on the red effect (e.g., Elliot et al., 2007; Sinclair et al., 1998), we weakened the evaluative emphasis and performance pressure, such as by not telling people that they would get personal feedback. Minimizing the impact of external pressures permitted a more powerful test of the impact of self-control strength. Nonetheless, telling participants (especially university students) they were about to take a cognitive test should motivate them to perform well.

Experiment 1

Experiment 1 tested the detrimental effect of exposure to the color red on mental computation. Participants were briefly exposed to either red or gray background colors, prior to a test of mental arithmetic. Because self-control involves overriding or altering prepotent responses, we manipulated depletion by requiring some participants (but not controls) to override overlearned, habitual responses. We predicted that exposure to red would reduce cognitive test performance among depleted participants but hardly or not at all among controls.

Method

Participants. Seventy-two German university students participated in the study. One participants' data were incomplete and could therefore not be used for analyses. The data of five additional participants were not analyzed (two because they were red–green color blind and three because they were aware of the actual purpose of the research). Thus, the final sample consisted of 66 participants (38 female; M_{age} = 22.32, *SD* = 2.80).

Design, procedure, and measures. Participants were randomly assigned to the conditions of the 2 (depletion vs. no depletion of self-control strength) × 2 (exposure to red vs. gray) between-groups design. The experimenter was blind to the condition. The study took place in a lab room at the University of Mannheim.

After giving informed consent, participants received a sheet with the task for the self-control strength manipulation. Participants were instructed to transcribe a passage discussing the history of the city of Mannheim, Germany. There were no further instructions in the no depletion condition. In the depletion condition, participants were further instructed to copy the text but to skip any instances of the letters e and

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n (e.g., "Mannheim" had to be written "Mahim"). These letters are the most frequently used letters in the German language, and so participants had to suppress their well-learned writing habits in order to perform the task correctly. Writing words is habitual and automatic for adults. Therefore, in order to skip the forbidden letters, they had to monitor their writing and suppress all impulses to write them when they came up. This procedure has proven effective in prior work (e.g., Bertrams, Englert, Dickhäuser, & Baumeister, 2013). After 6 min, all participants were stopped.

Afterward, manipulation checks on self-control exerted during the transcription were administered (four items; for example, "How effortful did you find the transcription task?"). The manipulation checks were responded to on scales from 1 (*not at all*) to 7 (*very*). Moreover, to rule out the potential alternative explanation that the depletion manipulation incidentally induced differences in momentary positive or negative affect, we applied the 20-item Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988; German version by Krohne, Egloff, Kohlmann, & Tausch, 1996). Ten items for positive affect (e.g., "enthusiastic") and another ten items for negative affect (e.g., "afraid") were rated on scales from 1 (*not at all*) to 5 (*extremely*).

Next, the participants received the instructions for the mental arithmetic task and a sample item. After participants said that they understood these instructions, the experimenter gave the participants a white two-ring binder containing the color manipulation and the measure of the dependent variable (i.e., arithmetic performance). The experimenter instructed the participants to open the binder and asked them whether they could see the word "Test." In the red priming condition, on the cover page in the binder the word "Test" was printed in black on a red rectangle. In the control condition, the rectangle was gray. After the participant acknowledged seeing the word, the experimenter asked him or her to turn the page and to begin solving the arithmetic problems. The color priming materials and procedure were adapted from recent research on this matter (Elliot et al., 2007; Maier et al., 2008). The arithmetic performance measure was taken from recent research on test anxiety (Bertrams et al., 2013). It involved a series of three-digit × one-digit multiplication problems (e.g., 773 × 2), which had to be done in one's mind, without writing. Participants had 3 min to solve as many as possible.

Then, the participants completed a post-task questionnaire. This contained questions with respect to suspicion about the hypothesis, noticing and remembering the color, color blindness, and personal details. As in prior color priming research (Elliot et al., 2007), the participants also indicated their Abitur score as baseline measure of cognitive ability (the Abitur is a standardized comprehensive exam in Germany that conventionally takes place at the end of high school). Finally, participants were thanked, debriefed, and given 4 Euros or course credit.

Results

Manipulation check. The manipulation check (α = .83) revealed that the transcription task required more self-control effort in the depletion condition than in the no depletion condition (M = 3.88, SD = 1.37 vs. M = 2.86, SD = 1.13), $t(64) = 3.28$, $p = .002$, $d = 0.81$, 95% confidence interval (CI) = [0.40, 1.63]. Thus, our manipulation of self-control strength was successful. A chi-square test confirmed that participants' color reports corresponded to their color condition, χ^2_{corr} (1, N = 66) = 51.39, $p < .001$, Φ = .91, 95% CI = [0.86, 0.94]. Thus, as in previous color priming research (e.g., Elliot et al., 2007), the participants were cognizant of the color on the cover page.

Arithmetic performance. A 2 × 2 ANCOVA on arithmetic performance (number of solved items), and with baseline cognitive ability (Abitur scores) as a covariate, yielded a significant interaction between self-control strength and color, $F(1, 61) = 4.24$, $p = .04$, $\eta^2_p = .07$. Neither the main effect of self-control strength, $F(1, 61) = 0.04$, $p = .84$, $\eta^2_p < .001$, nor the main effect of color, $F(1, 61) = 2.52$, $p = .12$, $\eta^2_p = .04$, was significant.

ANCOVA on only the depletion conditions indicated that depleted participants exposed to red performed significantly worse than those exposed to gray (M_{adj} = 2.81, SE = 0.83 vs. M_{adj} = 5.71, SE = 0.86), $F(1, 30) = 5.83$, $p = .02$, $\eta^2_p = .16$, 95% CI = [−5.35, −0.45]. A parallel ANCOVA on only the no depletion conditions found no difference between the red and gray conditions (M_{adj} = 4.32, SE = 0.76 vs. M_{adj} = 3.94, SE = 0.74), $F(1, 30) = 0.13$, $p = .73$, $\eta^2_p = .004$, 95% CI = [−1.82, 2.59]. Thus, as predicted, the red effect was found among participants who had exerted prior self-control effort—but not in the absence of such prior effort.

Supplementary analyses. The self-control strength manipulation neither caused differences in positive affect (α = .85), p = .09, nor negative affect (α = .83), p = .61. However, there was a trend for depleted participants to experience more positive affect than nondepleted participants. We repeated the main analyses while controlling for positive affect. This did not change the pattern of results. Thus, affect was not a viable alternative explanation for the moderating effect of ego depletion.

Experiment 2

Experiment 2 was a conceptual replication of Experiment 1 with a different performance measure, namely a standardized IQ test. Moreover, several new control measures were added in order to exclude potential alternative explanations for the moderating role of ego depletion. Again, we predicted that exposure to red (in contrast to gray) would reduce cognitive test performance, particularly among depleted participants, while nondepleted participants should remain relatively unaffected.

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Method

Participants. Eighty German university students were recruited for the study. Two were discarded because of vision problems (red–green color blindness, severe visual handicap) and another two because of guessing the purpose of the study, leaving 76 (60 female; M_{age} = 22.01, *SD* = 3.47).

Design, procedure, and measures. The design and procedure were the same as for Experiment 1, except for the following changes. After the transcription task and the corresponding manipulation check (but prior to the color manipulation), the participants completed several control measures that had not been applied in Experiment 1. First, participants completed one additional item on how much they perceived themselves as successful at the transcription task (Bertrams et al., 2013). The item was responded to on a scale from 1 (*not at all*) to 7 (*very*). This measure was included to check whether the manipulation was likely to provoke differences in perceived competence or self-efficacy.

Second, for the measure of affect, we replaced the (explicit) PANAS with the Implicit Positive and Negative Affect Test (IPANAT; Quirin, Kazén, & Kuhl, 2009). By this, we addressed the potential alternative explanation that the depletion manipulation incidentally induced differences in implicit affect. Based on the assumption that unconscious emotional states are projected onto stimulus words, for the IPANAT, participants are asked to rate to what extent six artificial words convey various emotions. For instance, the (non-)word "SAFME" was rated on scales from 1 (*doesn't fit at all*) to 4 (*fits very well*) as to how much it conveys each of six moods (e.g., "happy," "helpless").

Third, to evaluate differences in threat or incentive sensitivity between the depletion and the no depletion conditions as potential alternative explanations (see Schmeichel, Harmon-Jones, & Harmon-Jones, 2010), participants were given Carver and White's (1994) Behavioral Inhibition System/Behavioral Activation System Scales (BIS/BAS Scales; German: Strobel, Beauducel, Debener, & Brocke, 2001). This measure included the 7 BIS items (e.g., "I worry about making mistakes") for measuring threat sensitivity and the 13 BAS items (e.g., "If I see a chance to get something I want, I move on it right away") for measuring incentive sensitivity. All BIS and BAS items were responded to on scales from 1 (*applies to me not at all*) to 4 (*applies to me exactly*).

As already noted, Experiment 2 changed the measure of cognitive performance. The mental arithmetic test was replaced by an intelligence subtest, taken from the Intelligence Structure Test 2000 R (I-S-T 2000 R; Liepmann, Beauducel, Brocke, & Amthauer, 2007). It consisted of 20 items providing participants with a word pair, along with the first word of a second pair (e.g., "dark : bright = wet : ?") followed by five options (e.g., "rain, day, damp, wind, dry"). The task was to indicate the one word of the five options that completes the analogy (in the example, dry). Two parallel versions exist of this subtest—"Form A" and "Form C." After completing the transcription task, the corresponding manipulation check, and the control measures, participants received Form A in a white binder. The cover page contained the word "Test" in black ink on a white sheet. This test served as baseline measure of cognitive ability; therefore, it was not preceded by exposure to color. The participants were stopped after 5 min and told that they had completed the practice intelligence test and would now begin the real test. Then, the experimenter gave them another white binder containing Form C. The color priming manipulation was administered with the second test, in the same fashion as in Experiment 1. Performance in the second test was the primary dependent measure. As before, participants were stopped at 5 min.

As a final deviation from Experiment 1, participants also completed a five-item measure of how various worrisome thoughts (e.g., "Worries about the consequences of a possible failure") had distracted them during the IQ test (Bertrams et al., 2013). The items were answered on scales from 1 (*not at all distracted*) to 7 (*extremely distracted*). We used this measure to explore whether the experimental manipulations had an effect on explicit self-report measures of anxious responses.

Results

Manipulation check. The manipulation check (α = .83) indicated the successful manipulation of self-control strength (*M* = 4.45, *SD* = 1.33 vs. *M* = 2.48, *SD* = 1.19), $t(73) = 6.75$, $p < .001$, $d = 1.56$, 95% CI = [1.39, 2.55]. (One participant failed to answer the manipulation check but completed the transcription task in line with instructions.) Participants' reports of the color on the cover page of the second test corresponded to their color condition, $\chi^2_{corr}(1, N = 76) = 45.48$, $p < .001$, Φ = .80, 95% CI = [0.70, 0.87].

IQ test performance. A 2 × 2 ANCOVA on final IQ test performance (number of solved items), using baseline test scores as a covariate, revealed a significant interaction between self-control strength and color, $F(1, 71) = 6.07$, $p = .02$, $\eta^2_p = .08$. Neither the main effect of self-control strength, $F(1, 71) = 0.04$, $p = .85$, $\eta^2_p < .001$, nor the main effect of color, $F(1, 71) = 0.63$, $p = .43$, $\eta^2_p = .009$, was significant.

ANCOVA on only the depletion conditions revealed that depleted participants performed significantly worse after briefly seeing red than after seeing gray (M_{adj} = 11.07, *SE* = 0.58 vs. M_{adj} = 12.82, *SE* = 0.58), $F(1, 35) = 4.35$, $p = .04$, η^2_p = .11, 95% CI = [−3.46, −0.05]. In the no depletion conditions, however, color had no effect (M_{adj} = 12.27, *SE* = 0.59 vs. M_{adj} = 11.31, *SE* = 0.56), $F(1, 35) = 1.39$, $p = .25$, η^2_p = .04, 95% CI = [−0.69, 2.61]. Thus, Experiment 2 replicated the finding of Experiment 1 that priming with the color red impaired cognitive performance only after recent self-control effort.

Supplementary analyses. The self-control strength manipulation did not cause differences in perceived competence,

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implicit positive affect ($\alpha = .77$), implicit negative affect ($\alpha = .80$), threat sensitivity ($\alpha = .81$), incentive sensitivity ($\alpha = .73$), or baseline cognitive ability, all *p*s > .39. Thus, none of these potential confounds influenced the results. Moreover, we found no effect of self-control strength condition, color condition, or their interaction on self-reported distraction by worries ($\alpha = .92$), *p*s > .61.

Experiment 3

Experiment 3 sought to replicate the findings from the first two experiments despite substantial changes in methods, thereby increasing generality. Instead of showing the actual colors red and gray, we exposed participants to the word "red" or "gray" prior to the IQ task (Lichtenfeld et al., 2009). The words were presented in black on a white background. This time the participants completed the study on computers in a mundane environment (the computer lab of their school). The sample for this study was high school rather than university students, thus implicating a slightly different developmental stage. As in Experiment 2, we used a standardized IQ subtest, but a mathematical instead of a verbal one. Again, the prediction was that self-control strength and color would interact to determine IQ test performance.

Method

Participants. One hundred thirty students (81 female; $M_{age} = 16.39$, $SD = 0.60$) from a German high school took part. Data from five others were discarded: Two participants failed to complete the procedure and three were red–green color blind. No participant guessed the purpose of the study.

Design, procedure, and measures. The design and procedure were the same as in Experiment 1, except for the following changes. The experiment took place in the computer lab of the students' high school rather than in a university lab. It was computer-administered, enabling participants to do the study in groups of up to 18 at a time. The transcription task used a different story, this time focusing on the famous library in Alexandria, Egypt. Perceived competence in the transcription task was assessed (as in Experiment 2), whereas the PANAS was not administered again. As baseline ability measure, we did not use the Abitur score (because students had not yet taken the test) but rather the student's math grade from the most recent report card.

Moreover, immediately before the cognitive test, the color priming was administered by words instead of showing the color. That is, the computer screen informed participants that ostensibly in order to facilitate data entry, they had been randomly assigned to a group; by actual random assignment the group was either labeled as "group red" or "group gray" (Lichtenfeld et al., 2009). Everything in the study was presented in black on a white background. The manipulation of color word was presented for precisely 2 s.

To further increase generality, a cognitive performance measure different from the ones in the first two experiments was used. This time, we used a subtest of figural intelligence from the I-S-T 2000 R that required mental rotation. Each of the 20 items presented five geometric figures along with a cluster of disconnected segments. Participants had to choose which of the five figures could be fully constituted by those segments. The computer stopped the test at 2 min. Our dependent measure was the number of correct solutions.

In addition, after the test, a questionnaire assessed participants' general activation level, mood, motivations, and perceived competence during the IQ test using measures similar to the ones applied by Elliot et al. (2007). General activation was measured with six items (e.g., "active") taken from Thayer's (1986) Activation–Deactivation Adjective Check List (German: Imhof, 1998). These items were answered on scales from 1 (*not at all*) to 5 (*very*). The other self-reports were single-item measures (e.g., "How did you feel during the task," "How important was it for you to do well in the task"). They were answered on 7-point scales, where 1 indicated a low and 7 a high value on the respective variable. Furthermore, the measure on self-reported distraction by worries from Experiment 2 was applied again. In the post-task questionnaire, the students were also asked whether they will have to take a test yet this day.

Results

Manipulation check. The manipulation check ($\alpha = .68$) indicated a successful manipulation of self-control strength: The transcription task required more self-control effort in the depletion condition than in the no depletion condition ($M = 3.80$, $SD = 0.84$ vs. $M = 2.72$, $SD = 1.01$), $t(128) = 6.61$, $p < .001$, $d = 1.16$, 95% CI = [0.75, 1.40]. Participants felt somewhat less competent during the transcription task in the depletion condition than in the no depletion condition ($M = 4.17$, $SD = 1.28$ vs. $M = 4.67$, $SD = 1.24$), $t(128) = -2.24$, $p = .03$, $d = -0.40$, 95% CI = [−0.93, −0.06]. Therefore, we controlled for perceived competence in all following analyses (in addition to baseline ability). However, parallel analyses without that control yielded nearly identical results. The color manipulation was checked by asking participants to which group they had been assigned, and all answered correctly.

IQ test performance. ANCOVA on IQ test performance, with math grade from the most recent report card and perceived competence during the transcription task as covariates, revealed that the interaction between the self-control strength and the color word conditions almost significantly predicted test performance, $F(1, 124) = 3.80$, $p = .054$, $\eta_p^2 = .03$. There was neither a significant main effect of self-control strength, $F(1, 124) = 0.20$, $p = .66$, $\eta_p^2 = .002$, nor of color, $F(1, 124) = 0.31$, $p = .58$, $\eta_p^2 = .002$.

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In the depletion conditions, briefly seeing the word "red" led to significantly lower IQ test performance than seeing the word "gray" (M_{adj} = 3.83, SE = 0.42 vs. M_{adj} = 5.00, SE = 0.38), $F(1, 60) = 4.23$, $p = .04$, $\eta_p^2 = .07$, 95% CI = [−2.31, −0.03]. In the no depletion conditions, there was no difference between the red condition and the gray condition (M_{adj} = 4.62, SE = 0.41 vs. M_{adj} = 3.99, SE = 0.45), $F(1, 62) = 1.07$, $p = .31$, $\eta_p^2 = .02$, 95% CI = [−0.59, 1.84]. Thus, again, the red effect only reached significance when executive control had previously been exerted.

Supplementary analyses. There was no effect of self-control strength condition, color word condition, or their interaction on activation level ($\alpha = .84$), mood, motivation, or perceived competence during the intelligence task, all ps > .20. Controlling for whether the students had a test or an exam on the same day did not affect the results on IQ test performance.

Participants in Experiment 3 were asked to indicate how distracted they were by worrisome thoughts ($\alpha = .87$). ANCOVA yielded a significant interaction between self-control strength and color word, $F(1, 124) = 4.18$, $p = .04$, $\eta_p^2 = .03$. In the depletion conditions, participants in the red group reported more distraction than those in the gray group (M_{adj} = 4.43, SE = 0.28 vs. M_{adj} = 3.51, SE = 0.25), $F(1, 60) = 5.84$, $p = .02$, $\eta_p^2 = .09$, 95% CI = [0.16, 1.68]. In the no depletion conditions, the color manipulation had no effect (M_{adj} = 3.70, SE = 0.27 vs. M_{adj} = 3.93, SE = 0.29), $F(1, 62) = 0.31$, $p = .58$, $\eta_p^2 = .005$, 95% CI = [−1.02, 0.58]. The worry measure failed, however, to correlate with IQ test performance in the overall sample or in either of the self-control strength conditions, ps > .16. Therefore, distraction by worries may not have mediated the effect of color word on IQ test performance.

General Discussion

The Present Findings

Three studies found that brief priming with the color or word red caused decrements in cognitive test performance—but only among people who had exerted prior self-control and thereby depleted their momentary self-control strength. Participants who had not depleted their self-control strength showed no detrimental effects of exposure to red. Our finding that self-control strength moderated the red effect was consistent across three studies with different populations (university and high school), across different forms of color priming (the color itself and the name of the color), and across three different cognitive tests (one numerical, one verbal, and one figural). The moderating effect of self-control strength was not confounded with explicit affect, implicit affect, general activation level, sensitivity to incentives or threat, self-reported motivation, or self-perceived competence.

In Experiment 3, we also found that students who had been primed with the word "red" reported having been more distracted by worrisome thoughts during the test than those who had been primed with "gray." This finding was also only evident among participants who had engaged in prior self-control effort. However, the worry measure did not predict IQ test performance and thus did not mediate the red effect on performance in this experiment. In addition, no analogous effect appeared in Experiment 2. Thus, it seems unlikely that conscious perceptions of anxious responses mediated the color priming effect on performance. This result is largely in line with the recent color priming research, which, in the majority of the cases, did not reveal effects of red on self-report measures of anxiety and its correlates (e.g., Elliot et al., 2007; Maier et al., 2008). It is possible that people are only "fuzzily" aware of the anxious responses evoked by subtle threat cues, so that they are not able to report on them reliably.

Implications

Our findings contribute to the emerging research literature on color priming (Elliot & Maier, 2007, 2014; Fink & Matts, 2008; Guéguen, 2012; Hill & Barton, 2005; Lichtenfeld, Elliot, Maier, & Pekrun, 2012; Mehta & Zhu, 2009; Spence et al., 2010; Stephen et al., 2009). Research has established that different colors have different effects on performance, and the next step would be to establish when these effects do versus do not occur. Our experiments constitute one attempt at answering these second-generation questions.

The present results also help reconcile the well-established findings of automatic color priming with work on executive control. Presumably, people want to perform well on a test. When primed with a threatening implicit affective cue such as the color red, they must use executive control to get over evoked anxious responses and stay focused. The present studies replicated the red priming effects found in previous studies (e.g., Lichtenfeld et al., 2009; Maier et al., 2008; Sinclair et al., 1998), when executive resources were depleted. However, the effect of red on cognitive performance was completely eliminated among participants who were not depleted. These findings indicate that priming automatic responses can have palpable effects on objective performance—but also that these detrimental effects can be overridden or compensated by executive control. Indeed, abundant research suggests that one effect of controlled processes is to override incipient automatic responses (for a review, see Baumeister, Masicampo, & Vohs 2011).

Our results conform to, and thereby support, the theoretical framework we applied in the present work: the default interventionist perspective within the dual process theories (Evans & Stanovich, 2013; Morewedge & Kahneman, 2010). The responses elicited by a prime such as the color red may function automatically to alter performance but, if they are harmful, executive control intervenes and the default responses are overridden—provided that resources for engaging in executive control are intact. If such resources are lacking, little or no controlled intervention would take place, and

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the primes would have significant impact. Default interventionism is thus a useful theoretical approach for predicting the conditions under which detrimental priming effects can be observed. As in the present three experiments, priming effects may often be controlled and would not translate into dysfunctional behaviors or unfavorable outcomes. However, everything that interferes with individuals' ability to exert control over their responding may impede controlled intervention and thereby allow affective primes to impair performance.

Our findings are also in line with recent theorizing on avoidance motivation and limited resources (Roskes, Elliot, Nijstad, & De Dreu, 2013a, 2013b). These authors point out that avoidance motivation typically causes the recruitment of cognitive resources and control. However, when executive resources are low, they argue that avoidance-motivated people's performance should be impaired. They showed that avoidance motivation combined with lowered executive control due to time pressure indeed undermined cognitive performance (Roskes et al., 2013b). Activation of avoidance motivation is one effect of exposure to red (e.g., Elliot et al., 2007; Kliger & Gilad, 2012; Tanaka & Tokuno, 2011), and one reason for low executive resources is recent self-regulatory effort (e.g., Baumeister et al., 1998; Muraven et al., 1998; Pohl et al., 2013; Schmeichel, 2007). Thus, differences in avoidance motivation and executive resources were orthogonally manipulated in our three experiments and changed performance as suggested by Roskes et al. (2013a): Performance suffered when red activated avoidance motivation and, at the same time, executive control was low due to prior self-regulatory effort.

Furthermore, our findings have implications for test anxiety research. Prior research on explicit test anxiety and its effect on students' intellectual performance has yielded inconsistent findings (Zeidner, 1998). Recent studies demonstrated that self-reported state and trait anxiety impaired performance among people whose self-control strength had been depleted by prior exertion of self-regulatory effort—but anxiety did not impair performance among people whose executive resources were intact (Bertrams & Englert, 2014; Bertrams et al., 2013). Thus, ego depletion leaves performance vulnerable to impairment by explicit anxious responses, but when executive resources have not already been expended, people seem able to overcome those responses, to concentrate on the test, and hence to perform well. The present work extends this recent research by suggesting that self-control strength moderates the effect of implicit anxious responses on cognitive performance. Based on these findings, we assume that interventions to improve self-control strength (e.g., Bertrams & Schmeichel, 2014; Denson et al., 2011; Muraven, 2010; Oaten & Cheng, 2006) or to learn strategies for counteracting ego depletion (e.g., Friese & Wänke, 2014; Schmeichel & Vohs, 2009; Tyler & Burns, 2008) would help prevent the explicit as well as the implicit portions of anxiety from impairing performance in academic or psychometric testing.

In a broader context, our findings may contribute to the current controversy regarding the replicability of priming effects. Many studies have found significant priming effects (see Cameron, Brown-Iannuzzi, & Payne, 2012; DeCoster & Claypool, 2004). The failure of other studies to find priming effects (e.g., Doyen, Klein, Pichon, & Cleeremans, 2012; Pashler, Coburn, & Harris, 2012; Pashler, Rohrer, & Harris, 2013) has recently attracted attention if not notoriety. It is unfortunate that some of the debate has drifted into extreme caricatures, with one side supposedly assuming that priming is a real phenomenon and always works, and the other side implying that priming lacks reliable effects and published findings are factitious. It may be more constructive for the field to take the view that inconsistency in results calls for a study of moderators (see Cesario, 2014; Klatzky & Creswell, 2014, for a recent discussion supporting this argument). The theoretical framework (default interventionism) and empirical findings of the present work are consistent with such an approach. The detrimental effect of the red primings was only obtained among depleted participants and not among others. Even the absence of the red priming effect, however, was predictable and theoretically meaningful rather than constituting a failure to replicate the red effect. It is possible that the previous studies, which found the red effect, have been done on relatively ego depleted populations, such as students facing exams and deadlines, or even participants who had already expended self-regulatory effort that same day in other research procedures. Studies done with such populations may be more likely than others to yield significant red priming effects. Meanwhile, studies with nondepleted samples may not reveal these priming effects. Besides ego depletion, there may have been other circumstances that undermined executive control in prior studies, so that the red priming effect could emerge. For example, compared to our experiments, evaluative or time pressure may have been higher in previous red priming studies (e.g., Elliot et al., 2007; Sinclair et al., 1998), and—like ego depletion—pressure can impair executive control (Roskes et al., 2013a, 2013b).

Limitations and Future Directions

The present findings shed light on how red impairs cognitive performance. The underlying mechanism appears to work on the automatic level when executive control is low. Still, our studies do not tell us what the underlying processes actually are. We relied on the ample literature that red instigates automatic anxious responses, on one hand (e.g., Elliot et al., 2009; Maier et al., 2008), and that ego depletion is a state in which automatic responses are less likely to be overridden by executive control, on the other hand (e.g., Govorun & Payne, 2006; Hofmann et al., 2007). Therefore, we assumed that, after exposure to the color or word red, depleted participants were less able than nondepleted controls to prevent their anxious responses from impairing their performance. A mediating mechanism may be, for example, that depleted

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participants withdraw cognitively from performing the tasks rather than deliberately focusing attention on the test. To gain insight into such inner processes, future studies need to apply sophisticated methods. Eye tracking measures may be one possible way to determine whether exposure to red causes implicit mental disengagement from tests in depleted relative to nondepleted people.

We only compared red to achromatic gray and not to various other colors. Therefore, it remains unclear whether the same findings would have emerged with exposure to colors or color words other than gray in the control group. We are quite confident that the results would have been equivalent to the present ones as in previous research avoidance motivation and test performance after exposure to chromatic green were as after seeing gray (Elliot et al., 2007). We followed Maier et al. (2008) in using gray as the control, but researchers may find it useful to explore the full spectrum of colors in future studies.

Our findings on color priming may be applicable to some other kinds of priming. In addition to the color red, there are other implicit affective cues indicating threat (Friedman & Förster, 2010). These cues elicit implicit anxious responses and therefore may interact with self-control depletion to impair performance. However, empirical confirmation is needed to establish this. Furthermore, we do not know yet whether self-control strength could moderate undesirable priming effects in general, that is, beyond the achievement domain. Future research will show to what extent the present approach can be generalized. We would expect that the role of self-control strength in priming would be limited to the priming of undesirable rather than desirable or affectively neutral responses, because usually there should be no need to override the latter ones by executive control. Moreover, a precondition for executive control to be effective may be that the individual to some extent recognizes the primed responses or their effects (and wishes to override them). This may apply to priming with implicit threat cues (Li, Paller, & Zinbarg, 2008) but may or may not apply to other sorts of priming and cues.

There is no reason to assume that availability versus depletion of executive resources is the only moderator of the red priming effect. For instance, Cesario, Plaks, and Higgins (2006) demonstrated that people's attitudes can moderate how primes affect their behavior. Hofmann, Gschwendner, Friese, Wiers, and Schmitt (2008) found dispositional working memory capacity to moderate the influence of implicit tendencies. Although these studies were not on color priming, they point to the possibility that even the red effect on cognitive performance is moderated by attitudes or traits. The study of moderators holds promise of enabling the field to build on current knowledge about (color) priming and automatic processes.

In conclusion, our studies provide further evidence that priming with the color or word red can impair performance—but that people can resist and override these effects. When self-control strength is high, people can perform well despite adverse influences. When self-control strength is depleted, however, performance becomes vulnerable to impairment by affective color primes.

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Supplemental Material

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