Running Head: Red and knowledge

Color red in web-based knowledge testing

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Abstract

Computer- and web-based testing procedures are increasingly popular for the assessment of cognitive abilities and knowledge. This paper identified color red as a critical context factor that may influence the results. Two studies showed that color red may harm the performance in web-based tests of general knowledge. In Study 1 (N=131) a red (vs. green) progress bar impeded the performance in a knowledge test, but only for the male participants. In Study 2 (N=190) the color of the survey's forward button was manipulated (red vs. blue vs. mixed color) which led to a replication of the gender-dependent color effect. Evolutionary psychology and stereotype threat research explain why red impedes the activation of knowledge among men, but not among women.

Keywords: color, general knowledge, red, web-based testing, gender

Color red in web-based knowledge testing

The assessment of cognitive abilities with the help of personal computers, laptops, and portable devices is on the rise (cf. Hartig, Klieme & Leutner, 2008). In fact various sophisticated assessment procedures (e.g. adaptive testing) are hardly conceivable without computerized assistance. Current software used to create new computer-based questionnaires or to adapt existing instruments allows to integrate colored design elements, e.g., by incorporating the colored logo of a University or by including colored layout elements, such as a red or green progress bar. As outlined in the present paper, such color variations may have non-trivial consequences for the results obtained. This paper reports systematic effects of color red on the cognitive performance in a web-based test of general knowledge.

Color and cognitive performance

The relevance of color goes beyond aesthetics. The information linked with different colors support our everyday course of activities. In western societies, red is associated with “mistake” (teacher corrections at school), with “stop” (red traffic lights) and with “danger” (red traffic signs), but also with love and sexuality (red light districts, cf. Aslam, 2006). Pink is reserved for girls, blue is more a color for boys (Chiu, Gervan, Fairbrother, Johnson, et al., 2006; Shakin, Shakin, & Sternglanz, 1985), white is linked to immaculacy, black to mourning, etc. Although many color associations are a product of socialization, and these associations vary between regions and cultures (Aslam, 2006), there is evidence that color associations are rooted in biological response tendencies. Red is linked to danger as well as to love and both associations seem to have a phylogenetic history (Hurlbert & Ling, 2007). The association of red with love and sexuality, and related social practices of red Valentine Day’s chocolate boxes or red lipstick originate from biological predispositions of red as a sign of sexuality and reproduction (e.g., Barelli, Heistermann, Boesch & Reichard, 2007; Waitt, Gerard, Little, & Lrasielburd, 2006).

Whereas red signals openness and evokes approach tendencies in the reproduction context (Elliot & Niesta, 2008), it is linked to dominance and avoidance responses when it comes to male competition (Milinski & Bakker, 1990; Setchell & Dixson, 2001). The presence of color red indicates fighting ability; non-human primates who have a pale appearance tend to subordinate and avoid conflict when they are faced with brightly red colored males. The avoidance signal red seems to have a more relevant function for males because male primates tend to compete more than female primates (Setchell & Wickings, 2005).

Recent analyses of results in sports contests suggest that competitors who wear red sports clothes outperform competitors in other colors. Lower performance of those who faced a red opponent was found for the 2004 Olympic Games combat sports of boxing, tae kwon do, and wrestling (Hill & Barton, 2005), and the British soccer league, at least when the home games are considered (Attrill, Gresty, Hill, & Barton, 2008). Some of the success of red teams and individual competitors may be mediated by referee behavior (Hagemann, Strauss, & Leissing, 2008; see also Frank & Gilovich, 1988), however, facing red seems to provide a disadvantage even in online fighting games where no referee is involved (Ilie, Zagrean, & Moldovan, 2008). Available data for sportswomen who competed in the same sports at the 2004 Olympic Games reveal no color effect (Barton & Hill, 2005); descriptive statistics suggested that the color effect may even be reversed, i.e. facing red could convey an advantage for women (Ioan et al., 2007).

There is a rather long tradition of investigating the impact of red color on achievement beyond the sports context (e.g., Ainsworth, Simpson, & Cassell, 1993; Goldstein, 1942; Hammes & Wiggins, 1962), however, earlier results have been inconclusive (cf. Elliot, Maier, Moller, Friedman, & Meinhardt, 2007). Lately, the research on red and cognitive functioning has gained unprecedented momentum (Elliot et al., 2007; Ioan et al., 2007; Maier, Elliot, & Lichtenfeld, 2008; Mehta & Zhu, 2009). Ioan and colleagues (2007) suggested that red, due to its association with dominance impedes selective attention – at least among males. Prior to an experimental study, the experimenters announced the following test, in fact a stroop test, to be a measure of intelligence, and that test performance would be ranked by gender. As expected, men had greater problems with the task (the stroop interference was increased) when red color names were used, as compared to green or blue colors. Generally, women were slower in their reactions. In contrast to the male group, however, red did not increase the stroop interference; rather, red reduced the interference and lifted the female performance (Ioan et al., 2007). In another series of experiments, Elliot and colleagues (2007) demonstrated intriguing effects of red on cognitive performance in tests of fluid intelligence. Participants performed worse in an anagram test when the participant number was written in red color (vs. green or black, Experiment 1), and performed worse in an intelligence subtest (analogies or number series) when an introductory test booklet sheet was colored red (vs. green or white, Experiment 2; vs. green or gray, Experiments 3 and 4). Whereas self-report measures failed to provide evidence for mediation (Experiments 2-4), red led to less risky task choice (Experiment 5), and frontal cortical asymmetry (Experiment 6). These results suggested that processes triggered by avoidance motivation mediated the detrimental effect of red on the performance in the intelligence tests. This assumption was supported in subsequent series of experiments, which again employed fluid intelligence measures (Maier et al., 2008). Additional studies showed that red triggers avoidance behavior in the achievement context (Elliot, Maier, Binser, Friedman, & Pekrun, 2009) and that simply reading the word ‘red’ results in lowered fluid intelligence test scores (Lichtenfeld, Maier, Elliot & Pekrun, 2009). These studies involved both US and European samples. The impact of color red is supposed to be universal; however, data on non-Western countries is not available yet (Maier et al., 2008).

In the original Elliot et al. (2007) experiments gender was used as a covariate in the data analysis, but had no impact on task performance. Interactions between color manipulations and gender were not reported. In the later series of studies, gender did not moderate the effect of the color cue on intelligence test performance (Lichtenfels et al., 2009; Maier et al., 2008). This is at odds with earlier research in the sports context (Hill & Barton, 2005; Barton & Hill, 2005) and the work on stroop test performance (Ioan et al., 2007) which indicated stronger effects of color red for the male participants. The gender differences observed in the latter studies were explained with reference to our phylogenetic past. The association of red with avoidance and others' dominance was traced back to its adaptive function in competitive encounters. From an evolutionary standpoint males are more inclined to compete than women, hence, men should more strongly react on avoidance signal red than women (Hill & Barton, 2005; Ioan et al., 2007). Moreover we believe that gender differences in the red-effect may be due to competing situational cues that signal avoidance for women irrespective of colored stimuli. Individuals tend to adopt an avoidance goal when they are faced with color red (Elliot et al., 2007; Maier et al., 2008). The situational activation of avoidance goals, however, is not exclusive to color cues. Individuals tend adopt avoidance goals when they are faced with a self-relevant task in a domain in which the group the individual belongs to is believed to underperform (e.g., within the stereotype threat framework: Brodish & Devine, 2009; Seibt & Förster, 2004). As a consequence, when women are confronted with a supposedly male-typed task, avoidance signal red may have little additional influence, due to the negative performance stereotype that already evokes avoidance goals. Indeed, Ioan and colleagues (2007) emphasized the "inter-sexual competitive situation" prior to their cognitive tasks and found no effects of color red for the female subgroup.

Practical implications and open questions

What are the implications of this intriguing line of research? On the one hand, these recent results point at the need for far-reaching consequences in the future choice of colors. The reported effect sizes in the studies are substantial (Elliot et al., 2007; Maier et al., 2008), which suggests striking consequences of – supposedly incidental – color use in applied settings. When the effect sizes obtained in previous studies are extrapolated to the SAT with *M*=500 (*SD*=100), for example, effects due to red color would correspond to score differences of 50 (d = 0.5) up to 80 points (d = 0.8) or a percentile shift of 16 points. These projected test variations, which do not reflect differences in actual abilities but are merely a product of color cues, can yield considerable individual consequences, e.g., on college admissions or job recruitment. In addition to test-taking, red may impede performance across a range of cognitive activities, thus, these results highlight the urgent need to examine educational media, such as schoolbooks or web-based learning material as well as work facilities with respect to the specific colors used. Whereas some colors may help cognitive processing (Keller, Gerjets, Scheiter, & Garsoffky, 2006) red may produce detrimental effects.

On the other hand, the systematic analysis of the red color-performance link is quite recent, corroborated by only a few studies in a small number of laboratories. As outlined above, context matters regarding color effects, and despite the growing evidence on the detrimental effects of red on fluid intelligence measures, it remains open to what extent the effects generalize to cognitive performance in tasks where acquired knowledge and experience play a dominant role. This reflects the classic distinction between crystallized intelligence and general knowledge on one side and fluid intelligence on the other which is backed by the differential ontogenetic development and distinct neurophysiologic bases (e.g., Geary, 2005). Red can have negative effects in some cognitive domains – but positive effects in other domains as a recent study by Mehta and Zhu (2009) pointed out. These authors analyzed the performance in tasks that were presented in a computer lab with either red or blue background screen color. Whereas red (vs. blue) color impeded the performance in creative tasks, red *enhanced* the performance in a memory and a proofreading task.

In sum, these new and important studies demonstrated that red color induces an avoidance motivation which in turn has substantial effects on cognitive performance. Performance in tasks that require creative thinking and fluid intelligence suffered from color red (Elliot, et al., 2007; Ioan et al., 2007; Maier et al, 2008; Mehta & Zhu, 2009). Performance in memory and word processing tasks, by contrast, was lifted (Mehta & Zhu, 2009).

These recent results highlight the importance of investigating color effects in different domains and different settings, in order to provide reliable recommendations for practitioners who create study and work environments. As such it is important to extend previous findings from laboratory studies to the more applied setting of web-based assessment which gains increasing importance in various applied domains (cf. Bartram, 2006; Hartig et al., 2008; Sackett & Lievens, 2008). Human resource management, for example, increasingly relies on web-based procedures – from personality tests to achievement assessments – for the purpose of personnel selection and development (Ployhart, Weekley, Holtz & Kemp, 2003; Tippins et al., 2006). Even off-the-job certification programs like the "Test of English as Foreign Language“ (TOEFL) are provided as web-based tests more frequently (ETS, 2008). Whereas the medium of presentation in itself may not influence the test results (cf. Wang, Jiao, Young, Brooks & Olson, 2008; Williams & McCord, 2006) subtle changes in the mode of presentation may do so. Current software used for creating computerized and web-based studies provide the opportunity to integrate colored features into a survey or cognitive test. This includes rather unobtrusive elements such as the logo of a research institute, the progress bar or the forward-button.

The recent lab experiments on red and cognitive performance indicate that the use of colored elements should be re-evaluated in all web-based assessment. But do the lab studies translate to home computer use? Whereas in the lab, experimenters can control all physical aspects of colored stimuli, the colors of web pages or web surveys vary for each internet user, due to monitor calibration, background lights, etc. No research has tested yet the impact of color on the cognitive performance of home computer users.

Research Goals

The research presented here was guided by the following three goals. First, we wanted to extend the research on the color-performance link to the field of web-based assessment. This would enable us to appraise the detrimental effect of color red under more naturalistic conditions and to judge its robustness in an applied setting.

Second, we aimed at replicating the intriguing effects of red color in tasks of general knowledge. The performance in knowledge tests involves memory processes similar to the ones which were facilitated by color red (Mehta & Zhu, 2009). However, based on the evidence regarding fluid intelligence measures (Elliot, et al., 2007; Maier et al, 2008) we expected red color to impede performance on a general knowledge test.

Third, participant gender was of focal interest. In most knowledge fields that are prompted in standardized tests of general knowledge, men are perceived as more competent (e.g., Banwart, 2007), and men indeed obtain higher scores (e.g., Ackerman, Bowen, Beier & Kanfer, 2001). As a result, red as a signal of danger and likely underperformance should be highly influential for men who otherwise can expect decent success, whereas women were found to automatically adopt an avoidance motivation when a male-typed task is at hand (cf. Brodish & Divine, 2009; Seibt & Förster, 2004). Hence, the detrimental effects of color red should be stronger for men than for women.

We present two web-based studies which concordantly show that men – but not women – perform worse in a general knowledge test when color red (as compared to green or blue) is part of a survey's graphic design.

Experiment 1

Previous research demonstrated that rather subtle color cues are sufficient to affect the participants' cognitive performance (Elliot, et al., 2007; Maier et al, 2008). When developing online-surveys or online-experiments progress bars are a common design feature (cf. Heerwegh & Loosveldt, 2006). This dynamic graphical feature informs the respondent about his or her advancement in the study. Most survey research software provides the opportunity to include such a progress bar and the person in charge of programming the study may choose its color. We intended to increase the ecological validity of our research in manipulating the color of the progress bar, as it is one likely implementation of color in applied survey and testing situations. In line with previous research we assumed lower knowledge scores when red (vs. green) colored progress bars were included into the design of a web-based test. Following our reasoning on potential gender effects in the case of color and general knowledge, the latter effect was expected to be more pronounced for men than for women.

Method

Participants. The sample consisted of 131 students (91 women) aged *M*=25.1 years (*SD*=5.8) with majors in psychology and economics, who were invited by email to participate in a web-study on "General knowledge".

Cognitive measures. A short form of the German version of the Multiple Choice Vocabulary Test (MWT-B; Lehrl, 2005) was used as a baseline measure of cognitive functioning. This measure for general intelligence included 20 items, each consisting of five words from which only one was a meaningful word to choose.

General knowledge was assessed with a short German version of the General Knowledge Test (GKT-D, Lynn, Wilberg & Margraf-Stiksrud, 2004). This measure consisted of 40 questions from diverse topics, including biology, literature or history, (e.g., "Which Roman emperor conquered France and Britain?", "What is the Japanese currency?"). The sum of the correct answers given represented the general knowledge score, our dependent variable (Cronbach's α=.89).

Color manipulation. Starting with the first page of the General Knowledge Test, we integrated a progress bar, 100 x 15 pixels in size, on the upper right hand side of each page. The participants were randomly assigned to either a red or a green progress bar (see Figure S1 in the supporting material available online for an illustration of the progress bars employed in Experiment 1). We chose green as the control condition, because of its usage as a control color in previous studies (Elliot et al., 2007; Maier et al., 2008) and because green is a direct opposite of red in the color spectrum (Shevell, 2003). Colors are usually defined along three dimensions: hue (the pigmentation of the color, e.g. blue, red etc.), saturation, and luminosity (degree of darkness or lightness). In terms of the hue-saturation-luminosity scheme used with computers, we specified colors corresponding to "pure" red (hue=0, saturation=240, luminosity=120) and "pure" green (hue=120, saturation=240, luminosity=120). However, these colors are only properly reproduced on accurately calibrated monitors; unfortunately those are effectively never found in practice. Usually saturation and hue vary from monitor to monitor, even when models from the same manufacturer are considered. This implies that in a lab experiment where colors are presented on screen, displayed color may differ from the color specified by the experimenter (hue, saturation, and luminosity). At home and at work, internet users have different monitor models and graphic cards, and singular system calibrations. As a consequence, a red progress bar will be recognized as red, or green respectively, but it cannot be guaranteed that the color that is displayed follows exactly our intended hue, saturation, and luminosity. Despite this obvious limitation our approach strengthens the ecological validity of the presented studies, as we do not aim to reproduce synthetic conditions in a laboratory, but reflect real circumstances in applied settings. Except for this design element, the questionnaires were uncolored and identical in content. Taking into account the gender of the participants, this experiment followed a 2 (bar color: red or green) x 2 (gender: male or female) between subjects design.

Procedure. All items were presented online and were accessed by the participants via the web browser of their home computers. The software used for presenting the experiment and collecting data, *EFS-survey*, monitored potential repeat responders through IP protocols (cf. Gosling, Vazire, Srivastava, & John, 2004) and collected the time spent with different parts of the study. The web-based questionnaire started with a brief overall instruction and the MWT-B intelligence items. Subsequently, the Knowledge Test (GKT-D) was presented in 10 thematic blocks of four items each. The orders of the blocks as well as the order of the items on each page were randomized for each participant. Finally, demographic variables were assessed and the participants were debriefed.

Results and Discussion

We assumed that respondents in the green color condition outperformed participants in the red color condition and that this effect might be stronger in the male subgroup. By random assignment, 65 participants (47 female) answered the questions with the green progress bar, 66 (44 female) answered the questions with the red progress bar. To test our hypotheses, we conducted a 2 (color: green or red) x 2 (gender: male or female) analysis of variance. In line with previous studies that employed the same or similar measures of general knowledge, women obtained lower scores than men, $F(1, 126)=33.33$, $p<.01$, $\eta_p^2=.31$. As expected, we found evidence that the green color group scored higher than the red color group, $F(1, 126)=8.64$, $p<.01$, $\eta_p^2=.06$. However, this effect for color was qualified by an interaction between color and respondents' gender, $F(1, 126)=4.16$, $p=.04$, $\eta_p^2=.03$ (see Figure 1). Whereas male participants were significantly impeded by the color red, $F(1, 126)=8.90$, $p<.01$, $\eta_p^2=.07$, the color variation had no significant impact on women, $F(1, 126)=0.67$, $p=.42$, $\eta_p^2=.01$.

In order to control for potential sampling error, we recalculated our analysis with age and fluid intelligence as covariates. The results of however remained virtually unchanged: An ANCOVA with gender and color treatment as predictors and age and fluid intelligence as covariates yielded a main effect of color $F(1, 124)=10.03$, $p<.01$, $\eta_p^2=.07$ and an interaction effect of $F(1, 124)=4.44$, $p=.04$, $\eta_p^2=.03$.

Taken together, our study of participants who used their home computer to access the cognitive test correspond with previous lab research that reported detrimental effects of color red in achievement settings. A rather unobtrusive manipulation of the progress bar color influenced participants' performance. However, in line with some (but not all) previous studies, only male participants were impeded (cf. Ioan et al., 2007).

| Figure 1 around here |

Experiment 2

The goal of Experiment 2 was to provide further evidence for the gender-dependent effect of color red on online knowledge test performance in a second, independent sample (cf. Steiger, 1990). To guard against potential alternative interpretations of the results in Experiment 1 we changed the study design in several important ways. We again observed the performance in a web-based general knowledge test under different color conditions. However, unlike Experiment 1 we a) compared red with the color blue, which is associated with peace and tranquility (Aslam, 2006), to demonstrate that the observed effect is due to the color red and not the control color; b) we changed the design element that carried the color manipulation to highlight the relevance of the color manipulation itself rather than the object carrying the color; c) we included a mixed color condition where red color was only initially depicted to provide an even more subtle color cue compared to static color elements; and d) we used more knowledge test questions to investigate color effects and color-gender interactions in a range of knowledge domains.

We expected an effect produced by the color manipulation of the forward button resulting in the lowest knowledge scores in the red color condition and the highest scores in the blue color condition, with the mixed condition in-between. This result pattern was expected for male participants; in the female sub-sample, however, the color effects should be reduced or even absent leading to a gender by color interaction.

Method

Participants. Participants were invited to take part in the study on four public student message boards reaching students with majors in economics, computer sciences, medicine and psychology. All materials were presented online and were accessed by the participants via the web browser of their home computers. The same software was used as in Experiment 1. The recruited sample consisted of 190 students (99 women) with an average age of 24.3 years (SD=5.1).

Cognitive measures. As a measure of basic cognitive functioning, the German version of the Brief Verbal Intelligence Test was employed (VKI, Anger, Mertesdorf, Wegner, & Wülfing, 1980). This test consists of 20 words which have to be linked to one of four graphic scenes. Mainly focused on verbal intelligence, it was introduced as a proxy-measure for basic reasoning.

General knowledge was again assessed with the German General Knowledge Test (GKT-D, Lynn et al., 2004), albeit with a longer, 89-item version of this instrument (Cronbach’s α=.93). The knowledge domains included for example popular music, discoveries, sports, politics, art, and history.

Color manipulation. The color manipulation differed in three regards from the previous experiment. Firstly, we compared red with the color blue. Secondly, we changed the critical design element. We manipulated the “forward”-button, 80 x 22 pixels in size, which is an integral part of online surveys. This button allows switching to the subsequent page of an online survey. Similar to the progress bar, the forward-button is a likely implementation of color in applied survey and testing situations. Thirdly, we included a mixed color condition. For one third of the participants, all forward buttons on the pages of the general knowledge test were colored red, for another third of the participants, all forward buttons on the pages of the general knowledge test were colored blue. In the mixed color-condition, the first forward button on the introductory page of the general knowledge test was red, all subsequent 16 forward buttons were blue.

The participants were randomly assigned to one of the three color conditions (see Figure S2 in the supporting material available on-line for an illustration). Again “pure” colors of red and blue were specified, which correspond to a hue of 0° and 240°, full saturation and the same luminosity. Except for this design element, the questionnaires including the progress bar were uncolored and identical in content.

Procedure. The procedure was similar to Experiment 1. The web-based questionnaire started with a brief overall instruction and the VKI intelligence items. Subsequently, the Knowledge Test (GKT-D) was presented in 16 thematic blocks of 4-6 items each. The order of the blocks as well as the order of the items on each page were randomized for each participant. Finally, demographic variables were assessed and the participants were debriefed. The experiment followed a 3 (progress button: red or blue or mixed) x 2 (gender: male or female) between subjects design.

Results and Discussion

Respondents in the blue color condition should outperform participants in the red color condition with the mixed condition in-between. Based on previous research and the results of Experiment 1, this pattern of data was expected for males, however, predictions for the female subgroup were less clear. By random assignment, 62 participants (36 female) answered the questions with the blue forward-buttons, 71 participants (33 female) answered the questions with the red forward-buttons, and 57 participants (30 female) answered the questions with the progress bars that switched colors.

To test our hypotheses, we conducted a 3 (color: blue, red/blue or red) x 2 (gender: male or female) analysis of variance. In line with previous research we found a main effect for gender, women obtained lower scores than men, $F(1, 183)=25.22$, $p<.01$, $\eta_p^2=.12$. Contrary to Experiment 1 we found no main effect for the color manipulation, $F(2, 182)=0.44$, $p=.65$, $\eta_p^2=.01$. But again there was an interaction between color and respondents' gender, $F(2, 183)=5.24$, $p=.01$, $\eta_p^2=.05$ (see Figure 2). Whereas the color variation had no impact on women, $F(2, 182)=1.56$, $p=.21$, $\eta_p^2=.01$, male participants were significantly influenced by the color manipulation, $F(2, 182)=4.03$, $p=.02$, $\eta_p^2=.04$. As expected men achieved significantly lower scores in the red ($M=44.21$, $SD=2.24$) compared to the blue ($M=54.19$, $SD=2.71$) condition, $F(1, 87)=7.08$, $p<.01$, $\eta_p^2=.07$. In line with our hypothesis the knowledge scores of the red/blue condition ($M=48.48$, $SD=2.66$) fell between those of the blue and red conditions; yet the differences between the red/blue color group and the other groups failed to reach the level of significance, $F_{blue}(1, 87)=1.99$, $p=.16$, $\eta_p^2=.02$ and $F_{red}(1, 87)=1.33$, $p=.25$, $\eta_p^2=.02$.

| Figure 2 around here |

Again, we recalculated our analysis with age of the respondent and a baseline measure of cognitive functioning (VKI intelligence, Anger et al., 1980) as covariates. The results of an ANCOVA with gender and color treatment as predictors and age and intelligence as covariates, however, mirrored the previously reported effects, yielding no significant main effect of color $F(2, 180)=.83$, $p=.44$, $\eta_p^2=.01$ but a significant interaction effect of $F(2, 180)=4.24$, $p=.02$, $\eta_p^2=.05$.

Experiment 2 showed that graphic design features colored red (as compared to blue color) impede the knowledge test performance of our male subgroup, while women were unaffected. Additional analyses focused on separate knowledge domains. Descriptive data indicate that men obtained higher scores than women in all knowledge domains, except for the domains “fashion”, ”literature” and “nutrition”. Descriptive graphical slope analyses show that red has more negative effects for men than for women in all of the examined knowledge domains. Thus, our general pattern of results was found irrespective of the domain.

General Discussion

Colors are an integral aspect of human perception and part of our daily environment, but not much is known about its impact on everyday psychological functioning (Elliot et al., 2007). We expanded the recent surge in research on color psychology (Elliot et al., 2007; Ioan et al., 2007; Maier et al., 2008; Mehta & Zhu, 2009) with two web-based studies on general knowledge. We demonstrated that the detrimental effect of red on cognitive performance extends to the domain of general knowledge, a main indicator of crystallized intelligence. The impact of red was found in two independent experiments with two different contrast colors (green, blue) using two different color manipulations (progress bar, forward button). Whereas the performance of men dropped in the red condition, female performance remained unaffected. With effect sizes ranging between $\eta^2_p = .04$ and $\eta^2_p = .07$ the impact of color red is hardly non-trivial, but has to be considered of medium size according to conventional criteria (Cohen, 1992).

In previous research, a gender-dependent color effect had been reported by some researchers (Barton & Hill, 2005; Ioan et al., 2007), but others found similar color effects for both genders (e.g., Maier et al., 2008; Mehta & Zhu, 2009). In order to interpret the gender effect, we would like to stress two basic notions underlying the recent research on the impact of red color on human behavior: evolutionary advantage and context. A great majority of researchers that investigated the red color-performance link attributed the impact of color red at least in part to a signaling function which was adaptive in human phylogenetic history (Barton & Hill, 2005; Elliot et al., 2007; Ioan et al., 2007; Maier et al., 2008). According to this explanation, the association of red with avoidance and others' dominance (which leads to underperformance in achievement contexts) is rooted in competitive encounters. Throughout many species males are biologically programmed to compete with other males for status, territory, mates etc. Females on the other hand are inherently less competitive, which is attributed to different costs in reproduction (Buss, 2007). As a means of conflict resolution a variety of signals have evolved to reduce the frequency of destructive fights, which can be harmful to both opponents. The color red is one such signal of male dominance and testosterone level in many species including non-human primates (Pryke et al., 2002; Setchell & Dixson, 2001; Setchell & Wickings, 2005). Therefore, reacting to red has played an important role for the survival and reproduction of males in the competition and achievement domain (Barton & Hill, 2005; Ioan et al., 2007). For women, according to this reasoning, the association of red with dominance and avoidance had been of a weaker importance for survival and reproduction. Hence, according to evolutionary theories, men are expected to be more vulnerable towards the detrimental effects of color red than women in achievement contexts, a gender difference that is reflected by our findings.

The differential adaptive advantage throughout our phylogenetic history seems to play a role, but other factors and mechanisms may contribute to the gender-dependent color effects reported here and elsewhere. In the present studies women had lower knowledge scores than men overall, which is in line with many other studies that applied the present inventory (e.g., Furnham, Christopher, Garwood & Martin, 2007) or similar tests (e.g., Ackerman et al., 2001). General knowledge is a domain where women are perceived to perform worse than men on average (Banwart, 2007). In our studies, the actual gender difference was reduced in the red condition, due to the detrimental effect of red on the male subgroup. The red effect has been explained by a situational avoidance motivation (Elliot et al., 2007; Maier et al., 2008). However, color red is not the only sign that may trigger a situational avoidance motivation. Individuals are likely to adopt an avoidance goal when they are faced with a self-relevant task in a domain in which the group the individual belongs to is believed to underperform (e.g., Brodish & Devine, 2009). The situational predicament of stereotype threat (cf. Ryan & Ryan, 2005; Steele, 1997) impedes women in male domains. Stereotype threat findings regarding political knowledge (McGlone, Aronson, & Kobrynowicz, 2006) and general knowledge (Seibt & Förster, 2004) suggest that women adopt an avoidance goal when confronted with a general knowledge test. As a consequence, for those who are already in a state of avoidance motivation, the additional avoidance signal red should be less influential. Taken together both theoretical perspectives, evolutionary psychology and stereotype threat theory explain why only men were susceptible to the detrimental effects of color red on demonstrated knowledge.

Despite the contribution of our studies, several limitations have to be noted. First, the web-based approach made it impossible to control the color cues as strictly as in the lab. Participants used their private computers at home to access the study material. As different monitor types and settings transfer the same color settings differently, the exact hue or saturation of the displayed color red may have varied slightly from participant to participant. This source of variance may have lowered the power of our treatment. We further cannot rule out the possibility that singular users may have worked with a malfunctioning computer setting with distorted color display. However, these naturally occurring variations work against the impact of colored cues; thus, a more tightly controlled stimuli variation may have lead to more extreme effects (e.g., Maier et al., 2008). Second, in web-based studies without supervision environmental factors are generally less controllable than in comparable lab research and the participants remain rather anonymous. An extensive discussion on lab studies vs. web-based studies is beyond the scope of this work, however, existing research points at the reliability and validity of web-based data (e.g., Dandurand, Shultz &Onishi, 2008; Musch & Klauer, 2002; Preckel & Thiemann, 2003), especially when – like in our experiments – steps against repeat responders are taken (cf. Gosling et al., 2004). However, future research may profit from a combination of studies conducted online and in the lab. Third, we did not control for color vision deficiency which affects about 8% of the male and 0.5% of the female population in the (Caucasian) population (Coren, Ward, & Enns, 1999). Given that the effect of the color manipulation should be reduced or completely absent for participants with limited color vision, we may have underestimated the effect of color on men, who in our study already showed substantial effects. Fourth, our research did not directly address mediation. Recent research (Elliot et al., 2007; Maier et al., 2008; Mehta & Zhu, 2009) consistently showed that color red triggers avoidance motivation in achievement contexts which in turn leads to characteristic behavioral effects. We do acknowledge that an additional support of this mediational pathway would have strengthened our contribution. Our focus, however, was on an extension of the red-performance-link to hitherto unexplored tasks and contexts (web-based testing, general knowledge) and the moderating influence of gender.

Conclusions and future research

This is the first empirical investigation on the effect of red when individuals use their own computer at home or wherever they habitually connect to the internet. Thus, our results support the notion that the impact of color red is strong enough to take effect in everyday life, where perception is less controllable and individuals encounter multiple motivational signals (Elliot et al., 2007). Our experiments contained subtle color manipulations and demonstrated that, when colored red, frequently used design elements can impair cognitive performance. Although red may alleviate performance in simple tasks that require rigid processing (Mehta & Zhu, 2009) creativity, flexible processing, and the retrieval of stored knowledge are disturbed by red color. The fact that most computer-based tasks involve the use of acquired knowledge as well as flexible mental manipulation underscores the relevance of our results. Based on our own work and the intriguing literature on color that developed in recent years, we believe designers of web-based materials should bear in mind that the (incidental) use of color red can impair the cognitive performance of their participants or users.

Given the rather brief history of systematic research on the link between red and cognitive performance, more research is needed on the scope of this influence. This may imply an analysis of yet unobserved tasks (e.g., the impact of color on computer-based collaboration), as well as factors that affect motivational states such as high incentives to perform well (e.g., effects in occupational aptitude tests for personnel selection). Moreover, most studies so far manipulated rather small, unobtrusive parts of questionnaires. It is still unclear whether the dominance of the red color stimuli (e.g., the size, the stimuli’s function in completing a task) affects the process and results. Future research may further include investigations on additional mediating variables and processes (e.g., cognitive load; emotion regulation). Further research is needed on participant gender in the realm of color effects. This may involve a simultaneous investigation of different tasks and domains as well as approaches to contrast the theoretical frameworks that explain gender differences in the effect of color red on performance.

We believe that diverse lines of research on new media can profit from considering the relevance of color more often, as the recent color psychology our work was based on is not limited to questions of achievement and performance. Red color was found to enhance interpersonal attraction (Elliot & Niesta, 2008), and to influence consumer ad evaluations (Mehta & Zhu, 2009; Study 5) and health communication effects (Gerend & Sias, 2009). Color is omnipresent in educational and entertainment computer games, social networking sites, online advertising, and in many other content and applications. Its impact on the experience and behavior of computer users largely remains to be discovered.

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Figure caption

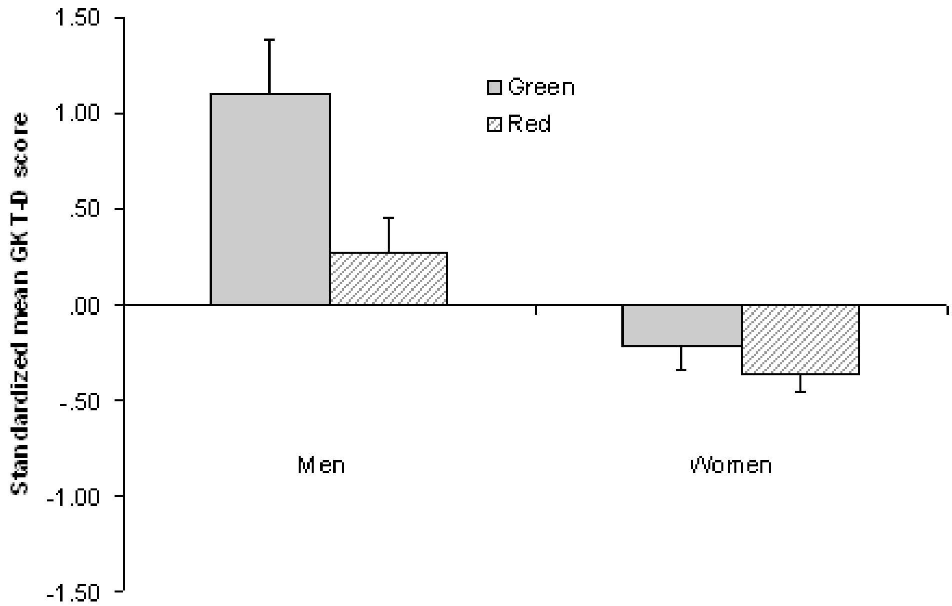
Figure 1. Standardized mean general knowledge scores (GKT-D) for gender under green and red color conditions (Experiment 1). Error bars ± 1 SE. *N* = 131.

Figure 2. Standardized mean general knowledge scores (GKT-D) for gender under blue, red/blue and red color conditions (Experiment 2). Error bars ± 1 SE. *N* = 190.

Figure S1. Color manipulation in Experiment 1.

Figure S2. Color manipulation in Experiment 2. Only the first three pages are shown.

Figure 1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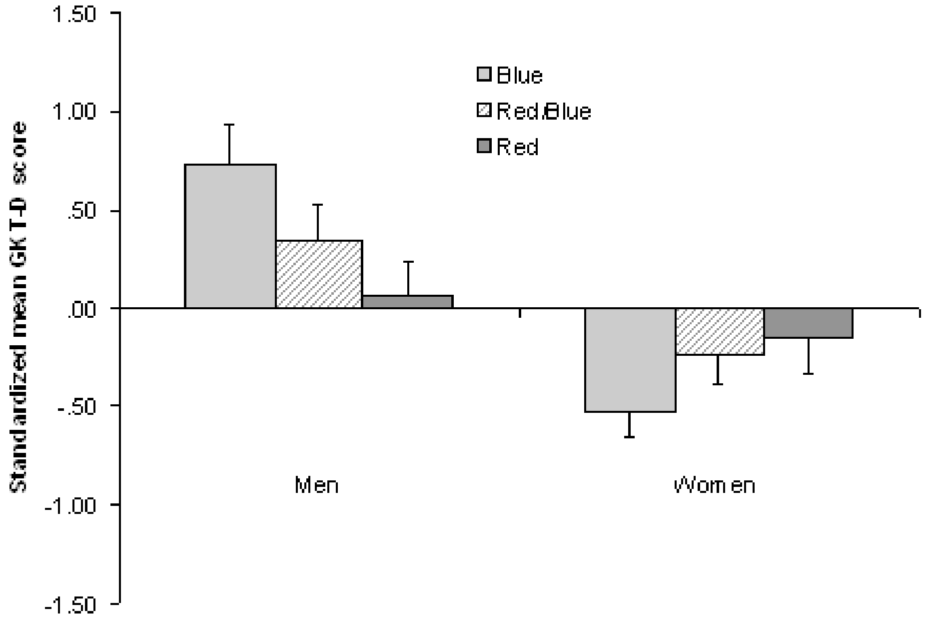
Standardized mean GKT-D score
Green
Red
Men
Women

Figure 2


1.50
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Standardized mean GK T-D score
Blue
Red/Blue
Red
Men
Women

Figure S1

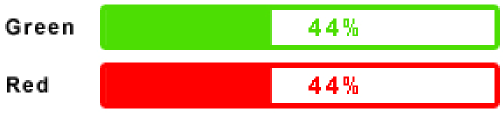
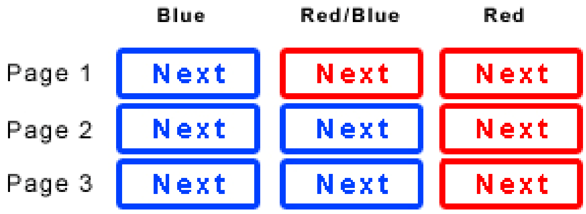


Figure S2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