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Color's impact on maximal torque production – Casting a light on the timing of viewing red

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Previous research has suggested that viewing the color red immediately prior and during motor performance facilitates motor action. However, viewing red at a delay prior to performance should cause a decline in motor action. In the current study we tested these assumptions. Participants performed maximal voluntary isometric contractions (MVIC) of the right knee extensors and rated the quality of each attempt. In the first experiment (n = 58) instructions in red, blue or gray (matched on lightness/saturation) were shown in a randomized order on a computer screen from five seconds prior to and during MVICs. Results revealed a significantly higher rate of torque development and better ratings when viewing red. In the second experiment (n = 32) color manipulated instructions (red, blue, gray) were shown from 50 to 40 seconds prior to MVICs. The results did not show the assumed decline when viewing red at a delay prior to motor action.

KEY WORDS: hue, force, performance, threat, cognition.

Introduction

Past research demonstrated that the color red not only possesses esthetical functions, it also carries psychological meanings that significantly affects the behavior of humans and non-human primates (Bergman, Ho, & Beehner, 2009; Elliot, 2015; Elliot & Maier, 2007; Setchell & Wickings, 2005). Most notably, research in evolutionary biology and psychology has indicated that the color red is associated with danger and threat and that these associations might affect human performance (Briki & Hue, 2016; Krenn, 2015; Mentzel, Schücker, Hagemann, & Strauss, 2017; Pravossoudovitch, Cury, Young, &

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Elliot, 2014; Zhang, Feng, Han, & Sun, 2018). However, research questioning the impact of the color red on performance revealed inconsistent findings: Several studies found the color red to enhance human performance, whereas others reported performance impairments (Elliot & Maier, 2012; Elliot, Payen, Brisswalter, Cury, & Thayer, 2011; Hill & Barton, 2005; Mehta & Zhu, 2009; Xia, Song, Wang, Tan, & Mo, 2016). Furthermore, small effect sizes were reported throughout the analyses and several studies did not detect significant effects of the color red (Allen & Jones, 2014; Carazo & Moncada-Jiménez, 2014; Curby, 2016; García-Rubio, Picazo-Tadeo, & González-Gómez, 2011; Kocher & Sutter, 2008; Krenn, 2014; Krenn, Pernhaupt, & Handsteiner, 2017). As a consequence, doubts were raised about the consistency and validity of the color red's impact. Thus, there is a high need for research scrutinizing moderating/mediating variables of the impact of the color red on human performance. The current study is aligned with this area of research and focuses on the impact of viewing the color red on simple motor output, taking the timing involved in perceiving the color red into consideration.

In intellectual and creative tasks past research found that viewing the color red decreased performance; whereas in detail-oriented and more simple cognitive tasks, the color red was found to increase performance (Elliot, Maier, Moller, Friedman, & Meinhardt, 2007; Mehta & Zhu, 2009; Xia et al., 2016). The authors argued that the color red – as a sign of threat and danger – increases avoidance motivation, making people more vigilant and risk-averse. This effect would further enhance human performance in simple and detail-oriented tasks, but hinder human performance on intellectual or creative tasks (Elliot & Maier, 2014; Elliot, Maier, Binser, Friedman, & Pekrun, 2009; Mehta & Zhu, 2009). However, motor tasks research investigating the impact of the color red revealed inconsistent findings. In a pilot study, Briki, Rinaldi, Riera, Trong and Hoe (2015) revealed that the color red decreased motor performance in a cycling task over time. They observed that athletes, who were exposed to a red environment covered less distance in a seven-minute trial than those exposed to green and gray environments. In contrast, Crane, Hensarling, Jung, Sands and Petralla (2008) reported that red light enhanced muscular power in a cycling task, whereas other studies failed to detect such a beneficial impact (Akers et al., 2012; Etnier & Hardy, 1997). Thus, research did not succeed at clarifying the conditions and characteristics of how the color red may affect cognitive and motor aspects of performance.

Some decades ago, several studies questioned the impact of perceiving the color red on force production. A few studies found higher grip strength

values after perceiving the color red (Green et al., 1982; Hasson, Williams, Gadberry, & Henright, 1989); whereas other studies, which controlled for potential confounding variables, failed to replicate these findings (e.g., controlled for saturation, lightness; (Dunwoody, 1998; Ingram & Lieberman, 1985; Keller & Vautin, 1998)). Recent research raised the idea that the timing of viewing the color red played a major role in determining the intensity of the color red's impact. Elliot and Aarts (2011) found that perceiving the color red prior to and during the performing of a strength test enhanced maximum force and the rate of force production. Participants viewing the color red produced greater force and reached peak force more quickly. In the same year, Payen et al. (2011) reported contrasting findings when participants perceived the color red several seconds prior – but not during – their task performance. By showing participants a red rectangle several seconds prior to the onset of a motor action, they found a decreased rate of force development. The authors argued that the color red functions as a threat cue that causes a phylogenetically basic avoidance/defense system taking care of the processing and responding necessary for handling such stimuli. This system mobilizes energy for protective action, which momentarily increases an individual's force production (Briki et al., 2015). The avoidance/defense system seems to be based on subcortical structures, mainly the amygdala and basal ganglia, which require – in case of any threat stimuli – motor output causing a fight or flight reaction (Carretié, Albert, López-Martín, & Tapia, 2009; Elliot et al., 2011; Payen et al., 2011). As a function of the temporal presentation of the threat cue, the immediate, urgent response might cause fear, facilitating a more efficient and effective simple motor output (Coombes, Cauraugh, & Janelle, 2007a, 2007b; Coombes, Higgins, Gamble, Cauraugh, & Janelle, 2009). However, a more distal, anticipatory response might inhibit efficient and effective motor action by providing anxiety and doubt about an upcoming social evaluation (Eysenck, Derakshan, Santos, & Calvo, 2007; Payen et al., 2011). Thus, by enlarging the timing interval between the color cue and onset of actual performance, the tendency of the color red to increase motor performance should decline. This seems to be in line with general threat research, which indicated that threat stimuli presented immediately prior to or conterminously with motor action facilitates motor response speed and accuracy, whereas threat stimuli more prior to motor action decreased the speed and accuracy of motor action (Chalabaev et al., 2013; Coombes et al., 2007a, 2007b; Coombes et al., 2009; Coombes, Naugle, Barnes, Cauraugh, & Janelle, 2011).

Research focusing the impact of the color red on motor action seems to point out a momentary benefit when viewing the color red. This benefit

might become a drawback if the time period in which the color red is perceived or the temporal gap between perceiving red and performing is increased (Briki et al., 2015; Elliot & Aarts, 2011; Payen et al., 2011). However, the studies dealing with the impact of the color red on motor output have fallen short of standardizing the temporal features of perceiving red. Most notably, the timing interval between the red stimuli and the onset of motor action was not standardized (Dunwoody, 1998; Elliot & Aarts, 2011; Green et al., 1982; Hasson et al., 1989; Payen et al., 2011). Taking the opposing results into consideration – namely that the color red may facilitate but also impede the extent and rate of force production due to the temporal presentation of red – the exact timing of perceiving red may play a crucial role in understanding how the color red might affect psychological functioning and motor behavior. Accordingly, the current study aimed to complement previous research at investigating the impact of perceiving the color red on the extent and rate of torque production in a standardized maximal isometric strength test. In the first experiment, color manipulation was implemented 5 seconds prior until the end of maximal torque measurement. In the second experiment, color manipulation was shown 50 seconds prior the onset of maximal torque measurement. To extend on previous research, in both experiments we chose within-subjects designs, use of larger sample sizes, standardized the timing of the color cues, controlled for saturation and lightness when manipulating the color's hue (Elliot, 2015) and used a highly reliable and valid measurement of torque and rate of torque development (Dirnberger, Wiesinger, Kösters, & Müller, 2012; Roth, Donath, Kurz, Zahner, & Faude, 2017).

Experiment 1

Method

Participants

A priori power analysis (G*Power, Version 3.1.9.2) was conducted, with a target power of .80, an expected Cohen's f of .10 (small effect size) and a large correlation of .85 between the different color conditions. A sample size of 50 participants was recommended. In total, 58 individuals (31 males, 27 females) participated in this experiment. Their mean age was 24.43 ± 2.79 years (range 18 - 32 years). Participants reported to exercise for 7.29 ± 3.72 hours per week. Inclusion criteria was limited to individuals without any color deficiency or health risks for the conducting of MVICs of the right knee extensors. To control for any muscle fatigue that could affect torque production, participants were instructed to refrain from participating in any exhausting physical activity within 24 hours preceding the experiment. Five partici-

pants guessed the main purpose of the study correctly (control question) and were excluded from further data analysis[1].

Design

A within-subjects design was assessed, in which participants had to conduct three maximal voluntary isometric torque measurements of the right knee extensor muscles on an IsoMed 2000-dynamometer (D&R Ferstl GmbH, Hemau, Germany). Participants were presented with a standardized set of instructions on how to execute the task using a computer screen displayed one meter in front of the participant. The color manipulation was implemented in participants' instruction. Before each MVIC, participants watched a five second countdown consisting of the individual numbers 5, 4, 3, 2, and 1. At zero seconds, the word "PUSH!" was displayed for 5 seconds. Each number of the five-second countdown and the instruction "PUSH!" was displayed in either red, blue or gray. These color conditions were shown in a randomized order. Thus, the color manipulation started five seconds prior to MVIC and lasted until the end of the maximal torque measurement (5 sec). Figure 1 displays the experimental procedure. Color manipulation was conducted with Adobe Photoshop CS5. Saturation and lightness were kept constant and its LCh values were measured on the screen via a spectrophotometer (i1 pro x-rite). The measured LCh parameters were: red (53.25/71.85/42.07), blue (52.40/73.93/288.19) and gray (52.85/-/145.09). The order of the color condition was randomized to control for any learning effects. To control for muscle fatigue in between the different trials, two minutes of rest were implemented after each MVIC.

Aligned with the methodology of Payen et al. (2011), two dependent variables for motor output were analyzed. First, the peak torque (PT) as a representation of the ability to produce a maximal voluntary contraction; second, the rate of torque development (RTD), calculated as the slope of the torque-time curve from the onset of the contraction to 250 ms. In addition, we asked participants to rate the quality of their attempts via four bipolar items (bad-good, lethargic-energetic, lazy-explosive, powerless-powerful) from 1 to 7. Participants rated each item via a keyboard, which was positioned next to them. The selection of the items resulted from the analyses of preliminary studies and were derived from previous color research in sport assessing face valid items to measure performance and a person's perception (Feltman & Elliot, 2011; Furly, Dicks & Memmert, 2012; Greenlees, Leyland, Thelwell, & Filby 2008; Krenn et al., 2017). Cronbach's alpha for all four items was .94. The items were also presented on screen during the rest periods.

Procedure

Upon arrival at the laboratory, participants were informed that the study was conducted to collect standard values for a maximum strength test with the IsoMed 2000 dynamometer. They filled out an informed consent form and a short questionnaire assessing sociodemographic and

[1] By including the participants, who guessed the purpose of the study correctly, the results of the experiments would not have changed.

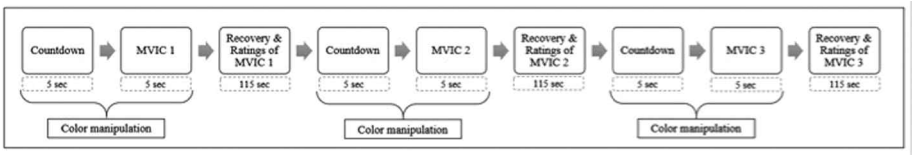

Fig. 1. - Experimental procedure of Study 1. The countdown (5-4-3-2-1) and the word "PUSH" (during maximal voluntary isometric contractions (MVIC)) was color manipulated and presented in randomized order (red/blue/gray).

sport-biographical data as well as any potential health risks for participating in the study. Afterwards participants had to take their place on the dynamometer to measure MVICs of the right knee extensor muscles. The subjects were tested seated with a hip angle of 75° and knee angle of 90°. Straps were positioned over the pelvis and tested thigh to prevent extraneous movement. Additionally, shoulder pads were used according to the manufacturer`s specifications.

All instructions were presented via a 23-in. screen (Acer T232HL) positioned 1 m in front of the participants. The instructions were shown in black text on a white background, whereas the color cues were displayed either in red/blue/gray text respectively on a white background. At first, participants received initial information about how to execute the maximum isometric torque measurements. They were instructed to push for 5 seconds as hard and as fast as possible, until the word "PUSH!" disappeared from the screen. To familiarize themselves with the device and task, they conducted four practice contractions; two with submaximal isometric torque (50%) and two with maximal isometric torque. Prior to each submaximal isometric measurement, one minute of rest was implemented, whereas prior to each maximal isometric measurement two minutes of rest were implemented. Afterwards, the experiment started with three MVICs, at which the order of the colored countdown and instruction to "PUSH!" in red, blue and gray text was randomized. Aside from the order of the color condition, all participants completed the same experimental procedure. At the end of the experiment, a control question concerning the color manipulation was asked. Five participants stated that the study had something to do with colors. Even when they did not guess the main purpose of the study correctly, we excluded their data from further analysis (this

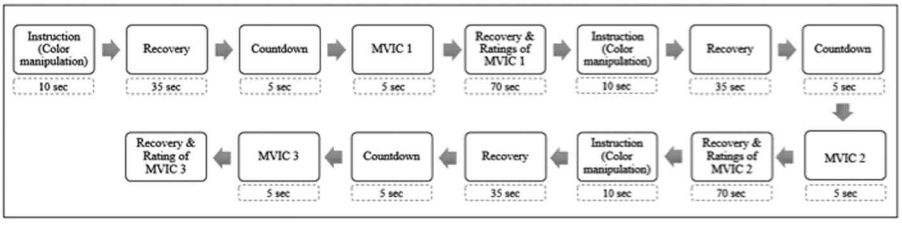

Fig. 2. - Experimental procedure of Study 2. Words of the introduction ("next strength measurement") were color manipulated and presented in randomized order (red/blue/gray) 50 seconds prior the maximal voluntary isometric contraction (MVIC).

selection did not affect the results). Finally, participants were verbally debriefed and informed about the actual goal of our study. The study was approved by the ethical committee of the University of Vienna.

Statistical methods

To analyze the data repeated-measures ANOVAs were used to examine any discrepancies between the red, blue and gray color condition for the PT, the RTD and the means of the individuals' self-reported quality of their attempts. To control for any gender effects, we implemented gender as independent variable. Bonferroni post hoc tests were assessed to clarify any significant differences between the color conditions. The alpha level was set at .05.

Results and Discussion

Repeated measures ANOVA did not reveal any significant impact of color on PT ($F(2,102) = 1.82$, $p = .17$). The means for the colors of red ($M = 206.07$, $SD = 84.39$), blue ($M = 202.99$, $SD = 85.09$) and gray ($M = 200.89$, $SD = 83.93$) did not differ. Also, the interaction of color condition and gender did not reveal a significant impact on PT ($F(2,102) = .80$, $p = .45$). However, for RTD a significant impact of color was revealed ($F(2,102) = 3.38$, $p = .04$, $\eta^2 = .06$). Bonferroni post hoc tests clarified that red was found to show a significantly higher RTD than blue ($p = .03$), whereas the difference to gray did not prove significance ($p = .14$). Figure 3 displays the significant effect. The interaction of color and gender did not reveal significance ($F(2,102) = 2.63$, $p = .08$). The effect of color on participants' self-reported quality of the MVIC ($F(2,102) = 3.47$, $p = .03$, $\eta^2 = .06$) was significant. Participants rated their attempts better after viewing red than after viewing blue or gray (see Figure 4). Bonferroni post hoc tests again detected a significant difference between red and blue ($p = .04$) but not between red and gray ($p = .38$). [please insert Figure 3 and Figure 4 here] However, the interaction of color and gender did not turn out significant ($F(2,102) = .16$, $p = .85$).

The results clarify that viewing the color red five seconds prior to and during a maximum strength test did affect the onset of motor action. The results corroborate the findings of previous studies to some extent (Elliot & Aarts, 2011; Green et al., 1982; Hasson et al., 1989). Viewing red immediately prior to and during a simple motor task increased the velocity of force production in comparison to blue, whereas the maximum torque generated did not differ between the red and the chromatic control (blue – matched to red on lightness and chroma) or achromatic control color (gray – matched to red on lightness). Furthermore, the self-reported quality of individuals' max-

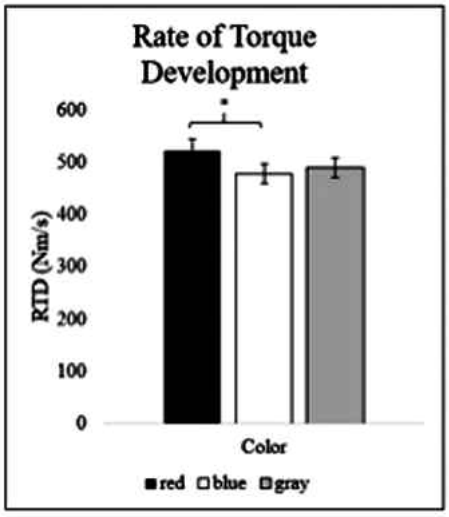

Fig. 3. - Means (incl. SE) for the rate of torque development (RTD) for all color conditions in experiment 1 (color was displayed in a 5- second countdown and during motor performance). * Significant at α =.05.

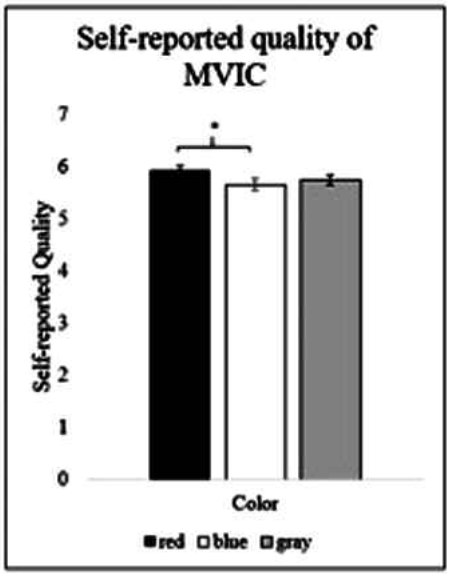

Fig. 4. - Means (incl. SE) for the self-reported quality of maximal voluntary isometric contractions (MVIC) for all color conditions in experiment 1 (color was displayed in a 5- second countdown and during motor performance). * Significant at α =.05.

imal isometric contractions went along with the higher RTD for viewing red in comparison to blue. Participants showed better ratings after the red color cues than after the blue color cues. Any interactional effects of color condition and gender did not reveal significance, which is line with previous findings on MVICs (Elliott & Aarts, 2011).

Experiment 2

The second experiment was aimed at analyzing the impact of viewing the color red 50 seconds prior to the onset of motor action. The design and procedure of experiment 1 was largely replicated.

Method

Participants

Again a priori power analysis (G*Power, Version 3.1.9.2) was conducted, with a target power of .80 and an expected Cohen's f of .10 (small effect size) and a large correlation of .90 between the different color conditions (which was adopted in consideration from the data analysis in experiment 1). A sample size of 34 participants was recommended. In total, 32 (17 male, 15 female) students of sport science and psychology participated in this study. Their mean age was 23.93 years (*SD* = 4.06; range 18 – 36 years). Participants stated to exercise for 8.93 ± 3.47 hours a week on average. Again, participation was limited to individuals without any color deficiency, without any health risks for conducting MVICs and without any participation in an exhausting physical exercise during the last 24 hours leading up to the experiment. Three participants guessed the main purpose of the study correctly (control question). In accordance with experiment 1, their data was excluded from further analysis[1].

Design & Procedure

The design and procedure of the first experiment was retained, with the exception of the timing of the colored stimuli to be viewed. The color manipulation was implemented for ten seconds in the rest period between the isometric measurements. Fifty seconds prior to the MVIC (45 seconds prior to the countdown), participants were informed that their next strength measurement would follow shortly. The words "next strength measurement" were displayed in the manipulated color of red (52.37/74.52/38.07), blue (52.90/75.93/282.19) and gray (52.65/-/155.91) on a white background (Arial, font size 115 Pt). The five-second countdown and the instruction "PUSH!" was now displayed in black text on a white background. Figure 2 displays the experimental procedure of experiment 2. The order of the color cues again was randomized. Statistical analyses were conducted as in experiment 1.

Results and Discussion

The repeated measures ANOVA did not detect any significant impact of color condition on PT ($F(2,54) = .09$, $p = .91$) or RTD ($F(2,54) = .94$, $p = .40$). Again, the maximum torques did not differ between the color conditions of red ($M = 214.99$, $SD = 69.74$); blue ($M = 214.92$, $SD = 62.05$) and gray ($M = 214.04$, $SD = 66.89$). The interaction of color condition and gender did not reveal significant for PT ($F(2,54) = .74$, $p = .48$), nor RTD ($F(2,54) = .13$, $p = .88$). Also, the self-reported quality of participants' attempts did not turn out to be affected by color condition ($F(2,54) = .04$, $p = .96$), neither did the interaction of color condition and gender ($F(2,54) = .41$, $p = .66$). The descriptive values of the RTD and the self-reported quality of the attempts are displayed in Figure 5 and Figure 6. The assumed inhibition of efficient and effective motor action due to the more distal response to the color red was not detected in the current experiment. Instead, the RTD even turned out higher after viewing the color red in comparison to blue and gray. In contrast to Payen et al. (2011), no impairment of strength performance was detected when viewing the color red at a larger timing interval prior to the onset of motor action. In accordance, the self-reported quality of participants' attempts did corroborate these null findings. In accordance to the results of experiment 1, no significant interaction between color condition and gender proved significant.

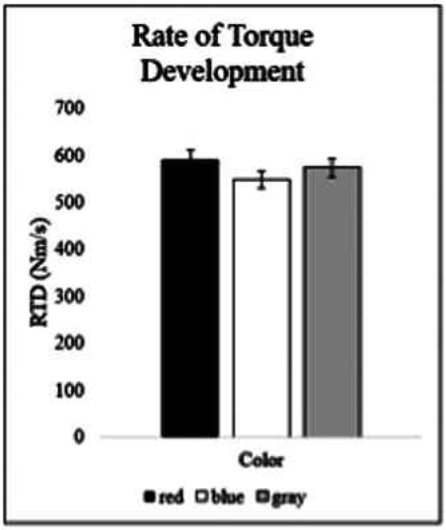

Fig. 5. - Means (incl. SE) for the rate of torque development (RTD) for all color conditions in experiment 2 (color was displayed 50-40 seconds prior to motor performance).

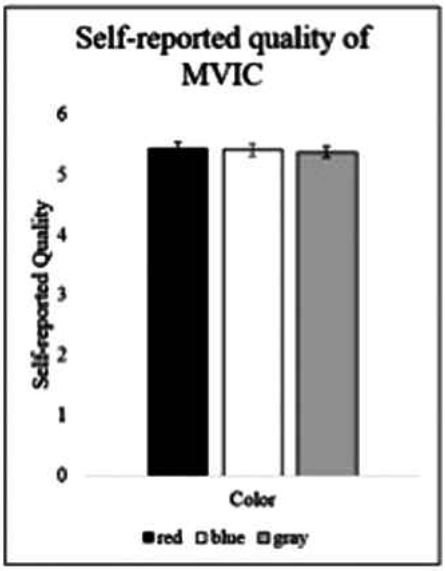

Fig. 6. - Means (incl. SE) for the self-reported quality of maximal voluntary isometric contractions (MVIC) for all color conditions in experiment 2 (color was displayed 50-40 seconds prior to motor performance).

General Discussion

The current study was aimed at investigating the role of the timing of viewing the color red by adding to previous research questioning the link between the color red and basic motor output (Akers et al., 2012; Crane et al. 2008; Dunwoody, 1989; Elliot & Aarts, 2011; Etnier & Hardy, 1997; Green et al., 1982; Hasson et al., 1989; Ingram & Lieberman, 195; Keller & Vautin, 1998; Payen et al., 2011). The results of the two experiments emphasized that being subjected to the color red immediately prior to and during a motor action slightly increased the RTD, but not the amplitude of torque production; whereas viewing the color red from 50 to 40 seconds prior to the onset of motor action did not affect the rate and amplitude of torque production. Past research assumed that perceiving the color red prior to motor performance decreases the velocity and amplitude of force production, whereas perceiving the color red during or immediately prior to the onset of motor action increases such (Elliot & Aarts, 2011; Payen et al., 2011). Thus, the results of the first experiment corroborated the findings of previous research to a certain extent. Viewing the color red five seconds prior to and during motor performance increased the rate of torque production in comparison to blue. This potential benefit of the color red was also

revealed in the self-reported quality of the maximal isometric contractions. Participants rated their attempts more positively after viewing the color red (better and more explosive, energetic, powerful) than after viewing blue. It seems that participants were able to detect their steeper slope of maximum torque production and/or were unconsciously affected by the color red, causing more beneficial ratings (cf. Elliot & Maier, 2012). In this regard, future research is required to clarify whether these better ratings were caused by the actually higher RTDs, or rather by a direct impact of the color red on participants' ratings. However, the first experiment did not reveal any impact of viewing the color red on the maximum force of motor output (Dunwoody, 1989; Ingram & Lieberman, 195; Keller & Vautin, 1998). This contrasts with the results of Elliott and Aarts (2011), Green et al. (1985), and Hasson et al. (1989) who detected a benefit of the color red for the peak amplitude of force production. It has to be considered that major differences between the studies might explain the contradictory findings. Most notably, the characteristics of the color manipulation (e.g., timing, hues, colored area) as well as the measurements and their devices differed. Here, further research is needed to clarify the exact interaction between viewing the color red and its specifications affecting the rate and extent of force or torque production of different body parts. However, previous research has already suggested that the color red – as a threat cue – possesses a strong emotional connotation, which ought to affect central motor processes more strongly than peripheral motor processes (Coombes et al., 2007b). As a consequence, the impact of color should be more easily detectable on the rate of force production than on its maximal peak (Coombes et al., 2007a; Coombes et al., 2011).

In the second experiment we did not find any inhibition of motor output after viewing the color red 50 to 40 seconds prior to the task performance. Neither the RTD, the PT, nor the self-reported quality of the maximal isometric contractions revealed any significant effect. On average, the highest RTD was observed in the red color condition, which contradicts our initial assumption. It was argued that the color red may provide anxiety as a distal, anticipatory response to its perception, which might inhibit motor performance (Coombes et al., 2007a, 2007b; Coombes et al., 2011; Eysenck et al., 2007). However, the comparability to previous research is limited due to different specifications of the color manipulations. The current study did not provide evidence that the color red impeded motor output or at least the rate of torque production (cf. Dunwoody, 1989; Ingram & Lieberman, 195; Keller & Vautin, 1998). Further research seems essential in order to clarify how and when the temporary benefit of the color red on motor output disappears or rather turns into an impairment.

The current study adds to previous research by substantiating the slight tendency of an increase of motor output during viewing the color red, whereas the assumed decline in motor output after viewing red at a delay prior to the onset of

motor action was not observed. Both results contribute to the scientific discussion about the true impact of the color red on motor action, without clarifying its exact value. The results have to be interpreted carefully taking a number of limitations into account. Most notably, effect sizes were small throughout the analyses, which reduces the validity of the findings. However, past research has already revealed the impact of color to be small in general (Elliot, 2015; Elliot & Maier, 2012; Feltman & Elliot, 2011; Hill & Barton, 2005). In both experiments, red also was merely compared to blue (chromatic control color) and gray (achromatic control color). Thus, the reported findings are limited to these comparisons. Considering that many colors have their own meanings and associations which might affect human performance and behavior, a conclusion of the observed red effect beyond the scope of the study has to be drawn cautiously (Elliot, 2015; Elliot & Maier, 2012; Krenn, 2014). Also keeping in mind that several previous studies did not detect such color effects (Akers et al., 2012; Dunwoody, 1989; Etnier & Hardy, 1997; Ingram & Lieberman, 195; Keller & Vautin, 1998) challenging the assumption of a valid impact of the color red on simple motor performances. The various findings in this research area clarify that the impact of color on motor output is still not well understood.

The differing area of letters and numbers which were color-manipulated in the first and the second experiment restricts the comparison of both experiments. In experiment 1 participants viewed a countdown (5-4-3-2-1) with different numbers in a row and the word "PUSH!"; whereas in experiment 2 merely three words were color-manipulated and shown for 10 seconds. Thus, the countdown and its changing numbers might have attracted more attention than the constant color-manipulated input in the second experiment, which might also have accounted for the reported results. Furthermore, the differing sample sizes in experiment 1 and experiment 2 are restricting the direct comparison of both experiments. However, even by taking the smaller number of participants in experiment 2 into consideration, the results clearly refute the assumed decline in motor output after viewing the color red 50 to 40 seconds before motor action. Nonetheless, further research has to overcome these limitations and try to analyze more comprehensively how and when the color red might affect motor output. In this regard, a single experiment investigating the assumed color - timing interaction directly, would be of great benefit.

The current study emphasized that viewing the color red immediately prior to or during motor performance enhances the RTD of maximal voluntary isometric knee extension as well as its individually attributed quality. It seems likely that the color red signalizes threat, which might temporarily increase motor output on simple tasks, whereas on more complex motor tasks (e.g. to dodge a punch in boxing) or analytical tasks red might impede performance (Briki et al., 2015; Elliot & Aarts, 2011; Elliot et al., 2007). However, the current study suggests a crucial role of timing of viewing the color red when generating motor output. From a practical perspective

it seems important to control for any color stimuli in the assessment of MVICs. Considering its potential to significantly affect the speed of force production, especially red stimuli might impair measurement's validity. Future research is needed in order to investigate when and how a benefit of red exists, disappears or rather changes to impair motor output.

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