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Viewing red prior to a strength test inhibits motor output

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ABSTRACT

The present research was designed to examine whether viewing a subtle threat cue, the color red, prior to a simple motor task influences strength output. Thirty-nine participants performed a maximal voluntary contraction of the thigh, viewed red or a chromatic or achromatic control color, and then repeated the maximal voluntary contraction. Participants also reported their general arousal and mood, and were asked to guess the purpose of the experiment. Results indicated that viewing red (relative to a control color) inhibited the rate of force development, but did not influence the peak amplitude of force production. Null findings for general arousal and mood indicated that the observed effect on rate of force development could not be accounted for by these self-report variables; no participant correctly guessed the purpose of the experiment. This research, in conjunction with recent work by Elliot and Aarts (in press) [19] clearly establishes a link between red and basic motor output, and highlights the importance of attending to the functional, as well as aesthetic, value of color.

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Research in evolutionary biology and psychology indicates that color is not only an aesthetic stimulus, but also carries important meaning. Red is the color that has received the most research attention. In human and non-human primates alike, red is associated with threat and danger. For example, in mandrills, a testosterone-based flush of red on the face of an opponent is a signal of dominance and attack-readiness [46] (for examples in other species and vertebrates see Andersson and Iwasa [4] and Gerald [28]). In humans, red on the face of a competitor may likewise indicate testosterone-fueled anger or aggressiveness [10,18] and, furthermore, red is used in student evaluation to indicate mistakes, in language to represent negative situations (e.g. "in the red"), and in traffic signals, alarms, and sirens to indicate impending danger [21,42]. The clear parallels across phylogeny in the signal value of red suggest a biologically engrained link between red and danger in humans that is bolstered and broadened by societal learning [23].

Given the associative link between red and danger, it is not surprising that experiments have shown that red evokes avoidance motivation and behavior in human participants in achievement situations. Viewing red, relative to other chromatic and achromatic colors, prior to an achievement task produces an increase in right frontal cortical activation [23] and an increase in local perceptual focus [36], both indicative of avoidance motivation [15,16]. Perceiving red also leads to the selection of easy rather than moderately challenging test items [23], less knocking on the door of a room where a test will be taken [22], and subtle postural movement away from an anticipated test [22].

Avoidance motivation (and associated processes such as anxiety) is known to interfere with fluid and efficient cognitive processing and to undermine performance on tasks requiring complex mental operations [9,20,30]. Accordingly, as a danger cue that evokes avoidance motivation in achievement settings, red should undermine intellectual performance. This is precisely what has been observed in recent empirical work. Viewing red, relative to other chromatic and achromatic colors, prior to engaging in an achievement task has been found to undermine anagram, analogy, and math performance [23,34,36].

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Recently, Elliot and Aarts [19] extended this research by examining the influence of red on performance on simple motor tasks. They found that participants who viewed red, relative to other chromatic and achromatic colors, while engaging in a pinchgrip or handgrip task produced greater strength output and did so more quickly (see [31] for a similar, but less systematic, observation). Elliot and Aarts [19] interpreted their findings in terms of the operation of a phylogenetically basic avoidance/defense system responsible for processing and responding to threat-relevant stimuli [17,38]. This avoidance/defense system is thought to be grounded in a network of largely subcortical structures (e.g. the amygdala and the basal ganglia) that detect threat stimuli and trigger autonomic activity required to support urgent and emphatic movement away from imminent danger [8,33]. Supportive research indicates that threatening pictorial images indeed activate the amygdala and basal ganglia [32,44], and produce voluntary motor behavior that is more forceful [11] and of greater velocity [12] than that produced by appetitive or neutral stimuli. The Elliot and Aarts [19] findings show that red operates as a threat stimulus in commensurate fashion.

In the Elliot and Aarts [19] research, participants engaged in the performance task immediately upon and during the presentation of the color stimulus. This is different than the "test cover" procedure, used in nearly all previous work on color and intellectual performance, in which the color stimulus is viewed several seconds prior to the onset of, but not during, task engagement (e.g. [23]). The immediate, urgent response to red seen in Elliot and Aarts [19] may be a subcortically based "call to arms" involving fear that facilitates efficient (rapid) and effective (forceful) motor action. On the other hand, the more distal, anticipatory response to red seen in research using the "test cover" procedure may draw on cortically based processing involving anxiety and concern about social evaluation that interferes with efficient and/or effective motor action. This distinction between fear-based and anxiety-based responding is consistent with threat models proffered in rodent research to explain differential responding as a function of the imminence of detected danger [7,26]. It is also consistent with findings from the human literature on threat stimuli and motor responding, in which threat stimuli presented conterminously with motor action have been shown to facilitate effective and efficient motor responding [11,12], whereas threat stimuli viewed prior to (but not during) motor action have been shown to decrease performance accuracy [14] and response speed in test anxious individuals [13].

In the present research, we made use of the "test cover" approach to color presentation to examine the influence of a prior, distal viewing of red, relative to other chromatic and achromatic colors, on performance on a simple motor task. In line with the above reasoning, we anticipated that the red stimulus viewed prior to the onset of motor action would produce slower and/or less forceful responding. Consistent with other research on red effects in achievement contexts (e.g. [23]), we anticipated that any observed effects would take place independent of general arousal and mood, and without participants being aware of the influence of color on their behavior. Critically, we conducted our research using precisely controlled color manipulations, and hues equated on lightness and (as applicable) chroma (see Elliot and Maier [21], for the importance of these factors). Evidence in support of our hypothesis not only would provide further evidence for the functional properties of the color red, but also would highlight the critical importance of attending to the temporal distance of threat cues in studying basic affective-motor processes (for calls for such work, see [11,48]).

Thirty-nine male undergraduates voluntarily participated in the study (age range: 18–37, M = 23.21; SD = 4.05). All participants gave informed consent. To avoid muscle fatigue that could lead to biased torques, participants were instructed to refrain from participating in any physical activity during the 24 h preceding the experimental session. Participants were randomly assigned to one of the three between-participants color conditions (n = 13 per condition): red, blue, or gray. Participants were required to make two isometric maximal voluntary contractions of the thigh, and the color manipulation was presented between these two contractions. Isometric voluntary contraction of the thigh was deemed an optimal task for the experiment, because measurement techniques in this area are well-developed and reliable. Aside from the color manipulation, all participants completed the same experimental procedure.

Motor performance was assessed via (1) maximal voluntary contraction (MVC) and (2) rate of force development (RFD). The MVC (Nm) is the peak of force reached after more than 300 ms during a strong muscle contraction [1]. A Biodex System 3 dynamometer (Biodex, Shirley, NY) with a 110° hip angle and a 90° knee angle (0° as full leg extension) was used to measure maximal voluntary isometric torque of the right knee extensor muscles [37]. To avoid hip motion during the contractions, straps were applied across the chest and pelvis. Arms were folded and placed on the chest to avoid any pulling from the arm rests of the chair. The knee axis was aligned with the dynamometer axis, and the ankle was attached to the biodex knee attachment extending from the transducer. The highest peak torques at Time 1 (T1) and Time 2 (T2) were, respectively, defined as MVC values.

The RFD assesses explosive muscle strength and is a determinant of the maximal force and velocity that can be produced during the initial phase of contraction (<250 ms; [1]). RFD is influenced by the level of neural activation and by intrinsic muscle properties (e.g. muscle size and fiber-type [2,3]). RFD (Nm/s) was defined as the slope of the torque–time curve (i.e., Δtorque/Δtime) in 25 incrementing time periods of 0–10, 0–20, up to 0–250 ms from the onset of contraction. The RFD score reflected the peak slope during the first 250 ms of the contraction.

In addition to measures of motor performance, we collected self-report measures of general arousal and mood. General arousal was assessed with the item "How energetic do you feel right now?" on a 1 (not all energetic) to 5 (very energetic) scale. This item is the highest loader on the General Activation subscale of Thayer's [49] Activation–Deactivation Adjective Check List. Mood was assessed with Seibt and Forster's [45] single-item measure "How do you feel right now?" using a 1 (very bad) to 9 (very good) scale.

Upon arrival at the laboratory, participants were informed that the experiment involved assessing the strength of the right thigh. They were tested individually by an experimenter who was blind to hypotheses and experimental condition. Participants performed two 5 s quadriceps maximal isometric contractions (at T1 and T2). Contractions were separated by a 90 s rest period. The color manipulation was presented between T1 and T2 using the test cover procedure [23]. Participants were handed a white binder with two pages in it. The first page contained the color manipulation, which was a piece of Epson Enhanced Matte white paper containing a 18 cm × 12.68 cm colored rectangle with the words "strength test" printed in black ink in 34 point font in the middle of the rectangle. Adobe Photoshop was used to put color on the rectangle, and the colors for the manipulation were selected using the CIELCh color model and a GretagMacBeth Eye-One Pro spectrophotometer. A trial and error process was used to find standard red, blue, and gray hues that were equal on lightness and (for the chromatic colors) chroma. The parameters for the printed colors were: red LCh(49.9, 50.9, 27.0), blue LCh(49.6, 50.4, 271.0), and gray LCh(50.1, –, 270.9). The experimenter instructed participants to open the binder to the first page containing the words "strength test"; after 2 s had elapsed, the experimenter told participants to turn the page to complete a brief questionnaire comprised of the general arousal and mood items. Participants were then instructed to close the binder and give it back to the experimenter. At the end of the rest period, participants performed their second MVC trial. At the end of the experiment, participants received a verbal funnel debriefing that probed for awareness of the purpose of the experiment (e.g. "What do you think we were trying to test?"). They were then asked to name the color that they saw on the manipulation, were told the true purpose of the experiment, and were dismissed.

A one-way between-participants ANOVA was used to examine the effect of color (red, blue, and gray) on the general arousal and mood variables. The effect of color on MVC and RFD was assessed using a 2 × 3 mixed-model Analyses of Variance (ANOVA). Time (T1, T2) was the within-participants factor and color condition (red, blue, and gray) was the between-participants factor. Tukey's post hoc tests were used to follow-up significant interactions; these follow-up tests focused on differences between T1 and T2 scores within color condition.

The one-way ANOVA comparing general arousal scores for participants who viewed red ($M = 3.77$, SD = 0.60), blue ($M = 3.69$, SD = 0.86), or gray ($M = 3.92$, SD = 0.76) was not significant ($F < 1$, $p = .73$). Likewise, the one-way ANOVA comparing mood scores for participants who viewed red ($M = 6.77$, SD = 0.93), blue ($M = 6.77$, SD = 1.64), or gray ($M = 7.00$, SD = 1.68) was not significant ($F < 1$, $p = .90$). Furthermore, the one-way ANOVAs comparing T1 MVC values (see Fig. 1A) and T1 RFD values (see Fig. 1B) across conditions were also not significant (Fs < 1.30, ps > .29). Thus, no general arousal, mood, or baseline MVC/RFD differences were observed between groups, meaning any observed group differences in MVC or RFD across time could not be attributed to variability in these measures.

Fig. 1A displays the MVC values for T1 and T2 by color condition. The corresponding mixed-model ANOVA revealed no significant main effect for time ($F < 1$, $p = .44$) or color ($F(2, 36) = 1.17$, $p = .32$), or the time × color interaction ($F < 1$, $p = .45$). Thus, there was no fatigue effect across time and the color manipulation did not influence peak MVC.

Fig. 1B displays peak RFD values for T1 and T2 by color condition. The corresponding mixed-model ANOVA revealed no significant main effect for time ($F(1, 36) = 2.07$, $p = .16$) or color ($F < 1$, $p = .67$). However, the time × color interaction was significant ($F(2, 36) = 4.86$, $p = .01$, $\eta_p^2 = .21$). Follow-up tests showed a significant reduction of RFD in the red condition ($t = 3.02$, $p = .05$, $d = .58$), but not in the blue or gray conditions (ts < 1.39, ps > .73, ds < .26). Viewing the color red between T1 and T2 resulted in a 25.5% reduction in RFD. Thus, viewing red, but not blue or gray, undermined the peak rate of change of force development. Importantly, this finding could not be accounted for by variation in peak force or self-reported general arousal or mood. No participant correctly guessed the purpose of the experiment, and all participants correctly reported the color that they saw on the manipulation.

The present study provides clear support for a link between red and basic motor functioning in humans. Viewing red as opposed to blue or gray prior to a simple strength test inhibited the rate of force development, but did not influence the peak amplitude of force production. These findings were obtained with color stimuli equated on lightness and chroma, thereby allowing hue to be unequivocally identified as the color property responsible for the observed effect. Null results were obtained for self-report measures and not a single participant was able to discern the purpose of the experiment; this suggests that the influence of color on motor behavior took place without participants' conscious awareness.

The present research extends and compliments recent research by Elliot and Aarts [19], and the clearest picture of the link between red and motor functioning may be obtained by juxtaposing the two sets of findings. In the present research, participants viewed red several seconds prior to, but not during, task performance, and these individuals exhibited less efficient motor output. In the Elliot and Aarts [19] research, on the other hand, participants viewed red immediately before and during task performance, and these individuals exhibited more efficient and more effective motor output. Red is a threat cue in achievement contexts [23,42], and the present findings, coupled with those of Elliot and Aarts [19], indicate that the temporal distance of this threat cue from the onset of task engagement is a critical factor in motor production.

We interpret this impact of temporal distance in terms of an anxiety–fear distinction: a distal threat cue is presumed to prompt anticipatory anxiety, which is known to interfere with motor functioning [13], whereas a proximal threat cue is presumed to prompt fear, which is known to facilitate motor functioning [12]. This interpretation is consistent with well-established models of threat responding in the broader animal literature. For example, the "threat imminence continuum" model [27] posits that animals respond differently to the threat of a predator depending on whether the predator represents a remote threat (i.e., a "post-encounter" context) or an immediate threat (i.e., a "circa-strike" context). A post-encounter context involves detection of, but not interaction with, the threat, and is characterized by anticipatory anxiety and passive defensive behavior such as freezing. This distal threat elicits activity in the cortical brain regions (e.g. the ventromedial prefrontal cortex [6]) which corresponds with relatively slow but thorough appraisal and response preparation processes. A circa-strike context involves direct interaction with the threat, and is exemplified by fear, panic, and urgent fight or flight behavior. Imminent threat elicits activity in the midbrain regions (e.g. the ventrolateral periaqueductal gray [26]) which corresponds with fast, obligatory, reflexive responding. Although most research supporting the threat imminence continuum model (and related frameworks [39]) has been conducted on rodents, recent research on the neurobiology of threat responding in humans has also yielded supportive evidence [40,41]. Our research, as well as that of Elliot and Aarts [19], was not explicitly designed to test the threat imminence continuum model, but the results may nevertheless be construed as further support for the generalizability of this model to humans. In subsequent work, it would be valuable to include both post-encounter and circa-strike relevant contexts in a single experiment in order to more directly compare the impact of these two conditions on human response to threat.

Our central finding in the present research is that viewing red prior to a strength task leads to a reduction in the rate of change of maximal force production. In essence, seeing red interferes with the "explosiveness" of strength output [47]. In addition to the aforementioned cortical and midbrain regions, areas of the basal ganglia have been linked to the parameterization and inhibition of force production [5,43]. Brain imaging studies in humans have shown that when controlling for force amplitude, the neural circuit that regulates the rate of change of force production includes the bilateral internal globus pallidus and the left subthalamic nucleus [50]. In addition, tracing studies in rodents have identified the basal ganglia as a structure capable of integrating emotional, cognitive, and motor processes [29]. Accordingly, a likely explanation for our central finding is that the red-induced anxiety that our participants experienced led to increased activity in the posterior regions of the basal ganglia which manifest behaviorally in a decreased rate of change of force production [43,50]. Further research is needed to directly document the neural pathways through which red exerts its influence on motor output.

Connecting anxiety and RFD, as we have done in the present work, may have applied, as well as conceptual implications. To the extent that anxiety interferes with the early phase of rising muscle force, it would undoubtedly interfere with activities requiring fast and forceful muscle movements such as karate, boxing, and sprinting [1]. Each of these activities requires limb movements involving contraction times of 50–250 ms, which is precisely where anxiety exerts its inimical effects. The importance of the anxiety–RFD relation likely extends beyond athletes to the broader populace. For example, in the elderly, "a high muscular RFD seems to be of vital

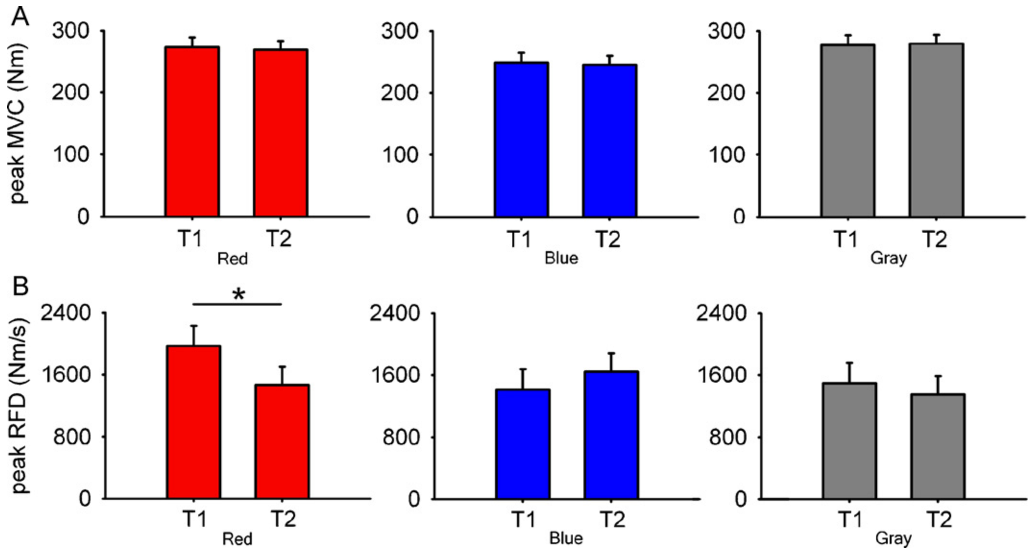

Fig. 1. Mean pattern of force as a function of color condition: (A) peak maximum voluntary contraction (MVC) in Newton meter (Nm) and (B) peak rate of force development (RFD) in Newton meter/second (Nm/s). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

importance for the ability to rapidly regain balance during sudden postural perturbations, thereby potentially reducing the risk of falls" [1, p. 1325]. Thus, ironically, an older person who is anxious about slipping may be putting him or herself at greater risk of suffering this exact fate.

In conclusion, red is a threat cue in achievement contexts that influences strength performance, as well as intellectual performance. The impact of red is subtle, yet powerful, and, as seen in emerging empirical work in both the achievement domain and (far) beyond [24,25,35], appears to be as pervasive as it is provocative.

References

[1] P. Aagaard, E.B. Simonsen, J.L. Andersen, P. Magnusson, P. Dyhre-Poulsen, Increased rate of force development and neural drive of human skeletal muscle following resistance training, J. Appl. Physiol. 93 (2002) 1318–1326.
[2] J.L. Andersen, P. Aagaard, Influence of maximal muscle strength and intrinsic muscle contractile properties on contractile rate of force development, J. Appl. Physiol. 96 (2006) 46–52.
[3] L.L. Andersen, J.L. Andersen, M.K. Zebis, P. Aagaard, Early and late rate of force development: differential adaptive responses to resistance training? Scand. J. Med. Sci. Sports 20 (2010) 162–169.
[4] M. Andersson, Y. Iwasa, Sexual selection, Trends Ecol. Evol. 11 (1996) 53–58.
[5] A.R. Aron, R.A. Poldrack, Cortical and subcortical contributions to stop signal response inhibition: role of the subthalamic nucleus, J. Neurosci. 26 (2006) 2424–2433.
[6] R.J. Blanchard, D.C. Blanchard, Anti-predator defense as models of animal fear and anxiety fear and defence, in: P. Brain, R. Blanchard, D. Mainardi (Eds.), Fear and Defence, Harwood Academic Publishers, Chur, Switzerland, 1990, pp. 89–108.
[7] M.E. Bouton, S. Mineka, D.H. Barlow, A modern learning theory perspective on the etiology of panic disorder, Psychol. Rev. 108 (2001) 4–32.
[8] L. Carretie, J. Albert, S. Lopez-Martin, M. Tapia, Negative brain: an integrative review on the neural processes activated by unpleasant stimuli, Int. J. Psychophysiol. 71 (2009) 57–63.
[9] A. Chalabaev, B. Major, F. Cury, P. Sarrazin, Physiological markers of challenge and threat mediate the effects of performance-based goals on performance, J. Exp. Soc. Psychol. 45 (2009) 991–994.
[10] M.A. Changizi, The Vision Revolution: How the Latest Research Overturns Everything We Thought We Knew about Human Vision, BenBella Books, Dallas, 2009.
[11] S.A. Coombes, J.H. Cauraugh, C.M. Janelle, Emotion and movement: activation of defensive circuitry alters the magnitude of a sustained muscle contraction, Neurosci. Lett. 396 (2006) 192–196.
[12] S.A. Coombes, J.H. Cauraugh, C.M. Janelle, Emotional state and initiating cue alter central and peripheral motor processes, Emotion 7 (2007) 275–284.
[13] S.A. Coombes, T. Higgins, K.M. Gamble, J.H. Cauraugh, C.M. Janelle, Attentional control theory: anxiety, emotion, and motor planning, J. Anxiety Disord. 23 (2009) 1072–1079.
[14] S.A. Coombes, C.M. Janelle, A.R. Duley, Emotion and motor control: movement attributes following affective picture processing, J. Motor Behav. 37 (2005) 425–436.
[15] R.J. Davidson, Emotion and affective style: hemispheric substrates, Psychol. Sci. 3 (1992) 39–43.
[16] D. Derryberry, M. Reed, Temperament and attention: orienting toward and away from positive and negative signals, J. Pers. Soc. Psychol. 66 (1994) 1128–1139.
[17] A. Dickson, M.F. Dearing, Appetitive–aversive interactions and inhibitory processes, in: A. Dickson, R.A. Boakes (Eds.), Mechanisms of Learning and Motivation, Erlbaum, Hillsdale, NJ, 1979, pp. 203–231.
[18] P.D. Drummond, Correlates of facial flushing and pallor in anger-provoking situations, Pers. Individ. Differ. 23 (1997) 575–582.
[19] A.J. Elliot, H. Aarts, Perception of the color red enhances the force and velocity of motor output, Emotion, 11 (2011).
[20] A.J. Elliot, J.M. Harackiewicz, Approach and avoidance achievement goals and intrinsic motivation: a mediational analysis, J. Pers. Soc. Psychol. 70 (1996) 461–475.
[21] A.J. Elliot, M.A. Maier, Color and psychological functioning, Curr. Dir. Psychol. Sci. 16 (2007) 250–254.
[22] A.J. Elliot, M.A. Maier, M.J. Binser, R. Friedman, R. Pekrun, The effect of red on avoidance behavior in achievement contexts, Pers. Soc. Psychol. Bull. 35 (2009) 365–375.
[23] A.J. Elliot, M.A. Maier, A.C. Moller, R. Friedman, J. Meinhardt, Color and psychological functioning: the effect of red on performance attainment, J. Exp. Psychol. Gen. 136 (2007) 154–168.
[24] A.J. Elliot, D. Niesta, Red: red enhances men's attraction to women, J. Pers. Soc. Psychol. 95 (2008) 1150–1164.
[25] A.J. Elliot, D. Niesta Kayser, T. Greitemeyer, S. Lichtenfeld, R.H. Gramzow, M.A. Maier, H. Liu, Red, rank, and romance in women viewing men, J. Exp. Psychol. Gen. 139 (2010) 399–417.
[26] M.S. Fanselow, Neural organization of the defensive behavior system responsible for fear, Psychon. Bull. Rev. 1 (1994) 429–438.
[27] M.S. Fanselow, L.S. Lester, A functional behavioristic approach to aversively motivated behavior: predatory imminence as a determinant of the topography of defensive behavior, in: M. Beecher (Ed.), Evolution and Learning, LEA, Hillsdale, NJ, 1988, pp. 185–211.
[28] M. Gerald, How color may guide the primate world: possible relationships between sexual selection and sexual dichromatism, in: C. Jones (Ed.), Sexual Selection and Reproduction in Primates: New Perspectives and Directions, American Primate Society, Norman, OK, 2003, pp. 141–172.
[29] S.N. Haber, The primate basal ganglia: parallel and integrative networks, J. Chem. Neuroanat. 26 (2003) 317–330.
[30] R. Hembree, Correlates, causes, effects, and treatment of test anxiety, Rev. Educ. Res. 58 (1988) 47–77.
[31] W. James, The Principles of Psychology, Henry Holt and Company, 1890.
[32] H. Kober, L.F. Barrett, J. Joseph, E. Bliss-Moreau, K. Lindquist, T.D. Wager, Functional grouping and cortical–subcortical interactions in emotion: a meta-analysis of neuroimaging studies, NeuroImage 42 (2008) 998–1031.
[33] P.J. Lang, The emotion probe: studies of motivation and attention, Am. Psychol. 50 (1995) 372–385.
[34] S. Lichtenfeld, M.A. Maier, A.J. Elliot, R. Pekrun, The semantic red effect: processing the word red undermines intellectual performance, J. Exp. Soc. Psychol. 45 (2009) 1273–1276.

[35] M.A. Maier, P. Barchfeld, A.J. Elliot, R. Pekrun, Context specificity of implicit preferences: the case of human preference for red, Emotion 9 (2009) 734–738.
[36] M.A. Maier, A.J. Elliot, S. Lichtenfeld, Mediation of the negative effect of red on intellectual performance, Pers. Soc. Psychol. Bull. 34 (2008) 1530–1540.
[37] K. Manal, D.P. Roberts, T.S. Buchanan, Can pennation angles be predicted from EMGs for the primary ankle plantar and dorsiflexors during isometric contractions? J. Biomech. 41 (2008) 2492–2497.
[38] F.A. Masterson, M. Crawford, The defense motivation system: a theory of avoidance behavior, Behav. Brain Sci. 5 (1982) 661–696.
[39] N. McNaughton, P.J. Corr, A two-dimensional neuropsychology of defense: fear/anxiety and defensive distance, Neurosci. Biobehav. Rev. 28 (2004) 285–305.
[40] D. Mobbs, J.L. Marchant, D. Hassabis, B. Seymour, G. Tan, M. Gray, P. Petrovic, R.J. Dolan, C.D. Frith, From threat to fear: the neural organization of defensive fear systems in humans, J. Neurosci. 29 (2009) 12236–12243.
[41] D. Mobbs, P. Petrovic, J.L. Marchant, D. Hassabis, N. Weiskopf, B. Seymour, R.J. Dolan, C.D. Frith, When fear is near: threat imminence elicits prefrontal–periaqueductal gray shifts in humans, Science 317 (2007) 1079–1083.
[42] A.C. Moller, A.J. Elliot, M.A. Maier, Basic hue-meaning associations, Emotion 9 (2009) 898–902.
[43] J. Prodoehl, D.M. Corcos, D.E. Vaillancourt, Basal ganglia mechanisms underlying precision grip force control, Neurosci. Biobehav. Rev. 33 (2009) 900–908.
[44] D. Sabatinelli, M.M. Bradley, J.R. Fitzsimmons, P.J. Lang, Parallel amygdala and inferotemporal activation reflect emotional intensity and fear relevance, NeuroImage 24 (2005) 1265–1270.
[45] B. Seibt, J. Forster, Stereotype threat and performance: how self-stereotypes influence processing by inducing regulatory foci, J. Pers. Soc. Psychol. 87 (2004) 38–56.
[46] J.M. Setchell, E.J. Wickings, Dominance, status signals, and coloration in male mandrills (Mandrillus sphinx), Ethology 111 (2005) 25–50.
[47] G.G. Sleivert, H.A. Wenger, Reliability of measuring isometric and isokinetic peak torque, rate of torque development, integrated electomyography, and tibial nerve conduction velocity, Arch. Phys. Med. Rehabil. 75 (1994) 1315–1321.
[48] J. Stanley, R.G. Knight, Emotional specificity of startle potentiation during the early stages of picture viewing, Psychophysiology 41 (2004) 935–940.
[49] R.E. Thayer, Activation–Deactivation Adjective Check List: current overview and structural analysis, Psychol. Rep. 58 (1986) 607–614.
[50] D.E. Vaillancourt, M.A. Mayka, K.R. Thulborn, D.M. Corcos, Subthalamic nucleus and internal globus pallidus scale with the rate of change of force production in humans, NeuroImage 23 (2004) 175–186.