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Regulating emotions uniquely modifies reaction time, rate of force production, and accuracy of a goal-directed motor action

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ABSTRACT

We investigated how emotion regulation (ER) strategies influence the execution of a memory guided, ballistic pinch grip. Participants ($N = 33$) employed ER strategies (expressive suppression, emotional expression, and attentional deployment) while viewing emotional stimuli (IAPS images). Upon stimulus offset, participants produced a targeted pinch force aimed at 10% of their maximum voluntary contraction. Performance measures included reaction time (RT), rate of force production, and performance accuracy. As hypothesized, attentional deployment resulted in the slowest RT, largest rate of force production, and poorest performance accuracy. In contrast, expressive suppression reduced the rate of force production and increased performance accuracy relative to emotional expression and attentional deployment. Findings provide evidence that emotion regulation strategies uniquely influence human movement. Future work should further delineate the interacting role that emotion regulation strategies have in modulating both affective experience and motor performance.

1. Introduction

From the rather mundane events of daily commutes (Pêcher, Lemercier, & Cellier, 2009), social interactions (van Kleef, 2009), and performance of occupational duties (Tsai, Chen, & Liu, 2007),

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to challenging tasks associated with executing skilled medical surgery (Arora et al., 2010), engaging in military maneuvers (Wallenius, 2004), and competing in sport (Causer, Holmes, Smith, & Williams, 2011), emotional states pervasively influence human behavior. A growing database indicates that emotions directly impact how people move by modulating the speed of reactions (Chen & Bargh, 1999; Rotteveel & Phaf, 2004), rate of movement (Gross, Crane, & Fredrickson, 2012), accuracy of movements (Coombes, Janelle, & Duley, 2005), and magnitude of force production (Coombes, Cauraugh, & Janelle, 2006; Coombes, Gamble, Cauraugh, & Janelle, 2008). However, people do not always experience emotions passively. Rather, in the interest of attaining affective, cognitive, and behavioral goals, they implicitly or explicitly apply regulatory strategies that modify emotional experiences and physiological reactivity (Gross, 1998; Jackson, Malmstadt, Larson, & Davidson, 2000; Kanske, Heissler, Schönfelder, Bongers, & Wessa, 2011; McRae et al., 2009; Webb, Miles, & Sheeran, 2012). Understanding how emotion regulation strategies influence motor execution is therefore fundamental to the development of empirically founded guidelines for implementing effective regulation strategies in myriad performance environments. Yet, how the deliberate regulation of emotion modulates the influence of emotional experience on human motor action remains unspecified.

In the present study, we evaluated how three established emotion regulation (ER) strategies influenced motor action under varying emotional conditions. Participants executed a memory guided, ballistic pinch grip while either passively experiencing emotional stimuli, or regulating emotional experiences via expressive suppression, emotional expression, or attentional deployment. *Expressive suppression* involved minimizing the external expressions of emotional experience. For example, participants were instructed to mask their expressions so that if someone were watching, they would not be aware of what the participants were feeling. In contrast, participants were instructed to fully express their emotional reactions during *emotional expression*. When employing *attentional deployment*, participants completed a backward counting task in which gaze was maintained on the screen, but attention was diverted to the counting task and away from emotional content. Reaction time (RT), peak rate of force production (PRF), and root-mean-square error (RMSE) were used to quantify how the execution of speeded motor actions varies as a function of induced emotional states and the strategies employed to regulate the experienced emotions.

Intuitively, effective regulation of emotional experience may seem beneficial to performance within emotionally charged environments. Supporting this notion, emerging evidence (Bresin, Fetterman, & Robinson, 2012) suggests that individual differences in adaptive ER tendencies predicts improved motor control accuracy. Additionally, work from several lines of research highlight common neurological networks activated during the experience of emotion, regulation of emotional experience, planning of action, and execution of motor responses (Coombes, Corcos, Pavuluri, & Vaillancourt, 2012; Heimer & Van Hoesen, 2006; Hikosaka, Sesack, Lecourtier, & Shepard, 2008; Mauss, Bunge, & Gross, 2007; Mogenson, Jones, & Yim, 1980). In addition to the affective benefits of managing emotional experience (e.g., Webb et al., 2012), actively regulating emotions during motor tasks should concurrently regulate the influence of emotional states on downstream motor actions. In accordance with previous evidence that emotional states speed RTs (e.g., Coombes, Higgins, Gamble, Cauraugh, & Janelle, 2009), we predicted that emotional states would speed RT on trials that followed unregulated viewing of emotional stimuli. A replication of this emotion-modulated RT effect would allow us to then determine whether ER strategies impacted ensuing motor actions. We expected emotional-state dependent RT differences to disappear when participants employed regulation strategies.

Although the active regulation of emotion may buffer the influence of emotional experiences on motor action, such regulatory benefits may potentially manifest at a cost to efficiency and efficacy of motor execution. Effective execution of goal directed, ballistic motor actions is primarily reliant on the integrity of top down executive processes that direct the initiation and control of movement (Coombes, Cauraugh, & Janelle, 2007a,b; Glover, 2004). ER strategies are known to activate pre-frontal regions associated with attention, cognition, and motor control (Coombes et al., 2012; Goldin, McRae, Ramel, & Gross, 2008; Kanske et al., 2011; McRae et al., 2009). Provided that dual-task paradigms impair motor performance—presumably due to competition for brain regions involved in both tasks—(Rémy, Wenderoth, Lipkens, & Swinnen, 2010), the implementation of regulation strategies that place demands on cognitive (e.g., attentional deployment; Kanske et al., 2011) or motor networks (e.g., emotional expression; Lee, Josephs, Dolan, & Critchley, 2006) during motor planning, should prove costly to subsequent motor actions. Although the expressive suppression strategy also competes for resources in frontal brain regions associated with cognition and motor planning, the activation of these regions appears later (10.5–15 s) during the regulatory process (Goldin et al., 2008). This delay suggests that expressive suppression may be an efficient strategy within the 10–15 s window following emotion elicitation. Accordingly, as participants regulated emotional experiences for 5–8 s in the current experiment, we expected slowed RTs and increased RMSE during attentional deployment and emotional expression trials compared to the unregulated and expressive suppression trials. In a similar paradigm, Coombes et al. (2009) report an increase in rate of force production (PRF) following slowed RTs. Therefore, when RTs were slower, we predicted that the resulting movements would be rushed, indicated by accelerated PRF.

In summary, we predicted that during the unregulated trials, emotional stimuli would induce changes in RT. Additionally, we predicted emotion regulation strategies would eliminate emotion-induced variation in RT. Further, considering evidence that suggests regulating emotions via attentional deployment or emotional expression might disrupt motor planning and execution processes, we predicted delayed reactions, accelerated rates of force production, and increased error during attentional deployment and emotional expression trials compared to unregulated and expressive suppression trials.

2. Methods

2.1. Participants

Forty-four undergraduate students (35 women: mean [*M*] age = 20.03, standard deviation [*SD*] = 1.04; 7 men: *M* age = 20.86, *SD* = 1.35) from the University of Florida participated in this study for extra course credit. Participants reported no neurological disorders or upper-extremity injuries within the past six months. Each participant provided written informed consent prior to beginning the study. Two female participants' data were excluded due to technical issues. One female participant's data were removed due to feeling ill during the experiment. One female and one male participant were dismissed due to reported difficulties with the experimental protocol. Additionally, all left-handed participants (5 females and 1 male) were omitted from statistical analysis to avoid hemispheric based affective differences (Casasanto, 2009) and handedness confounds (Nalçaci, Kalaycioğlu, Çiçek, & Genç, 2001). Table 1 summarizes the demographic information for the 33 participants (26 women) included in the statistical analyses.

Table 1
Demographic data for the 33 participants (26 women) included in the statistical analyses.

Variable	All Participants *M* (SD)	Male *M* (SD)	Female *M* (SD)
Age	20.2 (1.18)	20.8 (1.48)	20.1 (1.12)
MVC (N)	47.2 (14.0)	63.2 (17.7)	44.4 (11.4)
Target force (N)	4.72 (1.40)	6.32 (1.77)	4.44 (1.14)
Trait anxiety	42.15 (5.92)	40.8 (6.53)	42.39 (5.90)
State anxiety	31.61 (6.27)	29.6 (6.95)	31.96 (6.22)
BDI	7.82 (6.8)	9.6 (7.80)	7.5 (6.72)
PANAS pos.	35.3 (5.38)	33.4 (4.28)	35.68 (5.54)
PANAS neg.	18.0 (6.23)	20.0 (3.74)	17.68 (6.57)
BIS	14. 9 (2.73)	16.2 (1.48)	14.7 (2.85)
BAS	23.7 (3.9)	22.6 (2.30)	23.9 (4.13)
ERQ-R average	5.16 (0.72)	5.0 (0.17)	5.18 (0.78)
ERQ-S average	3.82 (1.26)	3.9 (1.14)	3.80 (1.30)

2.2. Instrumentation and task

Participants sat 1 meter from a computer screen (19 in, 48.26 cm; 1024 × 768 resolution) and performed isometric ballistic contractions with their right hand by pinching a force transducer (MLP-75, Transducer Techniques, Temecula, CA, USA) with the thumb and index finger. The force transducer's vertical position was adjusted to allow participants' right arms to rest comfortably on the armrest at a right angle. Analog output from the force transducer was amplified through a 15LT Grass Technologies Physiodata Amplifier System (Astro-Med Inc. West Warwick, RI, USA) at an excitation voltage of 10 V. Custom Labview software (8.6; National Instruments, Austin, TX) controlled trial onset, trial offset, visual stimulus presentation, and a 16-bit analog-to-digital converter (A/D) (PCI-6220, National Instruments, Austin, TX) which sampled the force at 100 Hz. Force data were streamed to disk for offline analysis.

2.3. Emotion manipulation

Visual stimuli are often employed to manipulate the emotional states of research participants in a variety of experimental paradigms and are categorized in terms of valence (how pleasant or unpleasant the stimuli are) and arousal (Lang & Bradley, 2007). Previous experiments (e.g. Coombes et al., 2009) have identified that images eliciting highly arousing pleasant and unpleasant states modify reaction times during execution of ballistic motor tasks. In particular, highly arousing images of a threatening attacker, and erotic couples have been employed to respectively manipulate unpleasant and pleasant emotional states. Neutral and blank images (black screens) are commonly employed to serve as a comparison between highly arousing images with low arousing images, or the absence of complex visual stimuli respectively. In the current experiment, participants viewed 60 digitized photographs representing three categories: (a) attack, (b) erotic couples, and (c) neutral objects. Additionally, participants viewed a blank (black screen) for 20 trials (five per condition). Pictures were selected according to affective normative ratings (NIMH, CSEA: Lang, Bradley, & Cuthbert, 2008) from the International Affective Picture System[1] (Lang et al., 2008). Due to an insufficient number of IAPS attack stimuli, internet search engines (e.g., Google, Yahoo, Bing) were used to obtain eight additional attack images of similar quality and content to IAPS images. All images were rated at the conclusion of the experiment using the 9-point Self-Assessment Manikin (SAM) (Bradley & Lang, 1994). Participants' ratings of valence (3.42) and arousal (5.39) for the non-IAPS attack images were comparable to ratings of valence (3.39) and arousal (5.60) for selected IAPS attack images.

2.4. Experimental design and procedure

We employed a four (condition) by four (valence category) experimental design. To begin the experiment, individualized maximal voluntary contraction (MVC: measured in Newtons) values were calculated for each participant using a previously established protocol (Coombes et al., 2009; Vaillancourt & Newell, 2003). Participants then trained to achieve motor task competency during an automated pre-experimental training session. The motor task throughout the experiment required participants to produce a pinch force equaling ten percent of their MVC. The training session concluded once participants were able to complete four consecutive trials within a range of ±20% of the individualized target force. Following the training session, participants progressed through a baseline condition followed by three randomized and counterbalanced ER conditions. Abbreviated condition instructions for the expressive suppression, emotional expression, and attentional deployment conditions are located in Table 2. Each of the four conditions consisted of 20 trials completed free from experimenter interaction in a sound-attenuated room. The 20 trials within each condition consisted of

[1] erotica: 4647, 4649, 4651, 4652, 4656, 4658, 4659, 4660, 4666, 4669, 4670, 4672, 4676, 4677, 4681, 4683, 4687, 4694, 4800, 4810; neutral: 7000, 7004, 7006, 7009, 7010, 7020, 7025, 7030, 7031, 7035, 7041, 7050, 7055, 7059, 7080, 7090, 7110, 7175, 7233, 7235; attack: 1050, 1051, 1120, 1300, 1321, 1726, 1930, 6230, 6250, 6260, 6300, 6510, eight additional attack images from internet searches evaluated for similar valence and arousal ratings depicting attacking animals and humans with guns and knives; black Screen: 1000.

Table 2
Abbreviated condition instructions.

Baseline:
…Maintain attention on the image for the entire time it is presented. Once the image disappears and the gray screen appears, respond by pinching the force transducer with a force equal to 10% of your maximum pinch force. You will complete this 10% pinch as quickly as possible…
Expressive suppression:
…While the image is on the screen, we want you to look at the image and hide or mask your emotional response so that if someone were watching you, they would have no idea what you were feeling. Maintain attention on the image for the entire time it is presented…
Emotional expression:
…While the image is on the screen, we want you to look at the image and express what you are feeling emotionally. You will be alone and this room is sound proof so feel free to express your emotions fully. Maintain attention on the image for the entire time it is presented…
Attentional deployment:
…While the image is on the screen, we want you to verbally count backwards as directed [by the cue preceding each trial]. For example if you were given the cue to count back from 13 by 4, you will verbalize "13, 9, 5, 1, −3, −7" and so on until the image disappears. Maintain attention on the image for the entire time it is presented…

five images per valence category. Image presentation order was randomized and counterbalanced within and across conditions. Prior to each of the regulation conditions, participants completed an inter-condition session comprised of five trials similar to those within the training session. Data from the inter-condition sessions were used to test for practice effect improvements in participants' task competency.

Individual trials during the training session, inter-condition sessions, and experimental conditions consisted of the presentation of a fixation cross (2 s) upon a grey background, an image (5–8 s), and performance of the targeted pinch task upon image offset and simultaneous presentation of the default grey background. The duration of image presentation was randomized across conditions and image type. Following each trial within the training and inter-condition sessions, participants received visual performance feedback. Performance feedback was not provided during baseline and regulation conditions. Feedback consisted of a white horizontal line, representing the 10% target force, and a black force trace that represented the force produced. Images during the training and inter-condition sessions included unique low to moderately arousing pleasant and neutral images from the IAPS.[2]

2.5. Data processing

Force data were processed offline using a customized Matlab program (MATLAB 7.9.0 R2009b, The MathWorks, Inc., Natick, MA, USA). Dependent measures included reaction time (RT), peak rate of change of force production (PRF), and root-mean-square error (RMSE). RT was calculated by measuring the time between picture offset and onset of force production. Force onset was measured as the time point when force production increased 3-fold above the mean force output of the 100 ms prior to image offset. PRF was calculated as the maximum of the first derivative of force for the period between force onset and the peak force value for each trial. RMSE was calculated by subtracting each trial's peak force from the target force value, squaring the difference, calculating the mean of the squared differences within each valence category, then computing the square root of each mean value. RMSE scores represented total error on the task controlling for error direction (above or below target). Fig. 1 displays data output from an exemplar trial. RTs less than 100 ms following picture offset were deemed "anticipation trials" and removed. Additionally, trials with RTs or raw error scores ±3 standard deviations from the mean were removed. Per

[2] Training Session Images: 1500, 1600, 1604, 1731, 2037, 2191, 2370, 2518, 5010, 5201, 5220, 5390, 5410, 5470, 5600, 5622, 5626, 5628, 5711, 5720, 5731, 5780, 5831, 5994, 6900, 7037, 7041, 7140, 7220, 7320, 7325, 7351, 7410, 7480, 7493, 7495, 7502, 7546, 7560, 7580, 7705, 8031, 8060, 8161, 8200, 8211, 8260, 8311, 8510, 9210.

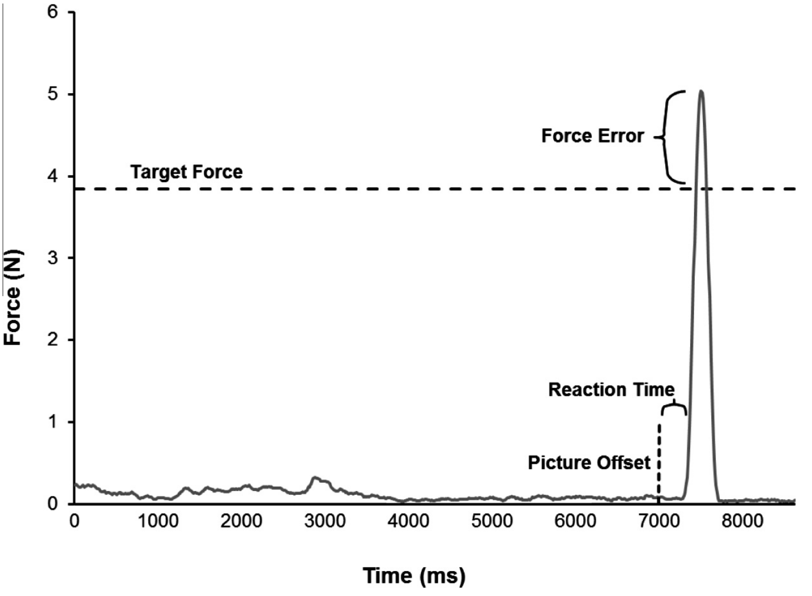

Fig. 1. Illustrative sample of force trends for one trial. Trial begins at picture onset and concludes after the participant produces a ballistic pinch. The gray dotted line at the top represents the 10% target and the black line represents the participants real-time force trace. The vertical, black dotted line near the *x*-axis represents the picture offset time stamp. Force error above or below the target was used to calculate RMSE. Reaction time was calculated as the time from picture offset until force output exceeded 3*x* the baseline value. Peak rate of force production was calculated as the peak of the first derivative between force onset and peak force.

exclusion criteria, 97.35% of experimental trials and 96.33% of inter-condition trials were included in the statistical analyses.

2.6. Statistical analyses

A one-way repeated measures analysis of variance (ANOVA) analyzed each dependent measure across the three inter-condition sessions to test for significant improvement or attenuation of task competency. Univariate tests evaluated participants' SAM ratings to determine validity of the emotional manipulation. Separate 4 (Condition: baseline, expressive suppression, emotional expression, attentional deployment) $\times$ 4 (Valence: erotica, neutral, attack, blank) repeated measures ANOVAs tested experimental hypotheses concerning performance differences for each dependent measure. For significant main effects and interactions, Bonferroni adjusted paired *t*-tests and simple effects tests were performed respectively. For ANOVAs, if the sphericity assumption was violated, then Greenhouse–Geisser degrees of freedom corrections were applied. The probability value was set at $p < .05$ for all analyses.

3. Results

3.1. Inter-condition sessions

Results from the three inter-condition sessions revealed similar performance. Neither RT, F (2, 62) = 0.751, $p = .476$, $\eta^2 = 0.024$, RMSE, F (2, 62) = 0.050, $p = 0.951$, $\eta^2 = 0.002$, nor PRF, F (1.542, 47.793) = 0.702, $p = 0.465$, $\eta^2 = 0.022$, varied significantly across inter-condition sessions.

3.2. Emotion manipulation

Univariate tests revealed significant differences in participants' ratings of pleasantness, F (2, 1917) = 299.942, $p < 0.001$, $\eta^2 = 0.238$, and arousal, F (2, 1917) = 608.305, $p < 0.001$, $\eta^2 = .388$, as a function of Valence. Follow-ups revealed that ratings (Mean [*M*], Standard Deviation [*SD*]) of pleasantness followed normed IAPS ratings (erotica ($M = 5.91$, $SD = 1.96$) > neutral ($M = 4.88$, $SD = 1.05$) > attack ($M = 3.58$, $SD = 1.96$). Additionally, erotica ($M = 5.64$, $SD = 2.33$) and attack images ($M = 5.68$, $SD = 2.30$) were rated similarly for arousal and both were rated significantly more arousing than neutral ($M = 1.98$, $SD = 1.88$) images (all p's < .05).

3.3. Reaction time (RT)

Analysis of RT revealed a significant main effect for Valence, F (3, 96) = 4.779, $p = 0.004$, $\eta^2 = 0.130$, and Condition, F (2.340, 74.873) = 5.193, $p = 0.002$, $\eta^2 = 0.140$. Follow-up tests revealed faster RT during neutral trials compared to blank trials. RTs also were faster during baseline compared to the attentional deployment condition. These effects were qualified by a significant Valence × Condition interaction, F (9, 288) = 2.421, $p = 0.012$, $\eta^2 = 0.070$. Follow-up tests revealed faster RT for the erotica, neutral, and attack trials compared to blank trials during baseline, as well as faster RT for neutral trials compared to blank trials during the suppression condition. Condition specific effects were also observed as a function of valence.

Simple effects analyses revealed that RT differences were observed across conditions as follows: reaction to erotica images [baseline < emotional expression and attentional deployment; expressive suppression < attentional deployment]; reaction to neutral images [baseline and expressive suppression < emotional expression and attentional deployment]; reaction to attack images [baseline < emotional expression and attentional deployment]; and reaction to blank images [emotional expression < attentional deployment]. Fig. 2 displays mean RT values for each Valence category by Condition.

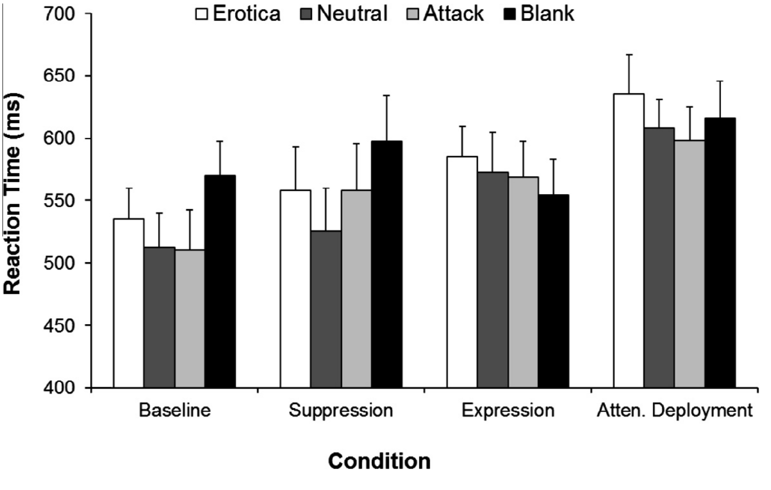

Fig. 2. Reaction Time (RT) for valence trials across each experimental condition. The error bars represent +1 SE from the mean. RTs varied as follows: collapsing across valence trials (baseline < attentional deployment); collapsing across all conditions (neutral < blank); within the baseline condition (erotica, neutral, and attack < blank); within the suppression condition (neutral < blank); during erotica trials (baseline < emotional expression and attentional deployment; suppression < attentional deployment); during neutral trials (baseline and suppression < expression and attentional deployment); during attack trials (baseline < emotional expression and attentional deployment); during blank trials (emotional expression < attentional deployment).

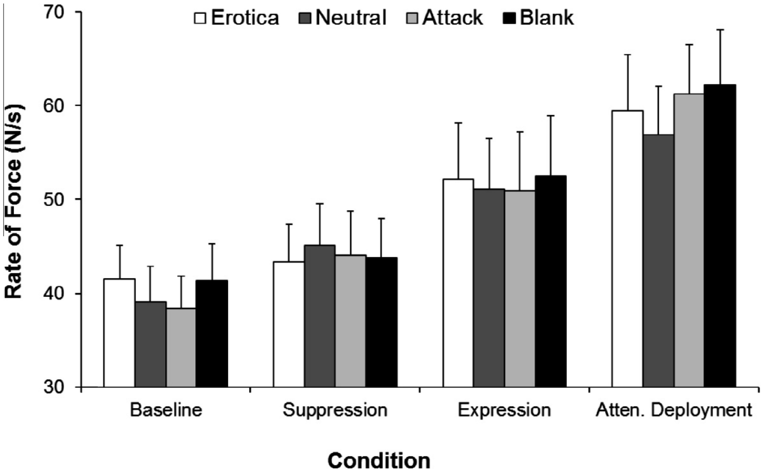

Fig. 3. Peak rate of change of force (PRF) for valence trials across each experimental condition. The error bars represent +1 SE from the mean. Collapsing across valence trials, PRF production was lowest in the baseline and expressive suppression conditions (baseline, suppression < emotional expression, attentional deployment).

3.4. Peak rate of change of force (PRF)

A significant main effect for Condition, $F\ (2.243, 71.768) = 18.166$, $p < 0.001$, $\eta^2 = 0.362$, was found for PRF. Follow-up tests revealed greater PRF for the attentional deployment condition compared to the baseline, expressive suppression, and emotional expression conditions. Furthermore, the emotional expression condition showed greater PRF compared to the baseline, and expressive suppression conditions. The main effect for Valence $F\ (3, 96) = 1.834$, $p > .05$, $\eta^2 = 0.054$, and the Valence × Condition interaction, $F\ (9, 288) = 1.496$, $p > .05$, $\eta^2 = 0.045$, were not significant. Fig. 3 displays mean PRF values for each Valence category by Condition.

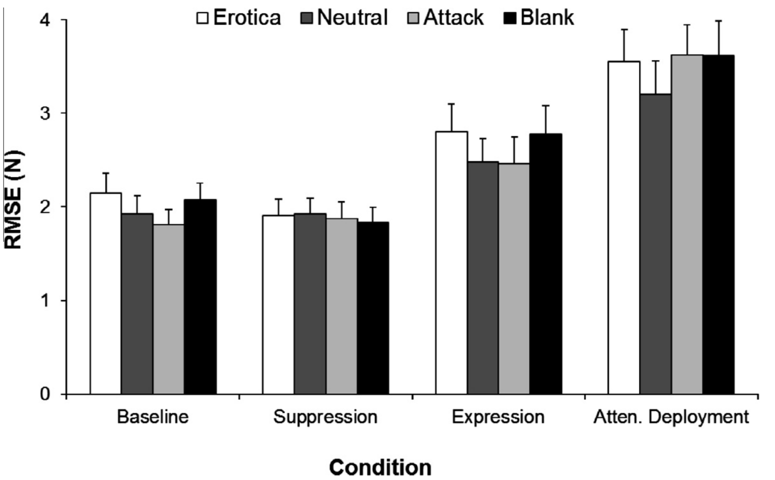

Fig. 4. Root-mean-square error (RMSE) for valence trials across each experimental condition. The error bars represent +1 SE from the mean. Collapsing across valence trials, total force error to the target increased during the attentional deployment condition compared to all other conditions. Additionally, participants were more accurate (decreased error) during the suppression condition compared to both the attentional deployment and the emotional expression conditions.

3.5. Root-mean-square error (RMSE)

Analysis of RMSE revealed a significant effect for Valence, F (3, 96) = 2.816, $p = 0.043$, $\eta^2 = 0.081$, and Condition, F (2.322, 74.289) = 15.295, $p < 0.001$, $\eta^2 = 0.323$. Follow-up tests on the Valence main effect revealed that participants performed the task with greater RMSE during erotica trials than during neutral trials. Follow-ups on the Condition main effect revealed greater RMSE for the attentional deployment condition compared to all other conditions. Additionally, participants performed the task with greater RMSE during the emotional expression condition compared to the expressive suppression condition. The Valence x Condition interaction was not significant, F (5.926, 189.635) = 1.155, $p > 0.05$, $\eta^2 = 0.035$. Fig. 4 displays mean RSME values for each Valence category by Condition.

4. Discussion

We sought to determine how implementation of ER strategies influences the ability to quickly produce a specified target force. Our findings supported the central hypothesis that while ER techniques effectively regulate the motor response variations associated with highly arousing emotional states, these regulatory benefits impart costs on motor efficacy.

Five key contributions emerged. First, we replicated previous work by showing that emotional stimuli speed reaction times. Second, we extended the current knowledge base by demonstrating that ER strategies eliminated the valence directed differences in reaction time. Third, attentional deployment was costly to performance as it slowed reactions, increased the rate of force production, and decreased force accuracy relative to the baseline condition. Fourth, expressive suppression and emotional expression were less costly—decreasing the rate of force production and improving force accuracy—than attentional deployment. Finally, expressive suppression was less costly than emotional expression, as suppressing emotional expressions resulted in reduced rates of force production and more accurate force production. As elaborated below, the current findings provide preliminary evidence that ER strategies should be appropriately tailored following careful consideration of contextual demands.

4.1. Manipulation check

Results indicate that the participants' ability to perform the motor task remained stable throughout the experiment; displaying similar reaction time, rate of force production, and force error values across the three inter-condition sessions. Additionally, IAPS images effectively manipulated emotional states. SAM ratings revealed erotica images to be more pleasant than neutral and attack images; attack images to be more unpleasant than neutral and erotica images; and erotica and attack images as more arousing than neutral images. Critically, the baseline condition replicated previous empirical efforts (e.g. Coombes et al., 2009) indicating that emotional states modulate goal directed motor actions in the absence of explicitly employed ER strategies. Within the Baseline condition, participants produced the fastest reaction times following emotional images compared to the blank images, indicating that exposure to emotionally arousing stimuli speeds the initiation of planned motor actions. Accordingly, the baseline condition provided a reliable basis of comparison to examine the influence of deliberate ER strategies on planned motor tasks.

4.2. Regulating emotion and motor execution

Reaction time differences observed as a function of stimulus valence generally disappeared during ER conditions. Consequently, results indicate that the ER strategies down-regulated the influence of emotional stimuli on the initiation of motor actions. Subsequently, the current experiment provides evidence consistent with Bresin and colleagues' (2012) assertion that motoric probes provide alternative modes of understanding regulatory processes and their influence on human behavior. It is important to note, however, that within the expressive suppression condition, participants responded more quickly to neutral images compared to blank images. In retrospect, this finding is reasonable considering that relative to the other valenced images (attack and erotica), suppressing instinctual responses to neutral stimuli likely required little to no effort and subsequently interfered less with successful completion of the motor task (Demaree et al., 2006; Schupp, Junghöfer, Weike, & Hamm, 2003).

Additionally, we observed increased force error for erotica trials compared to neutral trials across all conditions. Erotic image presentation may have compounded attentional, cognitive, and motor demands. Such an interpretation could be explained by an evolutionary drive competing for engaged attentional networks during the attentional deployment condition (Schupp et al., 2003); and a conflict between visceral reactions and perceptions of social expectations of appropriate responses towards taboo stimuli within the emotional expression condition (Lopez & George, 1995; Rupp & Wallen, 2008). Force error following erotica images was tempered during the expressive suppression condition; suggesting that suppression of emotional reactions to erotica may occur spontaneously to avoid social/cultural stigmas. In sum, all regulation strategies proved effective in eliminating valence driven modulation of motor execution.

4.3. Motor benefits and costs of employing regulatory strategies

Previous work (Webb et al., 2012) has emphasized that expressive suppression, relative to attentional distraction or cognitive restructuring strategies, provides limited benefits to affective experience, increases physiological arousal over time, and is therefore typically considered a less than optimal ER strategy. Our data indicate that within certain contexts, particularly temporally constrained motor tasks, expressive suppression may prove a beneficial ER strategy. While attentional deployment effectively regulated emotional reactivity, these regulatory benefits incurred reciprocal costs. The slowest reactions, greatest rates of force production, and greatest force error were found during the attentional deployment condition. Conversely, expressive suppression proved to be the most favorable strategy. When participants suppressed emotional expressions, rates of force production and force error were reduced relative to the emotional expression and attentional deployment strategies.

Although the reported data reflect only overt behavioral responses, considering the neural mechanisms potentially implicated in the observed behavioral responses is worth discussing in terms of offering consideration to why ER strategies might differ in the benefits and costs across varied performance contexts. Attentional deployment is known to tax the dorsomedial and dorsolateral prefrontal cortices. These cortical areas are associated with working memory and attentional control (Kanske et al., 2011; McRae et al., 2009). Moreover, the dorsomedial prefrontal cortex has been implicated in the control of motor force output under varying emotional conditions (Coombes et al., 2012). Accordingly, although our results provide further evidence that attentional deployment is effective in regulating emotion (Kanske et al., 2011; McRae et al., 2009), employing the strategy potentially disrupts mechanisms involved in executing motor actions. In contrast, expressive suppression has been shown to activate the integrated networks of the dorsomedial and dorsolateral prefrontal cortices later in the emotional experience and regulation processes (Goldin et al., 2008). Such a delay in the conscription of cortical resources, for the purpose of regulating emotions, may have allowed participants to better attend to emotional stimuli; permitting them to recognize and respond to image offset more quickly. Comparatively, emotional expression is known to activate the pre-motor cortex (Lee et al., 2006), while expressive suppression efficiently inhibits expressive motor output during short-term emotional experiences without displaying physiological resource allocation to the ventrolateral prefrontal cortex (Goldin et al., 2008)—a region associated with inhibitory control. Therefore, it is possible that expressive suppression provided performance benefits relative to the emotional expression strategy by eliminating the additive motor demands associated with expressing emotional experiences (Lee et al., 2006).

4.4. Implications and future directions

Our findings indicate that ER strategies, performed within contexts that require immediate action, reduce differences in motor reaction time induced by emotional reactivity. However, the benefits of regulating emotion come at a cost to performance. The cost/benefit relationship of ER in movement contexts is consistent with the notion that a fundamental purpose of emotions is to prime the motor system for actions that are beneficial to survival. Indeed, it is largely through motor actions that human beings are able to achieve appetitive goals and sustain pleasant affect, while avoiding aversive consequences and unpleasant emotions. Our evidence indicates that attempting to regulate the primitive, yet potentially adaptive, reactions elicited during an emotional cascade can yield short-term motor deficits. Accordingly, our results highlight the need to appropriately tailor emotion regulation interventions to the demands of specific performance contexts. For example, performances within certain environments may benefit from the facilitation of faster reaction times and increased force output provided by certain emotional states (Coombes et al., 2006, 2007b), whereas other performance environments may favor the regulation of emotions in spite of the subsequent costs to performance.

Importantly, our initial evidence indicates that particular regulation strategies may provide both regulatory benefits and induce minimal costs to motor actions. When considering both the reported results and the potentially implicated neural mechanisms, it seems reasonable to assert that within short-term performance contexts, expressive suppression provides regulatory benefits with minimal costs to motor actions, in part, because expressive suppression is relatively easy to perform. This phenomenon may also help explain why such a strategy persists in spite of the apparent long term costs to physiological and psychological well-being (Gross & John, 2003; Webb et al., 2012).

Although our data highlight the immediate benefits of expressive suppression, it is important to note that over longer durations, expressive suppression increases activation of cognitive and attentional systems (Goldin et al., 2008), as well as physiological responses (Gross, 1998). Expressive suppression also has limited long term efficacy in reducing emotional experience (Goldin et al., 2008; Gross, 1998; Gross & John, 2003). Therefore, expressive suppression might be an ideal regulation strategy when completing quick motor tasks within emotionally salient environments. However, when emotional demands require prolonged regulation, expressive suppression is likely more costly than strategies such as attentional deployment or cognitive reappraisal. Future studies should explore the costs and benefits of employing other ER strategies over the full time course of emotional experience.

While attentional deployment was more costly to performance than expressive suppression and emotional expression, it is certainly possible that other cognitively demanding ER strategies (such as cognitive reappraisal) present divergent, and potentially attenuated, costs to performance of goal directed motor actions. Indeed, recent investigations have identified advantages of reappraisal strategies that could improve performance on motor tasks compared to attentional deployment. For example, Kanske et al. (2011) found that while attentional deployment and cognitive reappraisal similarly down-regulate emotional experience through the engagement of cognitive resources, the two strategies activate distinct neural networks involved in cognitive restructuring (reappraisal) and attention (attentional deployment) respectively. Relatedly, Bebko, Franconeri, Ochsner, and Chiao (2011) found cognitive reappraisers attended more to the emotional regions of emotional scenes than expressive suppressors. Thus, cognitive reappraisal may prove a highly task relevant ER strategy within contexts where directing attention away from emotional stimuli harms performance. Accordingly, eye tracking technology could be implemented to ascertain how point of gaze preferences might be involved in various ER strategies (e.g., Ferri, Schmidt, Hajcak, & Canli, 2013) during concurrent motor task engagement. Further delineation of these visual attention mechanisms would assist in developing attentional strategies that aid in the regulation of emotions but also minimize costs to performance.

Finally, we provide speculation on the implicated neural processes responsible for the observed behavioral responses in an attempt to highlight the need for a better understanding of the mechanisms involved in concurrent ER and motor action. Understanding the implicated networks would help inform training and intervention guidelines for motor tasks that could benefit from efficient emotion regulation. For example, pleasant emotional states have been shown to facilitate gait initiation in people with Parkinson's disease (Naugle, Hass, Bowers, & Janelle, 2012); a population that also suffers from significant motor decrements during dual-tasks (O'Shea, Morris, & Iansek, 2002; Yogev et al., 2005). Additionally, emotional states have been shown to influence key performance factors in police officers that result in changes to gaze behavior, postural adjustments, decision making, and shooting accuracy (Nieuwenhuys & Oudejans, 2010, 2011; Nieuwenhuys, Savelsbergh, & Oudejans, 2012). Thus, identifying the most effective and efficient ER strategies, while minimizing costs to the integrated cognitive and motor networks, is a worthwhile and valuable endeavor.

5. Conclusion

While the majority of ER research has focused on the long-term health outcomes of regulating emotional experience, our data indicate that there are immediate benefits and costs associated with regulating emotions while performing goal directed motor actions. We observed delayed reaction times paired with accelerated rates of force production, and increased force error during attentional deployment. Additionally, performance while suppressing emotional expressions was comparable to performance in the absence of any explicit ER instructions. Expressive suppression might therefore be the ideal short-term ER strategy for performance of ballistic movements executed within emotionally rich environments (e.g., surgery, tactical operations, aircraft control, sport performance). Establishing whether and how the optimal employment of ER strategies varies based on environmental conditions, task requirements, and temporal constraints will help advance understanding of the performance and health consequences of human affective experiences.

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References

Arora, S., Sevdalis, N., Nestel, D., Woloshynowych, M., Darzi, A., & Kneebone, R. (2010). The impact of stress on surgical performance: A systematic review of the literature. *Surgery, 147*(3), 318–330.

Bebko, G. M., Franconeri, S. L., Ochsner, K. N., & Chiao, J. Y. (2011). Look before you regulate: Differential perceptual strategies underlying expressive suppression and cognitive reappraisal. *Emotion, 11*(4), 732–742.

Bradley, M. M., & Lang, P. J. (1994). Measuring emotion: The self-assessment manikin and the semantic differential. *Journal of Behavior Therapy and Experimental Psychiatry, 25*(1), 49–59.

Bresin, K., Fetterman, A. K., & Robinson, M. D. (2012). Motor control accuracy: A consequential probe of individual differences in emotion regulation. *Emotion, 12*(3), 479–486.

Casasanto, D. (2009). Embodiment of abstract concepts: Good and bad in right- and left-handers. *Journal of Experimental Psychology: General, 138*(3), 351–367.

Causer, J., Holmes, P. S., Smith, N. C., & Williams, A. M. (2011). Anxiety, movement kinematics, and visual attention in elite-level performers. *Emotion, 11*(3), 595–602.

Chen, M., & Bargh, J. A. (1999). Consequences of automatic evaluation: Immediate behavioral predispositions to approach or avoid the stimulus. *Personality and Social Psychology Bulletin, 25*(2), 215–224.

Coombes, S. A., Cauraugh, J. H., & Janelle, C. M. (2006). Emotion and movement: Activation of defensive circuitry alters the magnitude of a sustained muscle contraction. *Neuroscience Letters, 396*(3), 192–196.

Coombes, S. A., Cauraugh, J. H., & Janelle, C. M. (2007a). Dissociating motivational direction and affective valence. *Psychological Science, 18*(11), 938–942.

Coombes, S. A., Cauraugh, J. H., & Janelle, C. M. (2007b). Emotional state and initiating cue alter central and peripheral motor processes. *Emotion, 7*(2), 275–284.

Coombes, S. A., Corcos, D. M., Pavuluri, M. N., & Vaillancourt, D. E. (2012). Maintaining force control despite changes in emotional context engages dorsomedial prefrontal and premotor cortex. *Cerebral Cortex, 22*(3), 616–627.

Coombes, S. A., Gamble, K. M., Cauraugh, J. H., & Janelle, C. M. (2008). Emotional states alter force control during a feedback occluded motor task. *Emotion, 8*(1), 104–113.

Coombes, S. A., Higgins, T., Gamble, K. M., Cauraugh, J. H., & Janelle, C. M. (2009). Attentional control theory: Anxiety, emotion, and motor planning. *Journal of Anxiety Disorders, 23*(8), 1072–1079.

Coombes, S. A., Janelle, C. M., & Duley, A. R. (2005). Emotion and motor control: Movement attributes following affective picture processing. *Journal of Motor Behavior, 37*(6), 425–436.

Demaree, H. A., Schmeichel, B. J., Robinson, J. L., Pu, J., Everhart, D. E., & Berntson, G. G. (2006). Up- and down-regulating facial disgust: Affective, vagal, sympathetic, and respiratory consequences. *Biological Psychology, 71*(1), 90–99.

Ferri, J., Schmidt, J., Hajcak, G., & Canli, T. (2013). Neural correlates of attentional deployment within unpleasant pictures. *NeuroImage, 70*, 268–277.

Glover, S. (2004). Separate visual representations in the planning and control of action. *Behavioral and Brain Sciences, 27*(01), 3–24.

Goldin, P. R., McRae, K., Ramel, W., & Gross, J. J. (2008). The neural bases of emotion regulation: Reappraisal and suppression of negative emotion. *Biological Psychiatry, 63*(6), 577–586.

Gross, J. J. (1998). Antecedent- and response-focused emotion regulation: Divergent consequences for experience, expression, and physiology. *Journal of Personality and Social Psychology, 74*(1), 224–237.
Gross, J. J., & John, O. P. (2003). Individual differences in two emotion regulation processes: Implications for affect, relationships, and well-being. *Journal of Personality and Social Psychology, 85*(2), 348–362.
Gross, M. M., Crane, E. A., & Fredrickson, B. L. (2012). Effort-Shape and kinematic assessment of bodily expression of emotion during gait. *Human Movement Science, 31*(1), 202–221.
Heimer, L., & Van Hoesen, G. W. (2006). The limbic lobe and its output channels: Implications for emotional functions and adaptive behavior. *Neuroscience & Biobehavioral Reviews, 30*(2), 126–147.
Hikosaka, O., Sesack, S. R., Lecourtier, L., & Shepard, P. D. (2008). Habenula: Crossroad between the Basal Ganglia and the Limbic System. *The Journal of Neuroscience, 28*(46), 11825–11829.
Jackson, D. C., Malmstadt, J. R., Larson, C. L., & Davidson, R. J. (2000). Suppression and enhancement of emotional responses to unpleasant pictures. *Psychophysiology, 37*(4), 515–522.
Kanske, P., Heissler, J., Schönfelder, S., Bongers, A., & Wessa, M. (2011). How to regulate emotion? Neural networks for reappraisal and distraction. *Cerebral Cortex, 21*(6), 1379–1388.
Lang, P., & Bradley, M. M. (2007). The International Affective Picture System (IAPS) in the study of emotion and attention. *Handbook of Emotion Elicitation and Assessment*, 29.
Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (2008). International affective picture system (IAPS): Affective ratings of pictures and instruction manual. *Technical Report A-8*. University of Florida, Gainesville, FL.
Lee, T.-W., Josephs, O., Dolan, R. J., & Critchley, H. D. (2006). Imitating expressions: Emotion-specific neural substrates in facial mimicry. *Social Cognitive and Affective Neuroscience, 1*(2), 122–135.
Lopez, P. A., & George, W. H. (1995). Men's enjoyment of explicit erotica: Effects of person-specific attitudes and gender-specific norms. *Journal of Sex Research, 32*(4), 275–288.
Mauss, I. B., Bunge, S. A., & Gross, J. J. (2007). Automatic emotion regulation. *Social and Personality Psychology Compass, 1*(1), 146–167.
McRae, K., Hughes, B., Chopra, S., Gabrieli, J. D. E., Gross, J. J., & Ochsner, K. N. (2009). The neural bases of distraction and reappraisal. *Journal of Cognitive Neuroscience, 22*(2), 248–262.
Mogenson, G. J., Jones, D. L., & Yim, C. Y. (1980). From motivation to action: Functional interface between the limbic system and the motor system. *Progress in Neurobiology, 14*(2–3), 69–97.
Nalçaci, E., Kalaycioğlu, C., Çiçek, M., & Genç, Y. (2001). The relationship between handedness and fine motor performance. *Cortex, 37*(4), 493–500.
Naugle, K. M., Hass, C. J., Bowers, D., & Janelle, C. M. (2012). Emotional state affects gait initiation in individuals with Parkinson's disease. *Cognitive, Affective, & Behavioral Neuroscience, 12*(1), 207–219.
Nieuwenhuys, A., & Oudejans, R. D. (2011). Training with anxiety: Short- and long-term effects on police officers' shooting behavior under pressure. *Cognitive Processing, 12*(3), 277–288.
Nieuwenhuys, A., & Oudejans, R. R. D. (2010). Effects of anxiety on handgun shooting behavior of police officers: A pilot study. *Anxiety, Stress & Coping, 23*(2), 225–233.
Nieuwenhuys, A., Savelsbergh, G. J. P., & Oudejans, R. R. D. (2012). Shoot or don't shoot? Why police officers are more inclined to shoot when they are anxious. *Emotion, 12*(4), 827–833.
O'Shea, S., Morris, M. E., & Iansek, R. (2002). Dual task interference during gait in people with Parkinson disease: Effects of motor versus cognitive secondary tasks. *Physical Therapy, 82*(9), 888–897.
Pêcher, C., Lemercier, C., & Cellier, J.-M. (2009). Emotions drive attention: Effects on driver's behaviour. *Safety Science, 47*(9), 1254–1259.
Rémy, F., Wenderoth, N., Lipkens, K., & Swinnen, S. P. (2010). Dual-task interference during initial learning of a new motor task results from competition for the same brain areas. *Neuropsychologia, 48*(9), 2517–2527.
Rotteveel, M., & Phaf, R. H. (2004). Automatic affective evaluation does not automatically predispose for arm flexion and extension. *Emotion, 4*(2), 156–172.
Rupp, H., & Wallen, K. (2008). Sex differences in response to visual sexual stimuli: A review. *Archives of Sexual Behavior, 37*(2), 206–218.
Schupp, H. T., Junghöfer, M., Weike, A. I., & Hamm, A. O. (2003). Attention and emotion: An ERP analysis of facilitated emotional stimulus processing. *NeuroReport, 14*(8), 1107–1110.
Tsai, W.-C., Chen, C.-C., & Liu, H.-L. (2007). Test of a model linking employee positive moods and task performance. *Journal of Applied Psychology, 92*(6), 1570–1583.
Vaillancourt, D. E., & Newell, K. M. (2003). Aging and the time and frequency structure of force output variability. *Journal of Applied Physiology, 94*(3), 903–912.
Van Kleef, G. A. (2009). How emotions regulate social life: The Emotions as Social Information (EASI) model. *Current Directions in Psychological Science, 18*(3), 184–188.
Wallenius, C. (2004). Military observers' reactions and performance when facing danger. *Military Psychology, 16*(4), 211–229.
Webb, T. L., Miles, E., & Sheeran, P. (2012). Dealing with feeling: A meta-analysis of the effectiveness of strategies derived from the process model of emotion regulation. *Psychological Bulletin, 138*(4), 775–808.
Yogev, G., Giladi, N., Peretz, C., Springer, S., Simon, E. S., & Hausdorff, J. M. (2005). Dual tasking, gait rhythmicity, and Parkinson's disease: Which aspects of gait are attention demanding? *European Journal of Neuroscience, 22*(5), 1248–1256.