Published in final edited form as:

Res Q Exerc Sport. 2012 June ; 83(2): 353–358.

Influence of Emotion on the Control of Low-Level Force Production

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Abstract

The accuracy and variability of a sustained low-level force contraction (2% of maximum voluntary contraction) was measured while participants viewed unpleasant, pleasant, and neutral images during a feedback occluded force control task. Exposure to pleasant and unpleasant images led to a relative increase in force production but did not alter the variability of force production compared to conditions in which participants viewed neutral images. Findings are discussed with respect to prior work, emphasizing arousal specific changes that emerge at low target force levels.

Keywords

affect; arousal; error; variability

The link between emotion and motor systems has been examined in applied settings using gross motor tasks (Pijpers, Oudejans, & Bakker, 2005), and using grip force control in the laboratory (Coombes, Gamble, Cauraugh, & Janelle, 2008; Coombes, Higgins, Gamble, Cauraugh, & Janelle, 2009; Schmidt et al. 2009). (Grip force production is an ideal task to investigate the impact of emotion on movement. It is commonly used in daily living activities, such as drinking and grooming. The behavioral and neurobiological signatures of grip force are well understood (Prodoehl, Corcos, & Vaillancourt, 2009). In grip tasks, force production decays approximately 1.5 s after visual feedback during a sustained pinch grip task is removed (Davis, 2007; Vaillancourt & Russell, 2002). To examine how emotion influences decay in force production, Coombes et al. (2008) replaced visual feedback with a pleasant, unpleasant, or neutral image. They showed less decay in force production when participants viewed unpleasant and pleasant images versus neutral images. This finding suggested that emotional arousal leads to a relative increase in force production at a moderate force level and has since been extended to a maximal power grip force task (Schmidt et al., 2009). Although the amplitude of force varies as a function of emotion, the normalized variability of moderate force production does not.

The variability of force production increases when participants are threatened with electric shock during low-level force production (Christou, 2005; Christou, Jakobi, Critchlow, Fleshier, & Enoka 2004). This suggests that emotion-driven changes in variability may only occur when low levels of force control are required. Functional brain imaging studies support the idea that emotion's impact may vary with force level. Changes in force production amplitude lead to region-specific changes in brain activity in the basal ganglia,

primary motor/somatosensory cortex, and thalamus (Spraker, Yu, Corcos, & Vaillancourt, 2007). Low (< 4% of maximum voluntary contraction [MVC]) compared to moderate grip force production corresponds with increased activity bilaterally in the ventral premotor cortex, rostral cingulate motor area, and right intraparietal cortex (Ehrsson, Fagergren, Forssberg, 2001). The cingulate motor area (Morecraft & Van Hoesen, 1998), basal ganglia (Haber, 2003; Mallet et al., 2007), and thalamus (Haber, 2003) have been identified as candidate regions that integrate emotion and motor processes. These regions also scale with force production or are recruited during low but not moderate force control. It is plausible, therefore, that the neural circuits underlying different levels of force control may interact differently with those underlying emotional processing. Therefore, the effect of emotion on force control may not be uniform at both low and moderate force levels.

Emotional arousal increases force production but does not alter variability at moderate and maximal levels (Coombes et al., 2008; Schmidt et al., 2009). Unpleasant arousal increases force variability at low levels. Motivated by these findings, we designed the present study to answer two questions: (a) do pleasant and unpleasant emotional states increase force output at low target force levels, and (b) do pleasant and unpleasant emotional states increase variability of low-level force production? To address these questions, we replicated a previously used emotion and force control paradigm but set the target force to a low (i.e., 2% of MVC) rather than a moderate (10% of MVC) level (Coombes et al., 2008). If arousing emotional images increase motor system excitability (Coombes, Tandonnet et al., 2009; Hajcak et al., 2007; van Loon, van den Wildenberg, van Stegeren, Hajcak, & Ridderinkhof, 2010), we should see a relative increase in force production for pleasant and unpleasant images as compared to neutral images. Force is known to decay once visual feedback has been removed; therefore, the best index of such an increase would be the magnitude of the directional bias of force production, as indexed by constant error. (CE) We expected increased CE (representing less force decay), for trials executed during these emotional conditions compared to the nonemotional neutral condition. To address our second question, we tested the hypothesis that unpleasant images would lead to increased variability (CV) of force output, which would be consistent with Christou's (2005) findings.

Method

Participants

Twenty-eight undergraduate students (22 women, M age = 19.43 years, SD = .84) participated in this study for extra course credit. Participants were right-hand dominant, reported no central nervous system disorders, had normal or corrected to normal vision, and reported moderate levels of trait anxiety (State Trait Anxiety Inventory; M = 33.29, SD = 2.46). All participants provided written informed consent, and all procedures were approved by the university's Institutional Review Board.

Task

Participants sat 1 m from a 21-inch [53.3 cm] computer screen (1,024 × 768 resolution; 100 Hz refresh rate). Once seated, participants' elbows were placed at a 90° angle with the wrist midway between maximum supination and maximum pronation. They produced isometric contractions by pinching the transducer with the thumb and index finger of their right hand.

Force Task—A white stationary horizontal target bar was presented on the monitor at the target force level. A black horizontal bar represented the amount of force being produced. Participants adjusted their force output to position the black bar as accurately as possible over the white target bar, and to maintain the target force level (set at 2% of MVC) throughout each 11 s trial. Real-time visual feedback was available for the first 5 s of each

trial For the 20 experimental trials, visual feedback was replaced with a pleasant, unpleasant, or neutral image (see Figure 1). On 5 full feedback trials, feedback remained on the screen. Picture offset or a blank screen (full feedback trials) represented the end of each trial.

Emotion Manipulation—All participants viewed the same images. Twenty digitized photographs selected from the International Affective Picture System¹ (Lang, Bradley, & Cuthbert, 2005). represented pleasant (5 images), unpleasant (5 images) and neutral categories (10 images). Images were selected according to affective normative ratings to match arousal between pleasant and unpleasant images while differentiating each from neutral images, and to discriminate valence across all categories. Stimulus presentation order was randomized and counterbalanced.

Procedure

Participants' MVC scores ($M = 44.02$ N, $SD = 13.67$) were calculated using a previously established protocol (Vaillancourt & Newell 2003). Participants then received instructions, completed four practice trials (two feedback-only trials and two trials with unique neutral images), and then 20 experimental trials. Participants were instructed to match the target force bar as soon as both bars appeared on the screen and to sustain this force as accurately as possible during each trial.

Data Reduction and Statistical Analysis

The force-time series data were digitally filtered by using a fourth-order Butterworth filter with a 20 Hz low-pass cut-off. The time period of interest from each trial was divided into seven consecutive 1-s epochs, beginning 1s before picture onset (Epoch 0) and ending with picture offset (Epoch 6). Mean CE and CV-detrended were calculated for each 1-s epoch (100 samples). The dependent variable was derived by computing the mean of these 100 samples. CE was calculated as the distance between the target force and the amount of force being produced. Thus, CK indexed the direction of error or bias, with negative CE reflecting force production that was on average below the target force (i.e., negative bias) and positive CE reflecting force production that was, on average, above the target force (i.e., positive bias). CV-detrended is a measure of relative variability normalized to the magnitude of the corresponding absolute force value ($CV = SD\text{-detrended}/\text{mean force}$) and quantified total variability.

CE and CV-detrended were analyzed in separate repeated measures two-way analyses of covariance with four levels of valence (pleasant, unpleasant neutral, control) and two levels of time (at 2 s postpicture onset [Epoch 2: to determine the initial impact of emotion on the force task] and the last second of picture onset [Epoch 6: to compare to prior work]). The literature has suggested that maximal emotional reactivity during picture viewing occurs between 2 and 4 s (Bradley, Codispoti, Cuthbert, & Lang, 2001); Epoch 2 rather than Epoch 1 was analyzed to determine the initial impact of emotion on the force task. To control for any preintervention differences at Epoch 0 (the epoch prior to picture onset). Epoch 0 for each condition was added as a covariate. For all analyses (critical $p < .05$), the Greenhouse-Geisser conservative degrees of freedom adjustment was used if the sphericity assumption was violated. Follow-up analyses were conducted on the adjusted means using Bryant-Paulson's simultaneous test procedure.

¹Pleasant: 4647, 4660, 4800, 4659, 4670; unpleasant: 3064, 3030, 3060, 3068, 3071; neutral: 7000, 7010, 7030, 7025, 7090, 7059, 7175, 7052, 7050, 7055.

Results

Table 1 shows CE and CY-detrended scores for each epoch of interest (2 and 6).

Constant Error

Analysis of constant error revealed nonsignificant main effects of valence, $F(1.85, 42.49) = 2.73$, $p = .081$, $\eta^2 = .11$, and time, $F(1, 23) = .011$, $p = .918$, $\eta^2 = .01$. However, a significant Valence x Time interaction, $F(3, 69) = 3.34$, $P = .024$, $\eta^2 = .13$ was evidenced. As illustrated in Figure 2, the follow-up tests revealed that CE remained more positive (i.e., greater force production) during exposure to the pleasant and unpleasant conditions at Epochs 2 and 6 compared to the neutral conditions at Epochs 2 and 6 ($P < .05$). CE was significantly more negative (i.e., more force decay) during the neutral condition at Epoch 6 compared to the full feedback condition at epochs 2 and 6 ($P < .05$).

CV-Detrended

Analysis of CY-detrended revealed no significant effects: valence, $F(2.13, 49.06) = .467$, $p = .709$, $\eta^2 = .02$; time, $F(1, 23) = .046$, $p = .832$, $\eta^2 = .002$; or the interaction of Valence x Time, $F(3, 69) = .285$, $p = .836$, $\eta^2 = .012$.

Discussion

Our goal was to examine how exposure to emotional images influences low-level grip force control. The results supported our first hypothesis by showing that relative to neutral images, exposure to pleasant and unpleasant emotional images led to a maintenance of force production. Our second question concerned how the force production variability might be altered under emotional as compared to neutral conditions. Emotional state did not alter the variability of force production.

Previous evidence has shown that grip force control is influenced by visual feedback. When visual feedback is removed and replaced with a blank screen, force production decays, as reflected by increased error below the target force (Davis, 2007; Vaillancourt & Russell, 2002). We replicated this finding by showing that when visual feedback is replaced with a neutral image, the negative bias in force production progressively increased during the pinch grip task. This bias was not evidenced when feedback remained on the screen (i.e., full feedback condition) or when pleasant or unpleasant images replaced the feedback. Force production during pleasant and unpleasant conditions was more positive and above the target force compared to the neutral condition two seconds following picture onset.

Participants were unable maintain grip force during neutral stimuli in contrast to emotional images. Prior work has shown that viewing emotional images leads to a relative increase in force production, which helps participants to maintain the target force in the absence of feedback (Coombes et al., 2008). Emotions may serve as a protective mechanism that helps maintain force production when visual feedback is lost.

Although an emotion driven increase in force production has been shown previously, participants in these studies were required to produce force at moderate or high levels (Coombes et al., 2008; Schmidt et al., 2009). The current findings, therefore, demonstrate that although low, moderate, and high tone levels may rely on varying neural circuits (Ehrsson et al., 2001; Spraker et al., 2007), the effect of emotion on these circuits remains fundamentally similar. Emotion leads to an increase in excitability of the motor system, which is reflected in increased force output relative to force production under neutral or benign conditions (Coombes et al., 2008; Coombes, Tandonnet et al., 2009; Hajcak et al., 2007; van Loon et al., 2010).

Moreover, recent work (i.e., Naugle, Coombes, & Janelle, 2010) has demonstrated that the effect of emotion on sustained force production may be altered as a function of the relative force levels required on consecutive trials. When low-level forces (i.e., 2% MVC) must be produced in random conditions that include moderate (i.e., 10%) and moderately high (i.e., 35% MVC) alternatives, the overall level of bias in force production is several times greater than conditions in which only low-level force production is required, as was the case in the current project. While the magnitude of these biases is altered, the same arousal-based modulation of force control remains under these conditions. We hypothesize that the increased force production in random conditions arises from the need to produce multiple contractions at higher target force levels in the same session, although this remains to be empirically substantiated.

Our second question concerned whether emotional state impacts the variability of force output at low target force levels. Based on previous studies that used a threat of shock manipulation (Christou, 2005), we hypothesized that unpleasant emotional suites would lead to increases in variability of low-level force production. Our results did not support this hypothesis. Normalized variability did not differ between the four conditions when feedback was removed. Two explanations may account for the disparity between our findings and those reported by Christou. First, the threat of shock manipulation may be qualitatively different from the emotional image manipulation used in the current study. Although the threat of a painful shock is associated with excitation in emotion-related areas of the human brain that include amygdala (Delgado, Nearing, Ledoux, & Phelps, 2008), it also activates pain-related areas including thalamus, insula, somatosensory cortex, and anterior cingulate cortex (Bingel & Tracey, 2008; Oshiro, Quevedo, McHaffie, Kraft, & Coghill, 2009; Starr et al., 2009). Although a reciprocal relation has been demonstrated between emotion and motor systems as well as pain and motor systems (Del Santo, Gelli, Spidalieri, & Rossi, 2007; Hoeger Bement, Dicapo, Rasiarmos, & Hunter, 2008), it is plausible that the neural mechanism underlying these interactions may be different. In turn, how the fear of pain and emotion impact the variability of force control, respectively; may be qualitatively distinct.

The expectation of a discrete short duration shock may also affect activity in the motor system in a qualitatively different manner than sustained exposure to an emotional image. Moreover, Christou reported that age significantly contributed to the increased variability noted in the threat of shock condition. Their young adult group showed only marginal increases in variability during the threat of shock condition. The young adult sample in the current study may also have contributed to our non-significant variability findings. It is important to note, however, that our data corroborate previous evidence which showed that when target force levels are set at a moderate level (10% of MVC) there was no effect of emotion on the variability of force production (Coombes et al., 2008).

One limitation of the current study is the lack of direct physiological indexes of emotions elicited by the IAPS images. However, the reliability of self-report and physiological responses to the images used in the current study has been consistently demonstrated (Bradley, Codispoti, Cuthbert, & Lang, 2001). Also, there is no evidence that pairing emotion and motor processes alters the typical pattern of emotional reactivity demonstrated when passively viewing emotional images (Coombes, Janelle, & Duley, 2005; Schmidt et al., 2009). Future research efforts are needed to (a) qualify these findings in healthy and clinical samples across the lifespan (Christou et al., 2004), (b) investigate the cortical and subcortical neural circuits that underlie the interaction between emotion and movement (Borsook, 2007; Coombes, Tandonnet et al., 2009; Hajcak et al., 2007; Pessiglione et al., 2007; Schmidt et al., 2009; van Loon et al., 2010), and (c) examine the implications of emotion-induced changes in movement in a variety of performance settings (Woodman et

al., 2009). In conclusion, exposure to emotional images impacts the accuracy but not variability of a sustained low-level force contraction.

Acknowledgments

This research was supported in part by grants #F32-MH-83424 (Coombes) and #5R03MH70678 (Janelle) from the National Institutes of Health.

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Figure 1.

Figure 1A presents the participant's view during a trial. Each trial began with a white fixation cross visible for 1 s. Next, participants matched the black bar (which they controlled) with the stationary white target bar (representing 2% of maximum voluntary contraction) as accurately as possible, with their index finger and thumb in a pinch grip configuration. After 5 s, the feedback on the screen was replaced with a pleasant, unpleasant, or neutral image for 6 s. Participants continued to maintain the target force as accurately as possible during picture presentation. Figure 1B shows the experimenter's view during a trial and represents the general pattern of force production across the 11-s trial; ITI = intertrial interval.

Figure 2. Mean constant error scores for each condition for Epochs 0 through 6. Bars represent standard errors.

Table 1

Scores for each valence category for each time period of interest

DV	Time	pleasant		unpleasant		Neutral		Full feedback	
		M	SE	M	SE	M	SE	M	SE
CE (N)	2	0.009	0.007	0.008	0.008	-0.011	0.006	-0.005	0.001
	6	0.008	0.014	0.006	0.012	-0.026	0.011	0.003	0.004
CV (N)	2	0.102	0.002	0.102	0.002	0.104	0.001	0.102	0.001
	6	0.106	0.004	0.102	0.003	0.109	0.003	0.099	0.001

Note. M=mean; SE=standard error; DV=dependent variable; CE=constant error; CV=coefficient of variability.