

Emotional States Alter Force Control During a Feedback Occluded Motor Task

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The aim of the current experiment was to determine the extent to which pleasant and unpleasant emotional states altered the ability of men and women to control force production on a feedback occluded motor task that was not direction specific. Participants produced a precision pinch grip with visual feedback. After 5 s, feedback was occluded and replaced with a pleasant, unpleasant, or neutral image. The amplitude, variability, and structure of force production were calculated. As expected, the removal of visual feedback led to progressive force decay. More important, relative to neutral conditions, pleasant and unpleasant emotional states led to greater force production, resulting in attenuated force decay. The variability and structure of force production were not altered by affective state. In addition, men and women performed similarly across all conditions for all measures. We conclude that when sustained force production is not directed toward or away from the body, pleasant and unpleasant emotional states similarly excite the motor system. Neurobiological mechanisms are proposed to account for these findings. Implications and future research directions are discussed.

Keywords: emotion, force, variability, error, gender

Tasks requiring sustained isometric contractions have frequently been used in the motor control literature as a vehicle to better understand the impact of multiple factors on the functioning human motor system. Within force control protocols, participants are typically required to generate and sustain a predetermined level of force, usually a percentage of their maximum voluntary contraction (MVC), allowing the impact of environmental factors on the functioning motor system to be indexed in real time.

Substantial work has documented the rate of decay in force production as differing levels of force are maintained. For example, Vaillancourt and Russell (2002) required participants to sustain a target force level at a predetermined percentage of MVC (5%, 15%, 25%, 35%, 45%, 55%, 65%, and 75%) for 20s. For the initial 8s of each trial, subjects viewed real time visual feedback, but in a portion of the trials, visual feedback was removed for the remaining 12s. Subjects were instructed to maintain the target force level as accurately as possible during the entire trial. Findings corroborated previous evidence in that force production (at all MVC levels) began to decay approximately 0.5 to 1.5s following the removal of visual feedback (Vaillancourt, Slifkin, & Newell, 2001), leading the authors to posit that the 0.5 to 1.5s time period represented a limit on the temporal capacity that accurate visuomotor information can be retained in short-term memory. The pattern of force decay progressed exponentially during the remainder of the no feedback trials and there was greater force decay over

time as target force level increased. More important, variability (as indexed by standard deviation) within the decaying force trace remained stable within each trial.

Variability in precision pinch grip force production is influenced by a number of factors. Specifically, variability is attenuated when (a) using three as compared to two digits to generate low force output (Sosnoff, Jordan, & Newell, 2005), (b) when visual feedback is presented with greater visual gain (Sosnoff, Valantine, & Newell, 2006), (c) when force levels are relatively low (Vaillancourt & Russell, 2002), and (d) when visual feedback is presented more frequently (Sosnoff & Newell, 2005; Vaillancourt, Mayka, & Corcos, 2006). The precision pinch grip task has been particularly useful in advancing our understanding of how stress, age, and gender impact force control. For example, Noteboom and colleagues (Noteboom, Fleshner, & Enoka, 2001) demonstrated that experiencing unpleasant arousal (manipulated by threat of shock) results in increased variability of a sustained pinch grip task (target force = 4N; \approx 10% MVC), a pattern that was more profound in individuals who self-reported moderate as compared to low trait anxiety (Noteboom, Barnholt, & Enoka, 2001).

Christou and colleagues (Christou, 2005; Christou, Jakobi, Critchlow, Fleshner, & Enoka, 2004) later clarified these initial findings in two papers that used a similar threat of shock protocol to demonstrate that variability is exacerbated when unpleasant arousal is manipulated simultaneously with the occlusion of visual feedback. More important, they suggested that the enhanced force fluctuations caused by the stressor (evidenced by increases in standard deviation, coefficient of variation, and information transmission) were due to an increase in low-frequency output of the spinal motor neurons. That is, greater variability was associated with increased power within the 1 to 2 Hz frequency range of the power spectrum.

Thus, the precision pinch grip task has been tremendously helpful in developing our understanding of the functioning motor

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system. Given the wealth of data that has already been collated, the pinch grip is an ideally simple yet elegant task with which to evaluate how the functioning motor system is modulated during a simultaneous emotion manipulation. Although unpleasant emotional states have been the focus of prior work, if or how transient visually triggered pleasant emotional states alter the decay, variability, and structure of sustained isometric force control remains unknown.

Emotion, Arousal, and Valence

The role of the amygdala in the processing of emotion has long been established, but continues to be clarified. Early electrophysiological, lesion, and imaging studies associated amygdala activity with the processing of threatening, fearful, and highly aversive events (e.g., Aggleton, 2000). Reports that processing of positively valenced stimuli also coincides with significant amygdala activity (Garavan, Pendergrass, Ross, Stein, & Risinger, 2001; Hamann & Mao, 2002; Winston, O'Doherty, & Dolan, 2003) reiterated and specified the amygdala's role in the emergence of emotionally driven arousal states. Recently, the relationship between amygdala activation and emotional processing was further specified by Sabatinelli and colleagues (Sabatinelli, Bradley, Fitzsimmons, & Lang, 2005) who showed that when humans passively view emotionally arousing stimuli, a positive linear relationship exists between the arousing quality of those stimuli and amygdala activation. This same pattern of amygdala activation also holds true when emotional words are presented instead of emotional images (Lewis, Critchley, Rotshtein, & Dolan, 2007). However, when using words or images to elicit emotional responses it is difficult to manipulate a condition in which neutral stimuli are also highly arousing. Because highly arousing words or images are by default extremely valenced, it is difficult to decouple the effects of emotional arousal from the effects of emotional valence. To resolve this issue, researchers have turned to the chemosensory domain.

Efforts to establish whether the amygdala responds to emotional arousal, emotional valence, or their interaction has led to two prevailing views dominating the current literature: (a) amygdala activation is heightened by the intensity of experience (i.e., arousal), irrespective of valence (Anderson et al., 2003; Anderson & Sobel, 2003; McGaugh, Cahill, & Roozendaal, 1996; Small et al., 2003); and (b) amygdala function is characterized by the intensity/arousal of a stimulus only with respect to valence extremes (Winston, Gottfried, Kilner, & Dolan, 2005). Supporting the first view, Small et al. demonstrated that when concentrations of sweet (pleasant) and bitter (unpleasant) solutions were matched for intensity at strong and weak levels, the amygdala was responsive to the intensity of the stimulus irrespective of valence. However, although a tasteless solution was also included within the Small et al. experiment, the absence of an intense tasteless solution prevented a comprehensive conclusion. That is, if amygdala function is modulated by intensity/arousal irrespective of valence then one would expect amygdala activity to an intense neutral stimulus to scale in a similar fashion as it does to an intense pleasant or unpleasant stimulus. Winston et al. demonstrated that this is not the case. They reported that the amygdala responds differently to high as compared to low intensity odor for pleasant and unpleasant smells but not for neutral smells, leading to a conclusion that the amygdala codes the overall emotional value of a stimulus. That is,

amygdala activation is an interactive function of emotional valence and intensity.

With regard to previous emotion and movement protocols, pleasant and unpleasant emotional cues have typically been matched for arousal while being polarized for valence (Coombes, Cauraugh, & Janelle, 2007b). As such, although the use of visual images or threat of shock manipulations have prevented the inclusion of highly arousing neutral conditions, the majority of emotion-movement studies have focused on the impact of emotional valence (ensuring that emotional arousal is controlled for) on direction specific movements (i.e., flexion vs. extension; movement toward vs. away from the body).

Emotion and Movement

Emotions are widely regarded as states of action readiness, promoting the notion that a primary function of emotion is the preparation for action (Frijda, Kuipers, & ter Schure, 1989; Schupp, Junghofer, Weike, & Hamm, 2003). Advancing this premise, recent evidence suggests that manipulating emotional state preceding or during movement leads to consistent and repeatable alterations in overt motor behavior (Christou, 2005; Coombes et al., 2007b; Rotteveel & Phaf, 2004). A key issue within contemporary emotion and movement literature concerns the interaction between motivational priming and the direction of an intended movement. In general, unpleasant emotions (excluding anger, see Coombes et al., 2007, in press; Harmon-Jones, Lueck, Fearn, & Harmon-Jones, 2006; Marsh, Ambady, & Kleck, 2005) activate defensive circuitry, which prime withdrawal behaviors and facilitate movements away from the body. Pleasant emotions, in contrast, activate appetitive circuits that prime approach behaviors and facilitate movements toward the body (Chen & Bargh, 1999; Marsh et al., 2005; Rotteveel & Phaf, 2004).

We have previously demonstrated that exposure to unpleasant visual stimuli increases maximal force production relative to pleasant and neutral stimuli without increasing movement variability (Coombes, Cauraugh, & Janelle, 2006). In this case, force production was generated by extending the wrist and finger extensor muscles. The contraction was interpreted as an avoidance behavior because the executed dorsiflexion movement resulted in limb movement away from the body. In addition, participants were instructed to produce a maximal contraction during the exposure period, rather than a target force set at a predefined percentage of MVC, an approach that is typically used in the motor control literature (Christou et al., 2004; Sosnoff et al., 2005; Vaillancourt & Russell, 2002). Hence, no target force was required, nor was feedback provided. When considering the corpus of extant literature addressing emotion and movement, very little is known concerning the impact of pleasant and unpleasant emotions on movements that demand a sub-maximal target force that is not direction specific, even though many functional movements fall into this category.

Emotion and Movement: Gender Implications

Investigations focusing on emotion within picture viewing paradigms (Bradley, Molder, & Lang, 2005), pinch grip force control (Sosnoff et al., 2005), and the interaction between emotion and movement have generally ignored gender differences (Chen &

Bargh, 1999; Rotteveel & Phaf, 2004; but see Christou et al., 2004, for an exception), thereby implying that gender effects are equivocal. Supporting this notion, when males and females view affective images, valence and arousal ratings, facial electromyographic (EMG) activity, skin conductance response, startle modulation, visual cortex activity, and heart rate are statistically similar (Kemp, Silberstein, Armstrong, & Nathan, 2004; Sabatinelli, Flaisch, Bradley, Fitzsimmons, & Lang, 2004; Wrase et al., 2003). Indeed, healthy human males and females are most reactive to threat, mutilation, and erotica cues; cues that activate the defensive and appetitive motivational systems that underlie emotional experience (Sabatinelli et al., 2004).

Christou et al. (2004), however, reported that preceding and during a stress manipulation, females (as compared to males) self-reported greater anxiety levels and displayed greater variability on a pinch grip task, and displayed greater power in the 1 to 2 Hz range of the corresponding force spectra. In addition, Hillman and colleagues (Hillman, Rosengren, & Smith, 2004) evidenced greater movement away from unpleasant pictures by females as compared to males as indexed by postural sway during image presentation. This pattern of greater responsivity/variability by females to unpleasant stimuli dovetails nicely with the finding that females have a tendency to respond to negative emotional cues to a greater extent than males (Bradley, Codispoti, Sabatinelli, & Lang, 2001).

Present Study

Given the extant lack of clarity in the current emotion/movement database concerning the directionality of movement and the conflicting role of arousal and gender effects, our objective was to examine how positive and negative emotional states altered the ability of men and women to control force production on a task that was not direction specific. Our primary aim was to test two competing hypotheses concerning the extent of force decay as it relates to emotional state. If force production during a sustained contraction is altered by emotional valence, replacing visual feedback with an unpleasant mutilation image will result in greater force production, a consequential reduction in force decay, and an increase in information transmission (relative to pleasant and neutral stimuli). Alternatively, because our precision pinch grip task was not directed toward or away from the body, we expected similar and attenuated force decay and increased information transmission for arousing pleasant and unpleasant valenced states (relative to neutral). Our second aim was to determine the impact of emotional state and gender on the variability and structure of force production. Previous studies led us to test the hypothesis that greater variability would be evidenced during exposure to unpleasant as compared to pleasant and neutral conditions, with least variability evidenced during control conditions. In addition, we expected this pattern of activity to be more pronounced in women as compared to men, and further, that increases in variability would be reflected in increased power within the 1 to 2 Hz frequency range of the force power spectra. Finally, we had no reason to believe that emotional state or gender would diminish or enhance visuomotor working memory. As such, we expected time to initial force decay to remain consistent with previous accounts (0.5s to 1.5s).

Method

Participants

Forty-two undergraduate students (22 women, M age = 20.05, SD = 1.25; 20 men, M age = 19.80, SD = 1.44) from the University of Florida participated in this study for extra course credit. All participants were right hand dominant. Participants were naïve to the purpose of the experiment, reported no central nervous system disorders that would affect movement, and gave written informed consent to all procedures. Participants all reported moderate levels of trait anxiety (State-Trait Anxiety Inventory; [STAI] Spielberger, 1983). An independent t test revealed no difference between male (M = 36.00, SD = 3.64) and female (M = 36.72, SD = 5.23) trait anxiety scores, $t(40) = -.506$, $p = .616$.

Instrumentation and Task

Participants were seated in a chair positioned 1 m from a 21" CRT computer screen (1024 × 768 resolution; 100Hz refresh rate), with the right arm securely strapped onto the armrest. The elbow was placed at a right angle with the wrist positioned midway between full supination and pronation. Participants performed isometric contractions by pinching a force transducer (MLP-75, Transducer Techniques, Temecula, CA) with the thumb and index finger of their right hand. Prior to an MVC calculation (within the instruction set and during the practice period), it was made explicitly clear that only the thumb and index finger were to be used to pinch the transducer.

Participants' MVC was measured before the practice and experimental trials (men: M = 42.05 Newtons [N], SD = 11.85; women: M = 35.00 N, SD = 11.15). They were instructed to "squeeze as hard as possible" on the force transducer on hearing an audible beep, and then to relax on hearing a second beep 6s later. Participants completed three consecutive trials with a 60-s rest period between each trial. The greatest 10 force samples from each trial were averaged. The MVC value was computed as the average of the means obtained from each of the three trials (Vaillancourt & Newell, 2003), and this value was then used as the reference for computation of each participants target goal force. An independent t test revealed that a difference in male and female MVC values approached significance, $t(40) = -1.97$, $p = .056$, with trends indicating that males generally exhibited greater overall MVC than females.

Force output relative to the goal force was displayed on a computer monitor. Participants viewed a white stationary horizontal target bar (which was positioned at 10% of MVC) located center screen and a black horizontal bar at the bottom of the screen that represented the amount of force being produced by the participant. Each bar (1024 × 20 pixels) spanned the width of the screen. At trial onset (marked by appearance of a white target bar and black force production bar) participants gripped the force apparatus with the index finger and thumb and adjusted their level of force production to match that of the target bar. Feedback was presented for 5s. Following this initial 5-s period, visual feedback was occluded on 20 trials, during which an image was presented for 6s. Participants were instructed to maintain the target level of force production as accurately as possible throughout each 11-s trial. A custom LabVIEW program (Version 8.1; National Instru-

ments, Austin, TX) controlled trial onset, trial offset, visual stimulus presentation, and data analyses while also collecting and streaming raw data files to disk.

The force transducer (75 kg; 1.3 cm wide) had a sensitivity of 0.1% (Transducer Techniques, Temecula, CA). Analog output from the force transducer (sum of the thumb and index finger force) was amplified through a 15LT Grass Technologies Physio-data Amplifier System (Astro-Med Inc., West Warwick, RI) at an excitation voltage of 10 V. Custom Labview software controlled a 16-bit analog-to-digital converter (A/D; PCI-6220, National Instruments, Austin, TX) that sampled the force at 100Hz. The smallest increment of change in force detectable by the A/D card was 0.0016 N.

Emotion Manipulation

Participants viewed 20 digitized photographs selected from the International Affective Picture System¹ (Lang, Bradley, & Cuthbert, 2005). These pictures represented three emotional categories: (a) erotic couples, (b) mutilation, and (c) neutral. Five erotica, 5 mutilation, and 10 neutral images were selected according to affective normative ratings to match arousal between pleasant and unpleasant images while discriminating each from neutral images, and to differentiate valence across all categories.² In addition, five trials with constant feedback and no picture were included to provide a control condition. Stimulus presentation order was randomized and counterbalanced.

Procedure

The Institutional Review Board at the University of Florida approved all experimental procedures. After obtaining written informed consent, participants were seated in a comfortable chair in a private sound attenuated room in the laboratory. They then completed the MVC trials according to the steps described previously. Following completion of the MVC task, participants were given instructions for the pinch grip task. Participants were instructed to produce force by squeezing the transducer with their thumb and index finger only. The three remaining fingers were not constrained. Participants were instructed to match the black bar that they controlled, with the stationary white target bar (positioned at 10% of MVC), and to do so during the entire 11-s trial even if the bars were replaced by an image. Subjects executed 4 practice trials at 10% of their MVC (2 feedback only trials, 2 trials with unique neutral images). The experimenter remained in the room during the practice trials to ensure that participants were only using their thumb and index finger to produce force. After all questions had been answered, participants completed 25 experimental trials free of experimenter interaction. On completion, participants were fully debriefed.

Data Reduction

The force-time series data were digitally filtered by using a fourth-order Butterworth filter with a 20Hz low-pass cut-off. Force decay, force variability, and the structure of force were analyzed separately.

Figure 1 represents force trace exemplars from four individual trials. The epoch of interest from each trial was split into seven

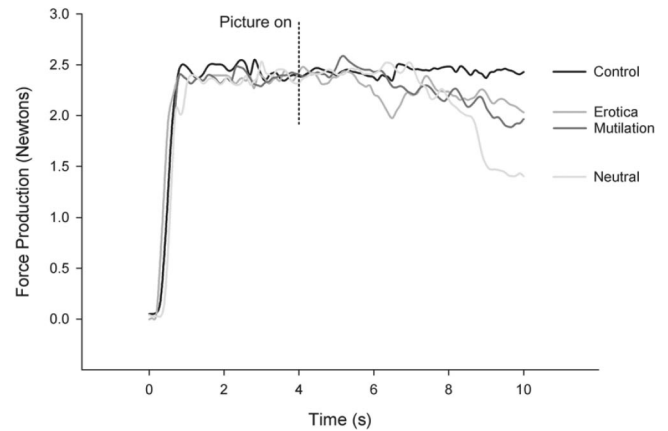


Figure 1. Sample force traces for 4 trials representing each valence category (control (no image), erotica, mutilation, and neutral). Representative samples are taken from 1 subject. Picture onset is delineated with a dashed line.

sequential 1-s epochs, beginning 1s prior to picture onset and concluding with offset of the respective IAPS image. Root mean square error (*RMSE*), constant error (*CE*), information transmission (*IT*), coefficient of variation (*CV*), time to initial error, and *SD* were calculated for each trial.

RMSE. For each data point, the vertical distance between the target force and the amount of force being produced was squared. For each 1-s epoch (100 samples), mean square error was first computed and then the square root was taken such that one *RMSE* value corresponded to each epoch.

CE. For each data point, the vertical distance between the target force and the amount of force being produced was calculated. The direction of error was therefore retained (i.e., $-/+$). For each 1-s epoch (100 samples), *CE* was derived by computing the mean of these 100 samples.

IT. The *IT* is based on information theory (Shannon & Weaver, 1949), which has been used to explain the impact of the environment on human performance, and represents the ratio of noise to information in a signal. Replicating previous calculations (Christou, 2005), mean force indexed the information transmitted, and the *SD* of force was used to index the amplitude of noise.

CV. *CV* scores were calculated and analyzed to ensure that variability was normalized to the magnitude of the corresponding absolute force value ($CV = SD/\text{mean force}$). This was essential given that males' MVC generally exceeded that of females.

Structure of force variability: Spectral analysis. A Fourier analysis was performed on the detrended force signal and auto-spectral analysis of the force signal was obtained using Welch's averaged periodogram method with a nonoverlapping Hanning

¹ Erotic couples: 4647, 4660, 4800, 4659, 4670; mutilation: 3064, 3030, 3060, 3068, 3071; neutral household objects: 7000, 7010, 7030, 7025, 7090, 7059, 7175, 7052, 7050, 7055.

² IAPS affective normative ratings: (a) Mutilation—valence ($M = 1.77$, $SD = 1.21$), arousal ($M = 6.78$, $SD = 2.27$). (b) Erotica—valence ($M = 6.71$, $SD = 1.85$), arousal ($M = 6.71$, $SD = 2.00$). (c) Neutral—valence ($M = 4.94$, $SD = 1.02$), arousal ($M = 2.57$, $SD = 1.84$).

window (LabVIEW 8.1). The data segment was composed of the 512 samples prior to picture offset. The window size for the force signal, which was sampled at 100Hz, was 128 samples, resulting in a resolution of .78Hz. For statistical comparisons, the frequency data were averaged within .78-Hz intervals from 0 to 12Hz. The summary statistics for the spectral analysis were the absolute power at each frequency and median peak frequency.

Statistical Analyses

To determine whether performance was similar across valence conditions prior to image onset, RMSE scores representing the 1s epoch immediately preceding image onset were analyzed in a two way Gender (man, woman) × Valence (erotic couples, mutilation, neutral household object, control) mixed design analysis of variance (ANOVA).

RMSE, CE, IT, and SD were each analyzed in 2 (gender: man, woman) × 4 (valence: erotica, mutilation, neutral household object, control) × 6 (time: epoch 1, 2, 3, 4, 5, 6) ANOVA with repeated measures on valence and time. In addition, for each dependent variable, planned comparisons were performed on the final 1s of image presentation with a two-way ANOVA (Gender × Valence) to determine the overall magnitude of decay across the 6-s feedback occlusion period. Spectral components of the force

data were analyzed using a 2 (Gender: man, woman) × 4 (Valence: erotic couples, mutilation, neutral household object, control) × 16 (Frequency Bin: 1–16) mixed model ANOVA. Finally, median peak frequency and time to initial error were each analyzed in separate two-way mixed design ANOVAs (Gender × Valence).

For all analyses, if *F* ratios involved valence, time, and/or frequency bin, and the sphericity assumption was violated, then Greenhouse–Geisser degrees of freedom corrections were applied. Follow-up analyses were conducted using simple effects tests and Tukey’s HSD procedure for significant interactions and main effects, respectively. For all analyses, the probability value was set at *p* < .05.

Results

RMSE

A baseline analysis of RMSE during the 1-s interval prior to picture onset demonstrated that performance was similar regardless of the ensuing experimental condition, *F*(3.00, 120) = .75, *p* > .05, gender, *F*(1.00, 40.00) = .55, *p* > .05, or an interaction between valence and gender, *F*(3.00, 120.00) = 2.49, *p* > .05. Mean and standard error values for RMSE and CE for each valence category for each time period are presented in Table 1.

Table 1
Mean RMSE and Mean CE and Respective SE Values

Valence	Time	RMSE				CE			
		Women		Men		Women		Men	
		<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
Erotica	0	0.20	0.04	0.13	0.05	0.01	0.01	0.01	0.01
	1	0.24	0.05	0.22	0.05	0.06	0.03	-0.02	0.03
	2	0.36	0.06	0.36	0.06	0.16	0.06	-0.02	0.06
	3	0.48	0.07	0.46	0.07	0.27	0.08	0.10	0.08
	4	0.57	0.08	0.56	0.08	0.35	0.10	0.22	0.10
	5	0.62	0.09	0.62	0.09	0.40	0.11	0.25	0.11
Mutilation	0	0.16	0.04	0.14	0.04	0.01	0.01	0.01	0.01
	1	0.21	0.04	0.21	0.04	0.06	0.03	0.02	0.03
	2	0.34	0.05	0.29	0.05	0.16	0.05	-0.02	0.05
	3	0.44	0.06	0.37	0.06	0.28	0.07	0.08	0.07
	4	0.52	0.07	0.46	0.08	0.36	0.08	0.20	0.09
	5	0.57	0.08	0.52	0.09	0.42	0.09	0.31	0.10
Neutral	0	0.16	0.04	0.15	0.04	0.00	0.01	0.01	0.01
	1	0.23	0.04	0.19	0.04	0.09	0.02	0.04	0.02
	2	0.40	0.05	0.35	0.05	0.28	0.05	0.16	0.05
	3	0.51	0.06	0.49	0.07	0.40	0.07	0.33	0.07
	4	0.59	0.07	0.59	0.08	0.48	0.08	0.45	0.09
	5	0.66	0.08	0.71	0.09	0.56	0.09	0.55	0.10
Control	0	0.19	0.04	0.14	0.05	0.01	0.01	0.02	0.01
	1	0.15	0.04	0.10	0.04	-0.01	0.01	0.00	0.01
	2	0.15	0.04	0.09	0.04	-0.01	0.02	0.01	0.02
	3	0.13	0.03	0.09	0.03	-0.03	0.02	0.00	0.02
	4	0.12	0.03	0.10	0.03	-0.04	0.02	0.01	0.02
	5	0.11	0.03	0.09	0.03	-0.05	0.02	0.00	0.03
	6	0.11	0.03	0.09	0.03	-0.05	0.02	0.00	0.02

Note. Data are presented for men and women, for each valence category across each time period. RMSE = root mean square error; CE = constant error; SE = standard error.

Figure 2 portrays RMSE for each experimental condition across the 6-s viewing period. These data clearly show that accuracy decreased as the time without feedback increased. The ANOVA confirmed that RMSE increased as time from feedback occlusion increased, $F(1.18, 47.13) = 62.40, p < .001$. A significant effect of valence, $F(1.99, 79.41) = 64.75, p < .001$, was also evidenced (control < mutilation = erotica < neutral), but main effects were qualified by a significant Valence \times Time interaction, $F(3.02, 120.96) = 36.46, p < .001$. Follow up analyses revealed similar RMSE during Epoch 1 across all conditions. Attenuated error was evidenced during all control conditions relative to the vast majority of erotica, mutilation, and neutral conditions (1 to 6s). The progressive error in force across time bins was confirmed with significant differences emerging between early and late time periods within erotica, mutilation, and neutral conditions (0 to 1s < 2 to 6s; 1 to 2s < 3 to 6s). The increase in RMSE late in the viewing period during neutral conditions was confirmed by significantly greater error in later neutral conditions (4 to 6s) relative to all conditions between 2 and 4s. A main effect of gender and all higher order interactions involving gender failed to reach significance ($ps > .05$).

We predicted that exposure to highly valenced highly arousing stimuli would result in increased force production and therefore attenuated error within the final epoch of the viewing period (see Figure 2). A two-way repeated measures ANOVA (Gender \times Valence) was used to evaluate the mean magnitude of decay for men and women 5 to 6-s postfeedback occlusion. A main effect of valence was evidenced, $F(1.75, 70.12) = 67.37, p < .001$, with follow-up tests revealing attenuated error during control conditions (relative to all others), greater error during neutral conditions (relative to all others) and no difference between erotica and mutilation images (see Figure 2). Neither the main effect of gender nor the Gender \times Valence interaction were significant ($ps > .05$).

CE

Although we expected the force trace to decay following the occlusion of feedback, the calculation of CE was included to allow confirmation of the direction of error. Figure 3 shows CE for each experimental condition across the 6-s viewing period. CE was significantly altered by valence, $F(1.85, 70.47) = 24.97, p < .001$,

and time, $F(1.16, 43.97) = 45.90, p < .001$, but these effects were superseded by a significant Valence \times Time interaction, $F(2.95, 112.00) = 29.11, p < .001$. Follow-up tests revealed that CE was attenuated during control conditions relative to neutral exposure periods (2 to 6s) and erotica and mutilation exposure periods (3 to 6s). CE during late time periods during exposure to neutral images (4 to 6s) was greater than all time periods for erotica and mutilation conditions as well as early neutral conditions (0 to 3s). CE was also attenuated in early time periods (0 to 2s) for erotica, mutilation, and neutral conditions relative to later time intervals (3 to 6s). Neither the main effect of gender nor the remaining higher order interactions were significant ($ps > .05$).

Given a priori expectations, a planned comparison of the overall magnitude of CE during the final second of the feedback occluded portion of the experiment was conducted. A significant effect of valence was evidenced, $F(1.82, 69.14) = 32.29, p < .001$, with mean comparisons mirroring RMSE findings. Specifically, CE during control conditions was significantly attenuated relative to all feedback occluded trials; greater decay was evidenced during exposure to neutral images relative to all other conditions, and CE during exposure to mutilation and erotica images was indistinguishable (control < mutilation = erotica < neutral). Main effects of gender and the Gender \times Valence interaction were not significant ($ps > .05$).

IT

Significant main effects of valence, $F(2.10, 84.17) = 43.33, p < .001$, and time, $F(2.70, 107.78) = 10.21, p < .001$, substantiated RMSE and CE scores, with follow-up tests revealing a similar arousal driven pattern for valence (control > mutilation = erotica > neutral), and a progressive increase in IT across time periods (0 to 1s < all < 5 to 6s). Planned comparisons on the final 1-s epoch followed the same pattern as the valence main effect noted above (control > all, mutilation = erotica, > neutral), $F(2.70, 107.78) = 10.21, p < .001$ (see Figure 4). Main effects of gender and higher order interactions were not significant for the Gender \times Valence \times Time ANOVA or the Gender \times Valence planned comparisons ($ps > .05$).

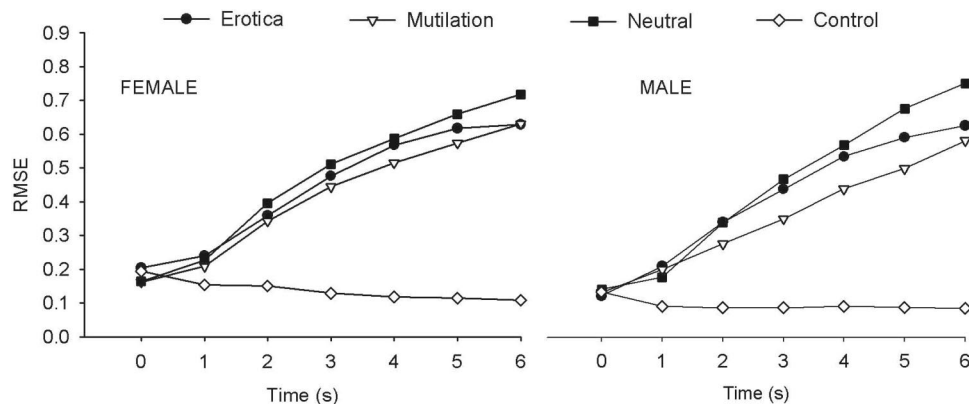


Figure 2. Mean RMSE for females (left) and males (right) as a function of valence category across time, beginning 1s prior to image onset.

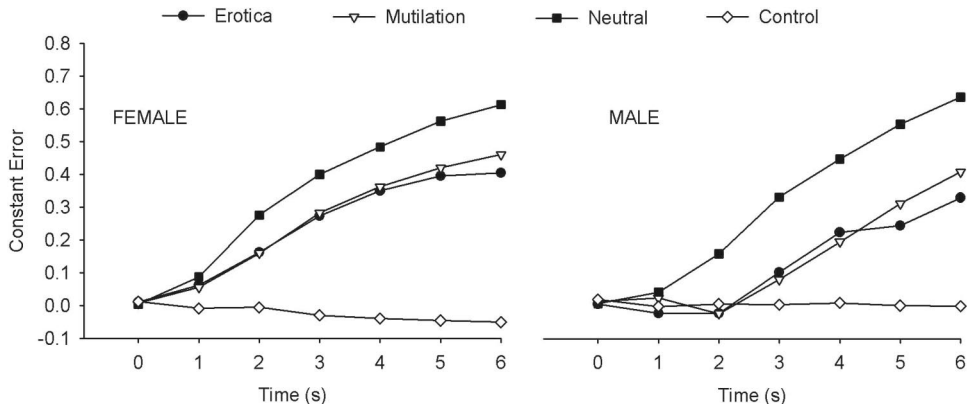


Figure 3. Mean CE for females (left) and males (right) across time (beginning 1s prior to image onset) for each valence category. Positive values represent a decrease in force production.

SD

Analysis of SD revealed a significant main effect of time, $F(2.42, 96.63) = 10.74, p < .001$. Follow-up analyses indicated a progressive decrease in variability across time windows (1s > 4–6s, 2s > 4s, 2–3s > 6s). Main effects of valence and gender and all higher order interactions were not significant ($ps > .05$).

CV

The CV was calculated to control for changes in mean force production between and within groups. Main effects of valence, $F(1.25, 49.86) = 5.91, p = .013$, and time, $F(2.20, 87.95) = 3.04, p = .048$, were identified (see Figure 5). Follow-up tests revealed that variability was greatest during feedback occluded conditions relative to the control condition, and further, that variability was greatest at the beginning (0 to 3s) as compared to the end of the trial (5 to 6s). When accounting for the amplitude of force production, variability of force production was not altered by gender, nor any higher order interactions ($ps > .05$).

Time to Initial Error

A significant main effect of valence, $F(1.754, 66.67) = 12.79, p < .001$, was evidenced. Follow-up analyses revealed that time to initial error occurred latest for control conditions relative to all other categories ([msec] erotica $M = 576.44, SE = 67.03$; mutilation $M = 612.71, SE = 73.58$, neutral $M = 527.46, SE = 42.59$; control $M = 1206.90, SE = 144.74$). Neither the gender main effect nor the Gender x Valence interaction were significant ($ps > .05$).

Force Spectrum

The median peak frequency for the force spectrum was 1.53 (± 0.84) Hz in the presence of visual feedback. When feedback was replaced with erotica images, the median peak frequency was 1.44 (± 0.59) Hz, with mutilation images 1.56 (± 0.72) Hz, and with neutral images 1.48 (± 0.49) Hz. Main effects of valence, $F(3.00, 120.00) = .81, p = .49$, gender, $F(3.00, 120.00) = .26, p = .85$, and a significant Gender x Valence interaction, $F(1.00, 40.00) =$

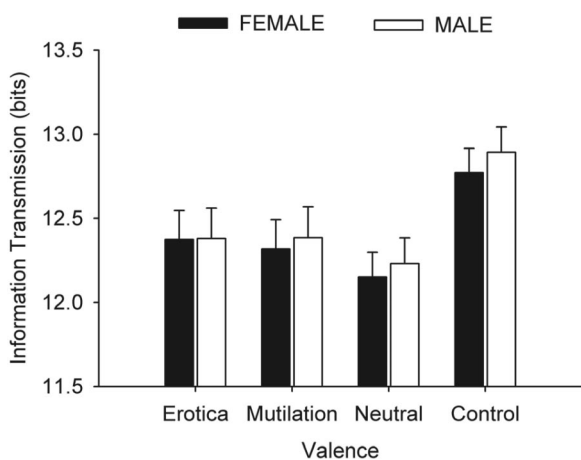


Figure 4. Mean Information Transmission for males and females for each valence category.

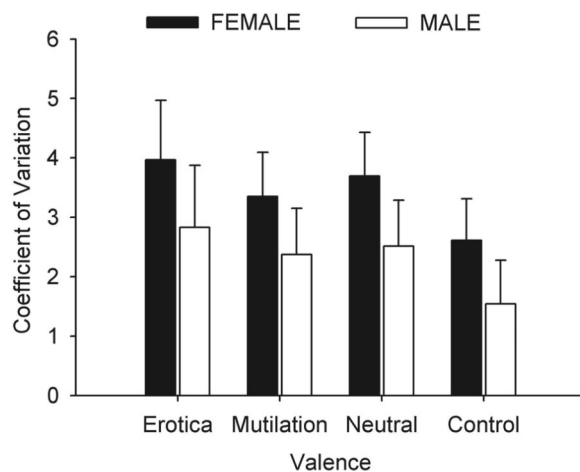


Figure 5. Mean SD of the detrended force data for females and males across time.

.26, $p = .85$, were not significant indicating that gender, emotional context, and the presence/absence of visual feedback did not affect shifts in median peak frequency.

Although variations in power within the force spectrum (0 to 12Hz) were significantly different across epochs, $F(1.23, 49.07) = 100.85$, $p < .001$, this main effect was qualified by a significant Valence \times Epoch interaction, $F(4.17, 166.78) = 3.26$, $p = .012$. Post hoc tests indicated greater power at .78Hz for all conditions relative to power in all other valence conditions for all other frequencies. In addition, power at 1.56Hz was greater than power at each epoch between 8 and 12Hz across all valence categories. Main effects of valence and gender, and all remaining higher order interactions were not significant ($ps > .05$).

Discussion

We examined the impact of emotional state and gender on force control during a feedback occluded precision pinch grip task. Male and female participants sustained a pinch grip to a constant target force with visual feedback, and then attempted to maintain the target force while emotional images replaced visual feedback for 6s. Our findings offer three novel contributions: (a) Extremely valenced cues attenuate force decay when they replace visual feedback during a precision pinch grip task; (b) emotional reactivity as indexed by modulation within the functional human motor system is similar between men and women; and (c) the variability and structure of force production at 10% MVC is immune to visually presented emotional cues.

The current study demonstrates that force control is modulated by highly arousing extremely valenced emotional stimuli. In line with our valence and arousal prediction, similar error and IT was displayed during erotica and mutilation conditions (high arousal), greatest error and least IT during the neutral condition (low arousal) and least error and greatest IT during the control condition. In line with a priori planned comparisons, this pattern was most distinguished during the final one second of image onset.

These data differ from previous reports that have shown robust effects of emotional valence on movement (Chen & Bargh, 1999; Coombes et al., 2007, in press; Marsh et al., 2005; Rotteveel & Phaf, 2004). Previous evidence indicates that movements directed toward the body are facilitated during exposure to pleasant stimuli and inhibited during exposure to unpleasant stimuli. Conversely, movements directed away from the body are facilitated during exposure to unpleasant stimuli and inhibited during exposure to pleasant stimuli (Chen & Bargh, 1999; Coombes et al., 2006, in press; Rotteveel & Phaf, 2004). For instance, Coombes et al. (2006) previously showed that sustained isometric contractions are executed with greater force during simultaneous exposure to unpleasant as compared to pleasant and neutral images. In the present study, force production during exposure to erotica (pleasant) and mutilation (unpleasant) images was indistinguishable and each was greater than force production during neutral conditions. A key difference between this and previous reports is the direction of the movement. In the current protocol, we deliberately chose an action that although functionally relevant, would not be inherently approach or avoidance directed.

When using picture stimuli to elicit emotional states one must accept that the absence of an intense neutral stimulus prevents interpretations based solely on arousal (Winston et al., 2005).

However, the inclusion of a low arousing neutral condition permitted the interpretation that extremely valenced highly arousing stimuli significantly impact the functioning motor system. More important, we suggest that this effect was not valence specific because the motor system was not executing direction specific movements (i.e., toward/away from the body). Supporting this general notion, neuroimaging and TMS evidence collected while viewing pictures has shown that amygdala activity and motor cortex excitability increase during exposure to extremely valenced highly arousing stimuli as compared to neutral stimuli (Hajcak et al., 2007; Sabatinelli et al., 2005). Our findings offer a behavioral correlate of these cortical and subcortical mechanisms by outlining a pattern of emotional responsivity within the functional motor system. In addition, the pattern of decay across male and female participants was similar, thereby corroborating previous reports that emotional reactivity to picture stimuli between men and women is similar (Kemp et al., 2004; Sabatinelli et al., 2004; Wrase et al., 2003).

Our second objective was to test the hypothesis that unpleasant emotional states would increase the variability and alter the structure of force production (as indexed by standard deviation, coefficient of variation, and force spectral power within the 1 to 2Hz range), and that this pattern would be exacerbated in women as compared to men (Christou et al., 2004). Measures of variability did not support our prediction. Indeed, variability in precision grip force production at 10% MVC was not significantly altered by emotional state, gender, or an interaction between these two factors. This finding does, however, corroborate previous work by demonstrating that although the amplitude of force production may change according to emotional state or according to target force level, the variability of the force being produced may remain constant (Coombes et al., 2006; Vaillancourt & Russell, 2002). Having controlled for the amplitude of force production by calculating CV, the expected increase in variability during the no feedback versus feedback condition was confirmed (Vaillancourt et al., 2006).

The pattern of activity evidenced within the force spectra substantiated our variability findings. That is, although the majority of power was evidenced at low frequencies (Christou, 2005; Christou et al., 2004; Vaillancourt & Newell, 2003), meaningful valence and gender effects were not identified. Given that increases in power at low frequencies have previously been linked to elevated variability of force production (IT, *SD*; Christou, 2005; Christou et al., 2004; Vaillancourt & Newell, 2003), the absence of any valence or gender effects within the power spectra correspond well with our variability measures.

Previous studies investigating the variability of force production have set target levels at $\leq 4\%$ MVC and manipulated a highly arousing unpleasant state via a threat of shock manipulation (Christou, 2005; Christou et al., 2004; Noteboom, Barnholt, et al., 2001; Noteboom, Fleshner, et al., 2001). As a result, the target force required much lower levels of force control and the emotional manipulation was presented via a different sensory modality. Arguably, the threat of shock manipulation is far more severe than the emotional cues included in the present study. These two methodological differences likely explain the discrepancy between our data and previous evidence (Christou, 2005; Christou et al., 2004; Noteboom, Barnholt, et al., 2001; Noteboom, Fleshner, et al., 2001). Future studies replicating the present protocol but

adjusting the target level to 2% MVC and/or implementing a threat of shock protocol with a 10% MVC target level with a matched pleasant condition would help clarify these disparate findings.

In line with previous evidence, removal of visual feedback resulted in force production deviating from the target force approximately 500 to 600msec post feedback occlusion (Vaillancourt & Russell, 2002). The window reported by Vaillancourt and Russell was 500 to 1,500msec. Our data fall into the lower end of this time frame suggesting that occluding visual feedback with an image as compared to a blank screen may decrease the temporal capacity of short term visuospatial working memory.

A synthesis of the contemporary physiological and behavioral data permits advancement of a tentative neurobiological account for the current findings. Evidence suggests that amygdala function is characterized by the intensity/arousal of a stimulus only with respect to valence extremes (Winston et al., 2005). It is plausible, therefore, that during exposure to mutilation and erotica images, increased amygdala activation stimulated neural circuits within the basal ganglia and thalamus that have the capacity to alter (and increase) motor cortex excitability (Haber, 2003; Haber, Fudge, & McFarland, 2000). To date, the majority of evidence suggests that emotion and movement are integrated in higher cortical and sub-cortical centers (i.e., basal ganglia, anterior cingulate cortex, pre-frontal cortex) that then project to the periphery (Etkin, Egner, Peraza, Kandel, & Hirsch, 2006; Haber, 2003; Haber et al., 2000). This tentative outline of a possible neural correlate cannot, in its current form, account for why emotional valence and movement direction interact. Understanding this interaction at the neurobiological level is essential if we are to fully understand how to best regulate motor functions that are strongly influenced by emotional states.

Resolution of conflict between motivational priming and movement direction tendencies may require input from the anterior cingulate cortex (ACC) in addition to amygdala, motor cortex, thalamus, and basal ganglia activity (Etkin et al., 2006; Haber, 2003; Haber et al., 2000). Etkin et al. recently demonstrated that relative to congruent conditions, the rostral ACC is active when participants have to respond to emotional words that are displayed over incongruent emotional facial expressions. Consequently, it is plausible that increased rostral ACC activity may positively correlate with increased movement time (Chen & Bargh, 1999; Rotteveel & Phaf, 2004), or decreased force production (Coombes et al., 2006) when motivational priming and movement direction are paired incongruently. We postulate that because our pinch grip task was not directed either toward or away from the body, the neural structures underlying our precision pinch grip task did not have to resolve conflict between primed and intended movement direction. In consequence, the force decay changes noticed under emotionally valenced conditions are interpreted as reflecting a general pattern of increased motor system excitability relative to neutral conditions.

In addition to further qualifying the neural correlates that underlie the interaction between emotion and movement (Pessiglione et al., 2007), future research should also establish the role that attention may play in modulating motor behavior during varying emotional states. The addition of eyetracking measures to the current protocol would help clarify the extent to which the images interfered with force control. Indeed, indexing search rates during

exposure to emotional and neutral images would offer insight into the role that attention may have played in our current findings.

The comprehensive lack of a gender finding within the current study is important given that nongender specific emotional reactivity evidenced in other behavioral and psychophysiological indices apparently transfers to the voluntary motor domain. Related to the notion that different people may respond in different behavioral ways to emotional stimuli, we predict that taking individual difference factors (e.g., behavioral inhibition, behavioral activation; Gray, 1990) into account may permit specification of variations in human motor responses within varying emotional contexts. We hope that the present study will help inform and motivate future behavioral, electrophysiological, and neurobiological studies to further delineate the complex interaction between emotional state and motor behavior.

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