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Emotional reactivity and force control: The influence of behavioral inhibition

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ABSTRACT

Individual difference measures have been shown to alter emotional arousal and emotional arousal alters force production during force control tasks. In the current study we examined whether individual differences in behavioral inhibition influence force control during emotional image viewing. Subjects who scored high and low in behavioral inhibition (BIS) produced force with visual feedback for 5 s. Feedback was then removed and replaced by a mutilation, attack, erotica, or neutral image for 6 s. The magnitude and direction of error in force production during image presentation was compared between groups and across image type. The high BIS group displayed a relative increase in force production during exposure to attack and mutilation images compared to the low BIS group. Bias scores (i.e., comparison of unpleasant image to neutral or pleasant image) further confirmed these findings by demonstrating a relative increase in force for the high BIS group during attack and mutilation images as compared to erotica images, whereas the low BIS group displayed the reverse effect. Together these findings extend the premise of action readiness to demonstrate that dispositional differences in behavioral inhibition interact with emotional state to alter force production.

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1. Introduction

One subcomponent of emotional expression is action readiness (Frijda, 1986, 2009). Emotion driven changes in action readiness have been demonstrated across a range of tasks using a range of different experimental approaches. Behavioral and neurophysiological studies have shown that viewing emotional stimuli leads to changes in excitability of the corticospinal motor tract (Coombes, Tandonnet et al., 2009; Hajcak et al., 2007), the initiation and execution of approach and avoidance arm movements (Chen & Bargh, 1999; Rotteveel & Phaf, 2004), the amplitude, accuracy, and variability of force control (Coombes, Cauraugh, & Janelle, 2006, 2007a, 2007b; Coombes, Gamble, Cauraugh, & Janelle, 2008; Coombes, Janelle, & Duley, 2005), and changes in posture and the initiation of gait (Hillman, Rosengren, & Smith, 2004: Naugle, Joyner, Coombes, Hass, & Janelle, accepted for publication). Related work has demonstrated links between subclinical depression and a reduction in force amplitude following transcranial magnetic stimulation (Oathes & Ray, 2006), and clinical bipolar depression and the steadiness and velocity scaling of force production (Lohr & Caligiuri, 2006). The DSM-IV diagnostic criteria for major depression include agitation and psychomotor retardation which present clinically as a reduction in speed, a delay in motor initiation, body immobility, and postural abnormalities. Rates of agitation and psychomotor retardation in depressed individuals ranges from 46% to 67% (Sobin & Sackeim, 1997). In addition to the co-morbid motor abnormalities in depression, atypical balance and motor functions have been reported among individuals with high trait anxiety (Coombes, Higgins, Gamble, Cauraugh, & Janelle, 2009; Wada, Sunaga, & Nagai, 2001), phobic/panic symptoms (Yardley, Britton, & Lear, 1995), and obsessive compulsive disorder (Leocani, Locatelli, & Bellodi, 2001). While it is clear that individual differences and experimentally induced emotional states independently influence the motor system, it is not fully understood how these factors interact to influence voluntary motor control. All previous work which has integrated emotion and motor control has either implemented a between group design to examine force control in depression (Lohr & Caligiuri, 2006; Oathes & Ray, 2006), or has used a within-subject design to examine how experimentally induced emotional states alter motor system activity (Chen & Bargh, 1999; Coombes et al., 2008; Hajcak et al., 2007). The objective of the current paper was to examine how behavioral inhibition interacts with emotional state to influence one's ability to control force production.

1.1. Behavioral inhibition system (BIS)

Reinforcement Sensitivity Theory (RST) postulates the existence of three major systems of emotional responding: the behavioral inhibition system (BIS), the behavioral activation system (BAS), and the fight/flight/freeze system (FFFS) (Gray, 1970, 1982; Gray & McNaughton, 2000). BIS is hypothesized to regulate affect and behavior in response to signals of punishment, non-reward, and novel stimuli, whereas BAS directs behavior in response to appetitive and rewarding cues. Individuals high in BIS sensitivity are characterized by worry proneness and anxious rumination, which ultimately lead to a constant vigilance for danger and a high susceptibility for anxiety disorders (Corr & McNaughton, 2008). Founded on Gray's BIS and BAS framework, Carver and White (1994) developed the first valid and reliable self-report measures (BIS/BAS scales) of sensitivity to BIS and BAS activation. The BIS and BAS scales primarily focus on affective consequences (i.e., *how a subject would feel* in response to various situations), and have consistently supported the existence of Gray's two orthogonal systems (e.g., Gomez & Gomez, 2002). Given that the BIS scale has been robustly implicated in affective disorders the focus of the current study was on behavioral inhibition.

Greater relative BIS activation coincides with exposure to conditioned and unconditioned aversive stimuli, leading to increased negative valence of the aversive stimuli as well as heightened arousal and attention, anxiety, passive avoidance, and the inhibition of behavior that may result in painful or negative consequences (Gray, 1994). Comparatively higher scores on the BIS scale have been associated with negative affect and self-reported anxiety (Buickians, Miklowitz, & Kim, 2007; Segarra et al., 2007) and the processing of unpleasant information such as during exposure to blood and disgust images (Caseras et al., 2006; Gomez & Gomez, 2002). BIS activation also correlates with greater right posterior temporal and parietal cortical activity (Hewig, Hagemann, Seifert, Naumann, & Bartussek,

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2006) and these cortical regions have been linked to greater anxious arousal (Nitschke, Heller, Palmieri, & Miller, 1999). Hence, evidence suggests that unpleasant cues elicit more intense emotional responses in individuals who show relative increases in BIS sensitivity.

1.2. BIS: implications for emotion and movement

Unpleasant emotional states prime movements away from the body, whereas pleasant emotional states prime movements towards the body (Chen & Bargh, 1999). However, evidence also suggests that emotional arousal rather than emotional valence alters gripping tasks that do not require movements that are directed towards or away from the body (Coombes et al., 2008; Schmidt et al., 2009). For instance, in the Coombes et al. study participants produced a pinch-grip force to a visible target line. Feedback was removed after 5 s and replaced with a pleasant, unpleasant, or neutral image. Although a decrease in force production was demonstrated (Vaillancourt & Russell, 2002), the magnitude of the decrease was greatest for neutral images as compared to pleasant and unpleasant images. The authors concluded that emotional arousal leads to a relative increase in force production. This emotional arousal effect was recently replicated and extended to a power grip task by Schmidt and colleagues who showed that the amplitude of maximal force production was increased following the presentation of pleasant and unpleasant as compared to neutral images. Although individual differences in affective disposition reliably predict the degree of emotional reactivity to affective stimuli, important questions remain concerning how individual differences and emotional state interact to influence a hand gripping task which is a critical component of many acts of daily living including drinking, eating, driving, and grooming. In the current study a high BIS group and a low BIS group completed a precision grip force control task during exposure to pleasant, unpleasant, and neutral images.

Given the wealth of evidence that has emerged concerning the neurobiological foundations and behavioral manifestations of BIS, we expected individuals with greater BIS sensitivity to experience more intense emotional responses (i.e., greater arousal) to unpleasant images which would be reflected behaviorally as a relative increase in force production during exposure to the unpleasant as compared to the pleasant and neutral images.

2. Methods

2.1. Participants

Thirty-seven subjects (31 females; age: $M = 19.78$, $SD = 1.18$) were selected from a total sample of 112 who were screened using Carver and White's (1994) Behavioral Inhibition System (BIS) scale. In accord with prior work (e.g., Shackman et al., 2006), subjects who scored in the upper and lower 20% on the BIS scale relative to the current sample, were included in the High BIS and Low BIS groups, respectively (High BIS; $N = 19$, Low BIS; $N = 18$)[1].

2.2. Instrumentation and task

Subjects were seated in a chair positioned 1 m from a 21″ CRT computer screen (1024 × 786; 100 Hz 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 supination and maximum pronation. Subjects performed a sustained isometric contraction by pinching a force transducer (MLP-75, transducer techniques, Temecula, CA, USA) with the thumb and index finger of their dominant hand. The force transducer (75 kg; 1.3 cm wide) had a sensitivity of 0.1%. Analog output from the force transducer (sum of the thumb and index finger force) was amplified through a 15LT Grass Technologies Physiodata Amplifier System (Astro-Med Inc., West Warwick, RI, USA) at an excitation voltage of 10 V.

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[1] Mean (SEM) BIS scores for High and Low BIS groups: (a) High BIS group – $M = 25.84$, $SEM = .29$, (b) Low BIS group – $M = 16.28$, $SEM = .56$.

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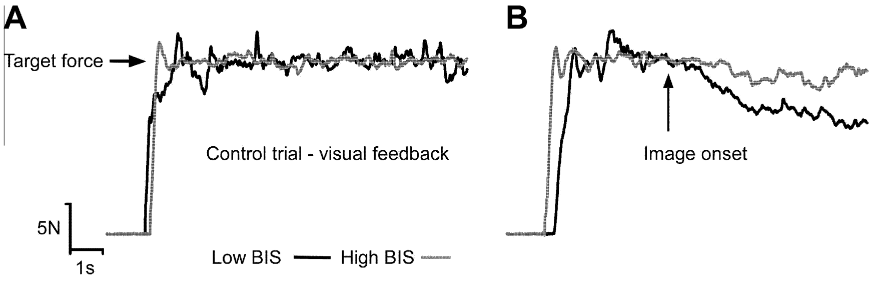

Fig. 1. Raw force traces from 2 individual subjects. Black lines represent an individual low in BIS and grey lines represent an individual high in BIS. Subjects were required to maintain their target level of force production (35% of MVC) as accurately as possible during the entire trial 11s trial. On all trials, feedback was presented for the initial 5 s. **A.** During control trials feedback remained on the screen for the remaining 6 s. **B.** During image trials feedback was replaced with a pleasant, unpleasant or neutral IAPS image.

Custom LabVIEW software controlled a 16-bit analog-to-digital converter (A/D) (PCI-6220, National Instruments, Austin, TX), which sampled the force at 100 Hz.

Prior to the practice and experimental trials, subjects' maximal voluntary contraction (MVC) was measured according to a well established method (Vaillancourt & Russell, 2002). The MVC value was then used as the reference for computation of the target goal force of interest for each individual. MVC levels between the High BIS and Low BIS groups were not significantly different, $t(35) = 1.745$, $p > .05$.

Visual feedback of force production for the pinch grip task was presented on a computer monitor that displayed two bars. A white stationary horizontal bar (positioned at 35% of MVC) located center screen represented the target force level, and a black horizontal bar represented the amount of force being produced by the subject. Subjects were instructed to alter their force production level which was represented by the black bar to match that of the white target bar. Participants sustained this level of force production as accurately as possible throughout the 11 s trial. Most acts of daily living require low to moderate levels of force production against an object (Marshall & Armstrong, 2004). Accordingly we chose to examine a pinch grip task with a target level of 35% of MVC.

2.3. Emotion manipulation

On 20 of the 25 experimental trials, visual feedback was occluded after 5 s with a digitized image selected from the International Affective Picture System[2] (Lang, Bradley, & Cuthbert, 2005), representing one of four affective categories: (1) erotic couples, (2) attack, (3) mutilation, and (4) neutral. The IAPS image covered the entire screen for 6 s. The images were chosen according to affective normative ratings. Valence was differentiated across all categories, while pleasant and unpleasant images were matched for arousal, distinguishing each from neutral images. The additional 5 trials were control trials in which feedback remained on the screen during the entire trial and no image was presented. Stimulus presentation order was randomized and counterbalanced.

2.4. Data analysis and statistical design

The force–time series data were digitally filtered with a fourth-order Butterworth filter with a 20 Hz low-pass cut-off. To determine the overall magnitude of force decay across the 6-s feedback occlusion period and to compare to prior work (Coombes et al., 2008), constant error (CE) was calculated for the last 1 s epoch of each trial. Fig. 1 shows exemplar raw force traces for two subjects during the control condition (1A) in which feedback remained on the screen and during a trial in which

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[2] IAPS images: erotic couples: 4647, 4660, 4800, 4659, 4670; attack: 3530, 6230, 6250, 6560, 6313; mutilation: 3064, 3030, 3060, 3068, 3071; neutral household objects: 7000, 7010, 7030, 7025, 7090, 7059, 7175, 7052, 7050, 7055.

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feedback was replaced by an image (1B). CE is calculated by subtracting the target force level from the produced force level, and therefore represents the direction of the error. For instance, in Fig. 1B the black line deviates further from the target line as compared to the grey line and this would result in a larger CE score. Each score would also be negative, indicating a decrease in force as compared to the target line. Hence, the grey line represents a relative increase in force production as compared to the black line.

To take into account variation between subjects' MVCs, we also calculated mean force as a percentage of MVC [mean force percentage = (mean force/MVC) × 100] for the last 1s epoch of each trial. The mean force as a percentage of MVC is hereafter referred to as mean force. Given strong a priori expectations, within group bias scores were calculated for mean force scores during image exposure. This procedure allowed us to create a single index for each subject that represented a direct comparison of the conditions that served as the basis for our hypotheses and indexed participants' sensitivity to each emotional category (mutilation versus neutral, mutilation versus erotic, attack versus neutral, attack versus erotic). A positive score indicates greater force production during the unpleasant category relative to the pleasant or neutral category, while a negative score indicates greater force production during the pleasant or neutral category relative to the unpleasant category.

We used a Student's t test to determine whether CE and mean force scores (collapsed across valence conditions) were equivalent between the low and high BIS groups during the 1 s before image presentation. This test of equivalence has been found to be effective at detecting population mean equivalence with small sample sizes (Cribbie, Gruman, & Arpin-Cribbie, 2004). CE and mean force scores during the final 1 s of image presentation were analyzed in separate 2 (Group: High BIS, Low BIS) × 5 (Valence: erotica, attack, mutilation, neutral household objects, control) ANOVAs with repeated measures on Valence. Follow-up analyses were conducted using simple effects tests and Tukey's HSD procedure for significant interactions and main effects, respectively. Given the specific hypotheses, planned comparisons were also conducted on the mean force bias scores between groups for each comparison of interest using independent samples t-tests.

3. Results

3.1. Constant error

The Student t test indicated that CE during the 1 s interval immediately preceding image onset did not vary as a function of BIS group, $t(35) = 1.66$, $p > .05$. Consequently, any changes in CE during image onset were not a function of group differences in force production prior to image onset.

The two-way ANOVA on the final 1 s of image presentation revealed a significant main effect of group, $F(1, 35) = 4.76$, $p = .036$, indicating that the high BIS group displayed a relative increase in force production as compared to the low BIS group. A significant main effect of valence was also evidenced, $F(2.56, 89.68) = 123.979$, $p < .05$, revealing a relative decrease in force production during all image presentation trials as compared to control trials. Each main effect was qualified by a significant Group - Valence interaction, $F(2.56, 89.63) = 3.179$, $p < .05$, with follow-up tests revealing that the High BIS group demonstrated a relative increase in force production during the presentation of attack and mutilation images as compared to the Low BIS group during the presentation of attack, mutilation, and neutral images. Finally, in line with the main effect of valence, follow up tests revealed that both groups demonstrated a relative decrease in force production during all image presentation trials as compared to control trials.

3.2. Mean force

The Student t test indicated that mean force during the 1 s interval immediately preceding image onset did not vary as a function of BIS group, $t(35) = 1.71$, $p > .05$. Consequently, any changes in force production during image onset were not a function of group differences prior to image onset.

Fig. 2 shows mean force amplitude during the final epoch of each trial for the low BIS group (black bars) and the high BIS group (grey bars). Both groups produced approximately 35% of MVC during the

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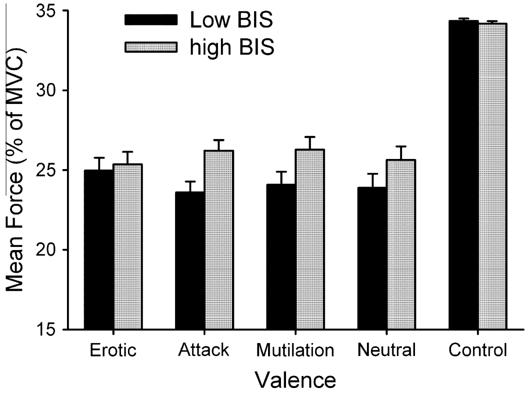

Fig. 2. Normalized mean force scores across valence conditions. The black bars represent the normalized mean force scores for the low BIS group and the grey bars represent the normalized mean force scores for the high BIS group. The target force was 35% of MVC. Error bars represent ±1 SE.

control condition. The figure also shows that the high BIS group displayed a relative increase in force production during attack and mutilation images as compared to the low BIS group. The two-way ANOVA on the final 1 s of image presentation demonstrated a significant main effect of valence, $F(4, 140) = 151.6$, $p < .001$, revealing greater force production during the control condition compared to all image conditions. The main effect was superseded by a significant Group × Valence interaction, $F(4, 140) = 3.39$, $p = .017$. Follow-up tests revealed that the High BIS group demonstrated greater force production during the presentation of (1) attack images compared to the Low BIS group during the presentation of attack and neutral images, and (2) mutilation images compared to the Low BIS group during exposure to mutilation, attack, and neutral images. Additionally, both groups produced more force during the control condition compared to all other conditions. The main effect of group was not significant, $F(1, 35) = 2.90$, $p = .098$.

Fig. 3 shows the planned comparisons of the mean bias scores for the low BIS group (black bars) and the high BIS group (grey bars). A significant effect of group was demonstrated on bias scores which contrasted force production during attack and erotica images, $t(35) = -2.36$, $p = .024$ (see A-E in Fig. 3). The High BIS group showed a relative increase in force production during exposure to attack

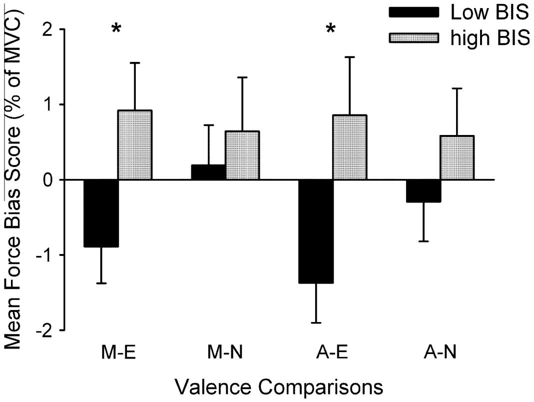

Fig. 3. Normalized mean force bias scores for the low BIS group (black bars) and the high BIS group (grey bars) for each bias score. The High BIS group displayed increased force production during exposure to attack and mutilation images as compared to erotic images. The Low BIS group displayed greater force production during exposure to erotica as compared to attack and mutilation images. Error bars represent ±1 SE. * = $p < .05$. M = mutilation, A = attack, E = erotica, N = neutral.

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as compared to erotica images, whereas the Low BIS group displayed a relative increase in force production during exposure to erotica as compared to attack images. A significant effect of group was also found for the mutilation-erotica bias score, with the data following the same pattern as the attack-erotica bias score, $t(35) = -2.45$, $p = .031$ (see M-E in Fig. 3). The mean force bias scores for mutilation-neutral ($t(35) = -0.503$, $p > .05$) and attack-neutral ($t(35) = -1.056$, $p > .05$) conditions were not significantly different.

4. Discussion

Emotional arousal leads to a relative increase in force production during gripping tasks (Coombes et al., 2008; Schmidt et al., 2009). In addition, individuals high in BIS display greater reactivity when viewing unpleasant images and respond with increased arousal (De Pascalis, Arwari, Matteucci, & Mazzocco, 2005; Gray & McNaughton, 2000). The current study merged these two lines of work to test the hypothesis that individuals high and low in BIS would display differences in force control while viewing pleasant and unpleasant images. Supporting our hypothesis, individuals high in BIS displayed a relative increase in force production when presented with attack and mutilation images compared to individuals low in BIS. Additionally, bias scores demonstrated that the high BIS group displayed a relative increase in force production during attack and mutilation images as compared to erotic images, whereas individuals low in BIS displayed a relative increase in force production during erotica images as compared to attack and mutilation images.

An ever expanding database of self report, behavioral, and neurobiological evidence supports the notion that extremely valenced highly arousing stimuli command greater attention. Such stimuli activate the defensive and appetitive motivational systems that underlie emotional experience, and this emotional experience is influenced by individual differences. For instance, the basic pattern of responding to extremely valenced cues with similar levels of arousal is modified by an individual's relative sensitivity to BIS. According to Gray (1982; Gray & McNaughton, 2000) and others (Carver & White, 1994; Gable, Reis, & Elliot, 2000; Heponiemi, Keltikangas-Jarvinen, Puttonen, & Ravaja, 2003; Perkins & Corr, 2006), individuals with relatively greater BIS sensitivity display greater affective reactivity to aversive cues which is reflected in increases in measures of arousal and attention. In particular, psychophysiological and behavioral studies have demonstrated that BIS activation increases *arousal* in response to aversive cues (Caseras et al., 2006; Gomez & Gomez, 2002; Gray & McNaughton, 2000; Hawk & Kowmas, 2003). Caseras and colleagues used a picture viewing startle blink paradigm and showed that individuals high as compared to low in BIS sensitivity displayed potentiated startle blinks during exposure to fear images, whereas both groups displayed potentiated startle blinks during exposure to blood and disgust images. Our findings extend this work to activation of the voluntary motor system by demonstrating that differences in BIS sensitivity during exposure to emotional images influences grip force control. The high BIS group displayed a relative increase in force production during the presentation of images that were both unpleasant and arousing, suggesting that valence driven differences in emotional arousal influenced force control. This effect was shown for both attack and mutilation images, whereas Caseras and colleagues only found between group differences in the startle blink during fear images. Together these findings suggest both similarities and differences in how voluntary and reflexive movements are influenced by individual differences in emotional reactivity and may reflect the differences in neural circuitry which underlie the blink reflex as compared to grip force control (Davis, Gendelman, Tischler, & Gendelman, 1982; Prodoehl, Corcos, & Vaillancourt, 2009).

With regard to the effect of emotion on voluntary movements, our findings support previous evidence in control samples which has demonstrated that compared to neutral images, highly arousing pleasant and unpleasant images increase motor cortex excitability (Coombes, Tandonnet et al., 2009; Hajcak et al., 2007), force production on a precision grip task (Coombes et al., 2008), and force production on a power grip task (Schmidt et al., 2009). Hence, previous evidence suggests that the relative increase in force production demonstrated in the current study can be attributed to an increase in emotional arousal in the high BIS group which was specific to unpleasant emotional images. An alternative explanation for our findings is that the high BIS group may have displayed an increase in stimulus-driven attention to the unpleasant images (Corbetta & Shulman, 2002; Eysenck, Derakshan, Santos, & Calvo, 2007) and this heightened attention served as a distraction from the force control task. This distraction may have averted the typical decrease in force production that occurs when visual feedback is removed during a force control task (Coombes et al., 2008; Vaillancourt & Russell, 2002). One could argue, however, that enhanced stimulus driven attention should exacerbate rather than avert performance deficits on the goal-driven attentional system (i.e., such as during a force production task: Coombes, Higgins et al., 2009). Therefore, while acknowledging stimulus-driven attentional alterations as a potential explanation, previous evidence leads us to interpret our findings as reflective of an individual difference driven change in emotional arousal. Importantly, this difference was reflected behaviorally in the modulation of grip force. We did not directly assess physiological indices of arousal or attention in the current study and acknowledge this inferential limitation.

Our data highlight the importance of considering individual differences in emotional reactivity when investigating the influence of emotion on force production of a functional, but *non-directional* movement task. A substantial corpus of the emotion and movement literature has focused on directional movements; movements that can be categorized as approach or avoidant oriented. Importantly, much of this work has neglected to consider the influence of individual differences in affective reactivity on emotion modulated movement. Elliot and Thrash (2010) and Thrash and Elliot (2002) recently suggested that an underlying core of BIS sensitivity is an avoidance temperament and underlying BAS sensitivity is an approach temperament. We encourage future researchers to examine whether BIS or BAS sensitivity is characterized by a tendency to produce avoidant or approach motor actions, respectively. Furthermore, given that emotions theoretically motivate behavioral responses to approach pleasant and avoid unpleasant stimuli (Frijda, 1986, 2009; Lang, Bradley, & Cuthbert, 1997), a potential avenue for future work would be to determine the influence of BIS and BAS sensitivity on emotion modulation of *directional movements*.

To our knowledge the current study is the first to examine the interaction between individual differences, emotional reactivity, and voluntary force control. Our findings extend previous literature which has examined the effect of individual differences in emotional reactivity on the involuntary startle blink (Caseras et al., 2006; Hawk & Kowmas, 2003). In conclusion, our findings demonstrate that when compared to individuals with low BIS sensitivity, individuals with high BIS sensitivity display a relative increase in voluntary force production during exposure to unpleasant as compared to pleasant emotional images.

Acknowledgments

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References

Buickians, A., Miklowitz, D. J., & Kim, E. Y. (2007). Behavioral activation, inhibition and mood symptoms in early-onset bipolar disorder. *Journal of Affective Disorders, 97*, 71–76.

Carver, C. S., & White, T. (1994). Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: The BIS/BAS scales. *Journal of Personality and Social Psychology, 67*, 319–333.

Caseras, F. X., Fullana, M. A., Riba, J., Barbanjo, M. J., Aluja, A., & Torrubia, R. (2006). Influence of individual differences in the behavioral inhibition system and stimulus content (fear versus blood-disgust) on affective startle reflex modulation. *Biological Psychology, 72*, 251–256.

Chen, M., & Bargh, J. A. (1999). Nonconscious approach and avoidance behavioral consequences of the autonomic evaluation effect. *Personality and Social Psychology Bulletin, 25*, 215–224.

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

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

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

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*, 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*, 1072–1079.

Please cite this article in press as: Coombes, S. A., et al. Emotional reactivity and force control: The influence of behavioral inhibition. *Human Movement Science* (2011), doi:10.1016/j.humov.2010.10.009

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*, 425–436.

Coombes, S. A., Tandonnet, C., Fujiyama, H., Janelle, C. M., Cauraugh, J. H., & Summers, J. (2009). Emotion and motor preparation: A transcranial magnetic stimulation study of corticospinal motor tract excitability. *Cognitive, Affective, and Behavioral Neuroscience, 9*, 380–388.

Corbetta, M., & Shulman, G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews of Neuroscience, 3*, 201–215.

Corr, P. J., & McNaughton, N. (2008). Reinforcement sensitivity theory and personality. In P. J. Corr (Ed.), *The reinforcement sensitivity theory of personality* (pp. 155–187). Cambridge: Cambridge University Press.

Cribbie, R. A., Gruman, J. A., & Arpin-Cribbie, C. A. (2004). Recommendations for applying tests of equivalence. *Journal of Clinical Psychology, 60*, 1–10.

Davis, M., Gendelman, D. S., Tischler, M. D., & Gendelman, P. M. (1982). A primary acoustic startle circuit: Lesion and stimulation studies. *Journal of Neuroscience, 2*, 791–805.

De Pascalis, V., Arwari, B., Matteucci, M., & Mazzocco, A. (2005). Effects of emotional visual stimuli on auditory information processing: A test of J. A. Gray's reinforcement sensitivity theory. *Personality and Individual Differences, 38*, 163–176.

Elliot, A. J., & Thrash, T. M. (2010). Approach and avoidance temperament as basic dimensions of personality. *Journal of Personality, 78*, 865–906.

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion, 7*, 336–353.

Frijda, N. H. (1986). *The emotions*. Cambridge: Cambridge University Press.

Frijda, N. H. (2009). Emotion experience and its varieties. *Emotion Review, 1*, 264–271.

Gable, S. L., Reis, H. T., & Elliot, A. (2000). Behavioral activation and inhibition in everyday life. *Journal of Personality and Social Psychology, 78*, 1135–1149.

Gomez, A., & Gomez, R. (2002). Personality traits of the behavioral approach and inhibition systems: Associations with processing of emotional stimuli. *Personality and Individual Differences, 32*, 1299–1316.

Gray, J. A. (1970). The psychophysiological basis of introversion-extraversion. *Behavior Research & Therapy, 8*, 249–266.

Gray, J. A. (1982). *The neuropsychology of anxiety: An enquiry into the functions of the septo-hippocampal system*. Oxford: Oxford University Press.

Gray, J. A. (1994). Three fundamental emotion systems. In P. Ekman & R. J. Davidson (Eds.), *The nature of emotion: Fundamental questions* (pp. 243–247). New York: Oxford University Press.

Gray, J. A., & McNaughton, N. (Eds.). (2000). *The neuropsychology of anxiety: An enquiry into the functions of the septo-hippocampal system*. Oxford: Oxford University Press (2nd ed.).

Hajcak, G., Molnar, C., George, M. S., Bolger, K., Koola, J., & Nahas, Z. (2007). Emotion facilitates action: A transcranial magnetic stimulation study of motor cortex excitability during picture viewing. *Psychophysiology, 44*, 91–97.

Hawk, L. W., Jr., & Kowmas, A. D. (2003). Affective modulation and prepulse inhibition of startle among undergraduates high and low in behavioral inhibition and approach. *Psychophysiology, 40*, 131–138.

Heponiemi, T., Keltikangas-Jarvinen, L., Puttonen, S., & Ravaja, N. (2003). BIS/BAS sensitivity and self-rated affects during experimentally induced stress. *Personality and Individual Differences, 34*, 943–957.

Hewig, J., Hagemann, D., Seifert, J., Naumann, E., & Bartussek, D. (2006). The relation of cortical activity and BIS/BAS on the trait level. *Biological Psychology, 71*, 42–53.

Hillman, C. H., Rosengren, K. S., & Smith, D. P. (2004). Emotion and motivated behavior: Postural adjustments to affective picture viewing. *Biological Psychology, 66*, 51–62.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1997). Motivated attention: Affect, activation, and action. In P. J. Lang, R. F. Simons, & M. T. Balaban (Eds.), *Attention and orienting: Sensory and motivational processes* (pp. 97–135). Mahwah: Erlbaum.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (2005). *International affective picture system (IAPS): Instruction manual and affective ratings. Technical report A-6*. Gainesvile, FL: University of Florida.

Leocani, L., Locatelli, M., & Bellodi, L. (2001). Abnormal pattern of cortical activation associated with voluntary movement in obsessive-compulsive disorder: An EEG study. *American Journal of Psychiatry, 158*, 140–142.

Lohr, J. B., & Caligiuri, M. P. (2006). Abnormalities in motor physiology in bipolar disorder. *Journal of Neuropsychiatry Clinical Neuroscience, 18*, 342–349.

Marshall, M. M., & Armstrong, T. J. (2004). Observational assessment of forceful exertion and the perceived force demands of daily activities. *Journal of Occupational Rehabilitation, 14*, 281–294.

Naugle, K. M., Joyner, J., Coombes, S. A., Hass, C. J., & Janelle, C. M. (accepted for publication). Emotional state affects the initiation of foward gait. *Emotion.*

Nitschke, J. B., Heller, W., Palmieri, P. A., & Miller, G. A. (1999). Contrasting patterns of brain activity in anxious apprehension and anxious arousal. *Psychophysiology, 36*, 628–637.

Oathes, D. J., & Ray, W. J. (2006). Depressed mood, index finger force and motor cortex stimulation: A transcranial magnetic stimulation (TMS) study. *Biological Psychology, 72*, 271–277.

Perkins, A. M., & Corr, P. J. (2006). Reactions to threat and personality: Psychometric differentiation of intensity and direction dimensions of human defensive behaviour. *Behavioural Brain Research, 169*, 21–28.

Prodoehl, J., Corcos, D. M., & Vaillancourt, D. E. (2009). Basal ganglia mechanisms underlying precision grip force control. *Neuroscience Biobehavioral Reviews, 33*, 900–908.

Rotteveel, M., & Phaf, R. H. (2004). Automatic affective evaluation does not automatically predispose for arm flexion and extension. *Emotion, 4*, 156–172.

Schmidt, L., Clery-Melin, M. L., Lafargue, G., Valabregue, R., Fossati, P., Dubois, B., et al (2009). Get aroused and be stronger: Emotional facilitation of physical effort in the human brain. *Journal of Neuroscience, 29*, 9450–9457.

Segarra, P., Ross, S. R., Pastor, M. C., Montanes, S., Poy, R., & Molto, J. (2007). MMPI-2 predictors of Gray's two-factor reinforcement sensitivity theory. *Personality and Individual Differences, 43*, 437–448.

Shackman, A. J., Sarinopoulus, I., Maxwell, J. S., Lavric, A., Pizzagalli, D. A., & Davidson, R. J. (2006). Anxiety selectively disrupts visuospatial working memory. *Emotion, 6*, 40–61.

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Sobin, C., & Sackeim, H. A. (1997). Psychomotor symptoms of depression. *American Journal of Psychiatry, 154*, 4–17.
Thrash, T. M., & Elliot, A. J. (2002). Implicit and self-attributed achievement motives: concordance and predictive validity. *Journal of Personality, 70*, 729–755.
Vaillancourt, D. E., & Russell, D. M. (2002). Temporal capacity of short-term visuomotor memory in continuous force production. *Experimental Brain Research, 145*, 275–285.
Wada, M., Sunaga, N., & Nagai, M. (2001). Anxiety affects the postural sway of the antero-posterior axis in college students. *Neuroscience Letters, 302*, 157–159.
Yardley, L., Britton, J., & Lear, S. (1995). Relationship between balance system function and agoraphobic avoidance. *Behaviour Research and Therapy, 33*, 435–439.

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