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Emotional State Affects the Initiation of Forward Gait

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The aim of the current study was to determine the extent to which pleasant and unpleasant emotional states impact the initiation of forward gait. Participants initiated gait and walked for several steps following the presentation of low arousing pleasant, high arousing pleasant, low arousing unpleasant, high arousing unpleasant, and neutral pictures. Reaction time, displacement, and velocity of the center of pressure (COP) trajectory, and length and velocity of the first and second steps were calculated. Exposure to the highly arousing unpleasant pictures reduced reaction times compared to all other affective conditions. Compared to the low arousing unpleasant pictures, exposure to the high and low arousing pleasant pictures increased the displacement of the COP movement during the anticipatory postural adjustment phase of gait initiation. Additionally, exposure to the low arousing pleasant pictures increased the velocity of the COP movement during the anticipatory postural adjustment phase, compared to the high and low arousing unpleasant pictures. Exposure to the high and low arousing pleasant pictures increased the velocity of the first step relative to the low arousing unpleasant pictures. These findings demonstrate that highly arousing unpleasant emotional states accelerate the initial motor response, but pleasant emotional states generally facilitate the initiation of forward gait due to the approach-oriented directional salience of the movement. These findings extend the scope of the motivational direction hypothesis by demonstrating the effects of emotional reactivity on the initiation of gait.

Keywords: affect, posture, locomotion, motivational direction, whole body movements

Gait initiation (GI), the phase between motionless standing and rhythmic walking, is a functional task involved in numerous activities of daily living (Hallet, 1990). Successful GI requires effective balance control as one moves from stable balance to continuously unstable gait (Halliday, Gai, Blessing, & Geffen, 1990). The GI process, which allows an individual to reach steady gait velocity by the end of the first step (Breniere & Do, 1986; Jian, Winter, Ishac, & Gilchrist, 1993), can be divided into two phases: an anticipatory phase and a step execution phase. During the anticipatory phase, anticipatory postural adjustments decouple the center of mass (COM) and the net center of pressure (COP), allowing GI to begin (Jian et al., 1993). Difficulty initiating gait often occurs when the displacements of the COP are too small and velocity of the COP movement is too slow. These postural and gait problems typically occur in the elderly and individuals with Parkinson's disease (PD) (Halliday, Winter, Frank, Patla, & Prince, 1998; Hass et al., 2004; Hass, Waddell, Fleming, Juncos, & Gregor, 2005). In each case, abnormalities in posture and gait significantly reduce quality of life and increase the risk of falls. It is essential, therefore, to understand the factors that alter spatial and temporal parameters of GI.

Postural adjustments during GI include a series of muscle activations and changes in ground reaction forces that move the net COP backward and toward the initial swing limb to move the COM forward and toward the stance limb (Crenna, Frigo, Giovannini, & Piccolo, 1990; Massion, 1992). The anticipatory phase ends at heel off of the initial swing limb. The execution phase begins when weight has been transferred to the stance limb (Crenna et al., 1990) and corresponds to the stepping motion from toe-off of the swing limb to heel strike of the same limb (Brunt et al., 1991; Elble, Moody, Leffler, & Sinha, 1994). Functionally, the backward movement of the COP during the preparatory phase covaries with gait velocity at the end of the first step (Breniere, Do, & Bouisset, 1987; Crenna & Frigo, 1991), revealing that the anticipatory postural adjustments are centrally controlled (Massion, 1992). Additionally, the initial lateral COP shift, which drives the COM toward the stance limb, preserves lateral stability during the step execution phase (Jian et al., 1993; Zettel, McIlroy, & Maki, 2002).

Given recent evidence, which has demonstrated that the speed and force of upper extremity voluntary movement initiation and execution vary as a function of transient emotional states (Coombes, Cauraugh, & Janelle, 2007b; Coombes, Gamble, Cauraugh, & Janelle, 2008; Coombes, Janelle, & Duley, 2005), it is reasonable to postulate that gait performance may be influenced by the emotional states under which gait is initiated and locomotion

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proceeds. Recent studies have shown that a high degree of integration exists among the circuits that regulate emotion and motor processes (Haber, 2003; Pessiglione et al., 2007). For instance, primate studies indicate that information from the limbic pathways can reach the motor pathways via the midbrain dopamine neurons, with the potential for shaping final motor behaviors (for review, see Haber, 2003). Importantly, PD research suggests that successful initiation of gait relies on nigrostriatal dopamine in the basal ganglia circuits, and that gait deficiencies in GI are driven by a lack of dopamine within these circuits (Takakusaki, Habaguchi, Ohtinata-Sugimoto, Saitoh, & Sakamoto, 2003). As such, activating dopamine in emotion circuits may be a complimentary method to facilitate the basal ganglia motor circuits underlying GI. Although it remains unclear whether emotion influences whole body movement, such possibilities hold substantial promise for aiding recovery among individuals who suffer gait problems.

Emotion-Modulated Movement

A growing body of literature supports the long-held notion that human emotion and motor actions are largely intertwined and reciprocally interrelated (Niedenthal, 2007). Affective theorists traditionally agree that emotions prime or facilitate action (Frijda, 2009; Frijda, Kuipers, & ter Schure, 1989; Lang, 1995), motivating behavioral responses to approach pleasant and avoid unpleasant stimuli and situations. The *motivational direction hypothesis* is founded on the principle that unpleasant emotions activate defensive circuitry and prime avoidance behaviors (although anger is one exception: Harmon-Jones & Allen, 1998; Harmon-Jones, Harmon-Jones, Abramson, & Peterson, 2009), whereas pleasant emotions activate appetitive circuits that prime approach behaviors (Cacioppo, Priester, & Berntson, 1993; Centerbar & Clore, 2006; Chen & Bargh, 1999; Duckworth, Bargh, Garcia, & Chaiken, 2002). Such evidence has typically been acquired using protocols that manipulate emotional states prior to or during the execution of upper extremity movements that are made toward or away from the body. Specifically, flexion movements are facilitated under pleasant emotional states (Chen & Bargh, 1999; Duckworth et al., 2002), whereas extension movements are facilitated under unpleasant emotional states (Chen & Bargh, 1999; Coombes, Cauraugh, & Janelle, 2007a, 2007b; Duckworth et al., 2002).

Importantly, research has indicated that aversive stimuli also alter movements that are not withdrawal-related (Coombes et al., 2005; Coombes, Higgins, Gamble, Cauraugh, & Janelle, 2009; Marsh, Ambady, & Kleck, 2005). Although inferences have been drawn from these data regarding the interdependence of emotion and approach/avoidant behavior, questions have surfaced regarding whether flexion and extension arm movements truly represent such behaviors. Accordingly, recent conceptual efforts have stressed the importance of considering how the direction of the movement interacts with reference to the self (Markman & Brendl, 2005; Rotteveel & Phaf, 2004). In other words, does the movement decrease (approach) or increase (avoidance) the distance between the affective stimulus and the representation of the self? In the current study, we extend previous work by examining the initiation and execution of forward gait. Forward gait clearly decreases the distance of the self to the location of affective stimuli, permitting a much purer direction-specific task, as compared to the upper limb flexion and extension movements that have frequented previous work in this area.

Whereas the upper extremity remains a favored target area for studies examining emotion-modulated movement, emotion-evoked postural adjustments during quiet standing have been studied (e.g., Adkin, Frank, Carpenter, & Peysar, 2002; Azevedo et al., 2005; Hillman, Rosengren, & Smith, 2004; Huffman, Horslen, Carpenter, & Adkin, 2009). For example, Hillman et al. (2004) found that females exhibited increased COP movement in the posterior direction (i.e., away from pictures) when viewing unpleasant pictures, whereas males demonstrated modest posterior COP movement under such conditions. The investigators suggested that the increased posterior movement during quiet standing was motivated by behavioral withdrawal from the unpleasant stimuli and may reflect early preparation for the initiation of a “fight or flight” response. Contrary to expectations, exposure to pleasant pictures did not lead to a shift in COP toward the pictures for males or females. Conflicting findings were reported by Azevedo and colleagues (2005), who revealed that passive viewing of mutilation pictures reduced overall body sway in the medial-lateral direction (i.e., standard deviation of COP trajectory) in male participants. Corroborating Hillman et al.’s suggestion of the underlying mechanism, however, Azevedo et al. postulated that reduced sway also reflected the activation of a withdrawal response as evidenced by “freezing behavior.” Methodological differences regarding the gender of participants, size of pictures, and outcome measures may have accounted for the contrasting withdrawal responses to unpleasant pictures in these two studies (i.e., increased freezing vs. increased posterior movement). For example, Hillman’s measure of interest was the displacement of the COP in the anterior-posterior direction, whereas Azevedo focused on the standard deviation of COP displacement and mean position. Hillman also presented pictures much greater in size than Azevedo, which could have led to larger effects. Finally, Hillman found the greatest modulation of postural responses to unpleasant stimuli in females, whereas Azevedo only assessed male participants. Nonetheless, these two studies demonstrate that unpleasant emotions are associated with specific postural adjustments.

Present Study

Our aim was to examine how pleasant and unpleasant emotional states impact the quality of GI. To achieve this aim, participants were required to initiate gait and continue walking several steps immediately after the offset of pictures, varying in emotional arousal and emotional valence. By implementing a movement that decreased the distance of the self to the position of the emotional stimuli, we were able to assess its impact on a pure approach-oriented behavior. The use of such a task removes the directional ambiguity found in previous work investigating approach/avoidant responses to affective stimuli (e.g., Chen & Bargh, 1999; Coombes et al., 2007a, 2007b; Duckworth et al., 2002). Given that we were primarily interested in comparisons of GI performance between pleasant and unpleasant conditions, we used GI performance after the neutral pictures as a control condition and evaluated the change in movement due to each affective category relative to the neutral category. Specifically, we wanted to determine the extent to which emotional arousal and valence altered reaction time, movement of the COP trajectory, and step execution during a forward GI task.

Two competing hypotheses were tested concerning how reaction time of GI would vary. First, if approach-related behaviors are only primed by pleasant cues that activate appetitive circuits (Cacioppo et al., 1993; Chen & Bargh, 1999; Duckworth et al., 2002; Lang, 1995), then we would expect the presentation of pleasant pictures to result in faster reaction times on the GI task, compared to unpleasant pictures. Alternatively, if unpleasant cues prime the motor system for action and expedite an initial motor response regardless of the motivational direction of the intended movement (Coombes et al., 2007a, 2009; Öhman & Soares, 1998), then we would expect the presentation of the unpleasant pictures to lead to faster reaction times on the GI task, compared to all other conditions. Bradley et al. (2001) showed that defensive responding to unpleasant picture stimuli can be ordered based on the degree to which the pictures elicit defensive activation, with more arousing pictures expected to engage the defensive system more strongly. Thus, we further hypothesized that reaction times would be speeded only during the *high arousing* unpleasant pictures (i.e., attack), which represent more imminent threat, compared to the low arousing unpleasant (i.e., sad people) pictures.

With regard to the COP trajectory, we hypothesized that the displacement and velocity of the COP movement would be greater after exposure to the pleasant, compared to the unpleasant, conditions. Specifically, we predicted (a) greater displacement and velocity of the posterior and lateral movement during the anticipatory postural adjustment (APA) period, (b) greater velocity of the medial movement during the weight-shift period, and (c) greater velocity of the anterior movement during the locomotor period (see Figure 1 for definitions of each phase). The anticipatory phase of GI includes the APA period of COP movement, whereas the weight shift and locomotor periods of the COP movement represent the beginning of the step execution phase of GI. Finally, we predicted greater step length and step velocity after exposure to pleasant, as compared to unpleasant, pictures.

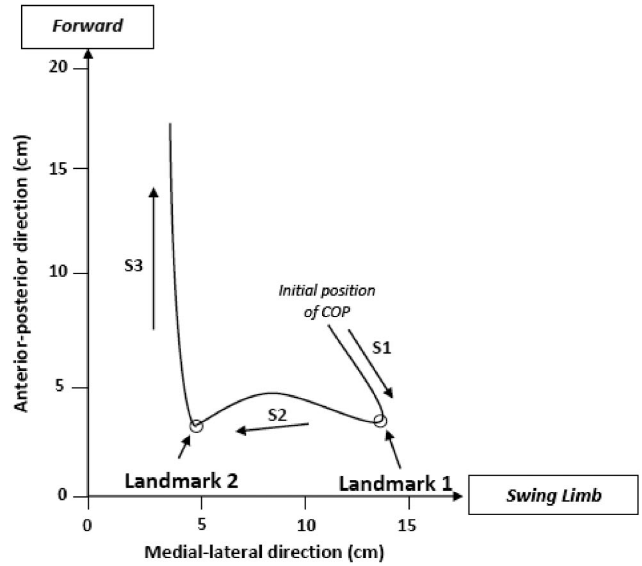

Figure 1. Overhead view of the path of the COP during forward GI when stepping with the right foot. Landmarks 1 and 2 were identified, leading to the separation of the COP trace into defined periods S1, S2, and S3. S1 (anticipatory postural adjustment period): begins with the initiation of the motor response and ends with COP located in its most posterior and lateral position toward the initial swing limb (landmark 1). S1 is important to producing the forward and stance side momentum needed to initiate gait. S2 (weight shift period): translation of the COP toward the stance limb ending at landmark 2, which is the position under the stance limb on which the COP begins to move forward under the foot. S2 is an important component in moving into single limb support and has been shown to compensate for changes in S1. S3 (locomotor period): landmark 2 until heel strike of the initial swing limb as the COP is translated anteriorly. Adapted from Hass et al. (2004). The influence of Tai Chi training on the center of pressure trajectory during gait initiation in older adults. *Archives of Physical Medicine and Rehabilitation, 85*, 1593–1598.

Method

Participants

Thirty-four undergraduate students volunteered to participate in the study (females = 17, males = 17). All subjects reported no lower extremity injuries in the last 6 months that would affect movement, and were similar across descriptive demographics and dispositional anxiety and depression (see Table 1). Subjects with behavioral data three *SD* from the mean for each picture category were considered behavioral outliers and were removed prior to statistical analysis. Thus, data for two subjects were removed from the COP analysis, and data for three subjects were removed from the step length and velocity analysis. Additionally, technical problems led to the exclusion of reaction time data from four participants. All participants were naïve to the aim of the study and completed a written informed consent prior to participating in the study.

Emotion Manipulation

Picture viewing was used to induce emotional states among participants during the experimental trials. Presented stimuli included 25 digitized photographs selected from the IAPS, representing five affective categories: (a) low arousing unpleasant, (b) high arousing unpleasant, (c) low arousing pleasant, (d) high arousing pleasant, and (e) neutral.[1] Pictures were presented on a screen located 6 m in front of participants. To control for valence and arousal, pictures were matched/polarized according to affective norms (NIMH, CSEA, 2005). We also included five catch trials, in which no image was presented. Pictures were projected onto a 2 × 1.5 m screen, using a NEC VT 670 digital projector. Pictures were 36 × 50 cm and 1,024 × 768 pixels. Stimulus presentation and order was randomized and counterbalanced across participants. A custom LabVIEW program (LabVIEW 8.1; National Instruments, Austin, TX) controlled trial onset, trial offset, and visual stimulus presentation. A computerized 9-point version of the self-assessment manikin (SAM: Lang, 1980) was used to obtain subjective ratings of valence and arousal at the conclusion of gait testing.

[1] IAPS Pictures: HA Unpleasant: 6210, 6250, 6510, 6370, 6260; LA Pleasant: 2900, 2800, 2703, 2141, 9421; HA Pleasant: 4607, 4659, 4694, 4670, 4687; LA Pleasant: 4598, 2071, 4623, 2345, 2058; Neutral: 2210, 2305, 2190, 2104, 2200.

Table 1
Participant Characteristics and Affective States and Traits

	Males (n = 17)		Females (n = 17)	
	M	*SD*	*M*	*SD*
Age	20.53	1.92	20.53	1.69
Mass (kg)	76.22	15.69	61.06	6.40
Height (cm)	176.48	7.69	162.95	5.70
Trait anxiety (STAI)	32.93	8.09	29.40	7.10
Depression (BDI)	6.80	6.14	6.67	3.50
State anxiety (STAI)	32.73	8.10	32.53	6.56

Instrumentation and Task

Participants were fitted with retroreflective markers, which were placed bilaterally on the lower body at the following locations: anterior superior iliac, posterior superior iliac, lateral epicondyle of the knee, lower lateral one-third the surface of the thigh, lateral malleolus, tibia, second metatarsal head, and calcaneus. Once the reflective markers were in place, each participant was given the opportunity to walk around the testing environment to become accustomed to the instrumentation. During the GI trials, the participants stood with their feet in a self-selected stance width, with both feet on one force platform (model 4060; Bertec, Columbus, OH). The positioning of the feet was recorded to allow standardization for all future trials. Participants selected the initial stepping limb, which was maintained throughout all trials. In response to picture offset, the participants began walking and continued walking for several steps (~4 m). We chose to have participants walk at picture offset, rather than picture onset, to avoid possible attentional effects on performance resulting from viewing the picture and initiating gait simultaneously. This approach replicates other studies that have required participants to execute movements after, rather than during, exposure to affective stimuli (Coombes et al., 2005, 2009). The kinematic characteristics of the locomotor tasks were sampled at a rate of 120 Hz, using a 10-camera Optical Motion Capture system (Vicon Peak, Oxford, UK). The motion capture system collected three-dimensional coordinate data from retroreflective markers. Ground reaction forces (GRFs) and COP measurements were collected from the first force platform at 1,200 Hz, using three Bertec force platforms (size 60 × 40 cm; Bertec, Newton, MA) mounted flush with the laboratory floor. The platforms were oriented such that the landing of the stepping foot occurred on the second platform and the first heel strike of the stance limb occurred on the third platform. Additionally, the force platforms were oriented so that the laboratory coordinated system coincided with the left anterior corner of the third force platform, with the x-axis aligned in the direction of forward progression.

Procedure

Upon arriving at the laboratory, participants signed a written informed consent approved by the University's Institutional Review Board and completed a battery of self-report assessments, including demographics, the state form of the State Trait Anxiety Inventory (STAI: Spielberger, 1983), the state version of the Positive and Negative Affect Schedule (PANAS: Watson, Clarke, & Tellegen, 1988), and the Beck Depression Inventory (BDI: Beck & Steer, 1987). After being fitted with the retroreflective markers, participants were familiarized with the protocol and then completed two practice trials, using unique neutral pictures. The practice trials were immediately followed by 30 data collection trials. Participants were informed that each trial would begin with the presentation of a fixation cross on the video screen (2 s), which would be replaced by an image for 2–4 s. They were instructed to look at the picture the entire time it was on the screen. At picture offset, the screen became blank (white) and participants were instructed to immediately initiate walking for several steps at their self-selected pace (see Figure 1 for gait protocol). Each participant performed five trials for each affective category and five catch trials. After the completion of the GI trials, participants completed the computerized SAM scale to provide an arousal and valence rating (scale: 1–9) for each picture previously viewed.

Data Reduction

Reaction time (RT), displacement, and velocity of COP in a given direction, step length, and average step velocity of the first and second steps were calculated.

RT. RT was calculated as the latency from the movement trigger (picture offset) to the initiation of the motor response. Initiation of motor response was defined as the time at which the weight shift (i.e., change in mediolateral GRF) between the swing limb and stance limb during GI reached a 5% threshold of force production, compared to the baseline value (Diermayr, Gynsin, Hass, & Gordon, 2008).

COP displacement and velocity. Movement of the COP trajectory was quantified by the displacements and velocities of the COP trace observed over time in both the mediolateral (ML) and anterior-posterior (AP) direction. The COP trace during the GI trials was divided into three periods (S1: anticipatory postural adjustment; S2: weight shift; and S3: locomotor) by identifying two landmark events (Hass et al., 2004), as illustrated in Figure 1. During these three sections, the following dependent variables were evaluated: (a) the displacement of the COP in the x (AP: anterior-posterior) and y (ML: mediolateral) direction and (b) the average velocity of the COP in the x and y directions. The GRF and moment data from the first force platform was used to determine the instantaneous COP.

Step length and velocity. The length and velocity of the steps for the first gait cycle were calculated. Step length of the first step was calculated as the displacement (cm) of the initial swing limb heel marker from its initial resting position until heel strike. Step length of the second step (i.e., contralateral step) was calculated as the displacement (cm) from the heel position of the swing leg at first heel strike to the heel position of the stance leg at heel strike. Step velocity for each step was calculated as the step length divided by the corresponding change in time (m/s).

Percent change scores. We created a single index for each movement variable that represented the change in movement due to each affective category relative to the neutral category. Percent change scores were calculated for each dependent variable after picture exposure, using the following formula: [(emotional category/neutral category)*100] – 100. A positive score indicates greater values for the dependent variable during the emotional category relative to the neutral category, whereas a negative score indicates reduced values for the dependent variable during the emotional category relative to the neutral category. These percent change scores served as the bases for all statistical analyses involving the movement outcomes.

Statistical Analyses

Descriptive characteristics were calculated for age, height, weight, and all affective state and trait measures. Preliminary analyses were first conducted on each dependent variable to determine whether the effect of emotion differed between genders. Gender did not have a significant effect on any dependent variable, so all consequential statistical analyses excluded gender as an independent variable. To determine whether differences existed in RT across the four picture categories, the percent change RT scores were analyzed with a repeated measures one-way ANOVA (picture category: LA pleasant, HA pleasant, LA unpleasant, and HA unpleasant). COP displacement and velocity percent change scores were evaluated during the three phases of the COP trace. Thus, three separate repeated measures one-way multivariate analyses of variance (MANOVAs) were used to test for differences among the four affective picture categories, while controlling for type I error. Percent change scores for step length of first and second step, stride length, and step velocity of first and second step were also analyzed with a repeated measures one-way MANOVA (picture category). For each MANOVA, separate ANOVAs were performed for follow-up testing, when appropriate. We also conducted one-way ANOVAs on the SAM valence and arousal ratings. For all ANOVAs, if the sphericity assumption was violated, then Greenhouse-Geisser degrees of freedom corrections were applied. Follow-up analyses were conducted using Tukey's HSD procedure. For all analyses, the probability value was set at $p < .05$.

Results

RT

Table 2 presents the raw RT data for each picture category. Figure 2 shows that RT on the GI task was shortened after the presentation of highly arousing unpleasant images. This pattern was confirmed by the significant repeated measures one-way ANOVA, which revealed that exposure to the high arousing unpleasant pictures speeded participants' RT, compared to all other affective picture categories, $F(1.985, 51.617) = 4.913$, $p = .011$ (see Figure 3).

Table 2
Summary Reaction Time Data for Each Picture Category

Picture category	HA-U	LA-U	HA-P	LA-P	Neutral	Catch
Reaction time (ms)						
Mean (*SD*)	270 (12)	305 (20)	321 (16)	305 (17)	304 (15)	298 (20)

Note. ms = milliseconds; HA-U = high arousal unpleasant; LA-U = low arousal unpleasant; HA-*p* = high arousal pleasant; LA-*p* = low arousal pleasant.

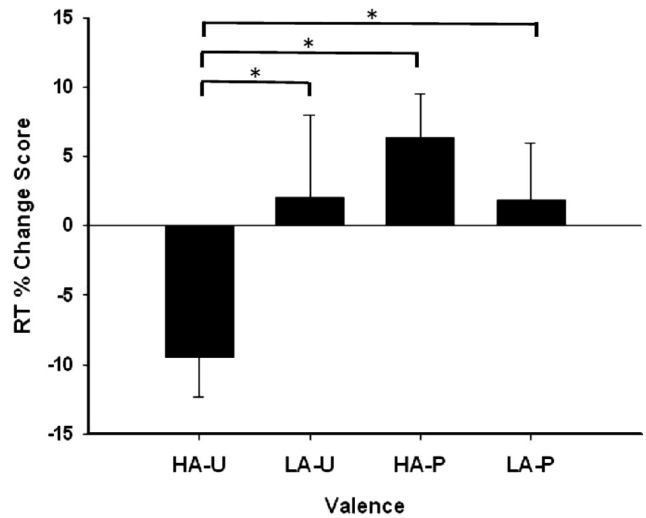

Figure 2. Mean and *SE* percent change scores for the reaction time data across the picture categories. HA-U = high arousal unpleasant; LA-U = low arousal unpleasant; HA-P = high arousal pleasant; LA-P = low arousal pleasant. * $p < .05$.

S1 Period of the COP Trace

Table 3 presents the raw displacement and velocity data for each picture category for the S1, S2, and S3 periods of the COP trajectory. MANOVA revealed a significant effect of picture category for the variables in the S1 period of the COP curve, *Wilks' lambda* = .790, $F(12, 230.472) = 1.787$, $p = .05$. Respective follow-up tests revealed a significant main effect of picture category for the displacement of the COP in the AP direction [$F(1.92, 57.96) = 3.188$, $p = .05$], the velocity of the COP movement in the AP direction [$F(2.43, 72.69) = 2.830$, $p = .05$], and the velocity of the COP movement in the ML direction [$F(3, 90) = 2.727$, $p = .05$]. Exposure to the high and low arousing pleasant pictures resulted in a significant increase in the magnitude of COP displacement in the posterior direction, compared to the low arousing unpleasant pictures (see Figure 3a). Similarly, velocity of the COP movement in the posterior direction was significantly greater after exposure to the low arousing pleasant pictures, compared to both categories of unpleasant pictures and the high arousing pleasant pictures (see Figure 3b). Finally, exposure to the low arousing pleasant pictures, compared to all other valence categories, resulted in a greater increase in the velocity of the COP movement in the lateral direction. Exposure to pleasant (compared to unpleasant) pictures, therefore, broadly facilitated gait initiation during the SI period, as indexed by increased distance and velocity of the COP movement in the posterior and lateral directions.

S2 Period of the COP Trace

MANOVA during the S2 period of the COP trajectory approached significance, *Wilks' lambda* = .791, $F(12, 206.660) = 1.787$, $p = .095$, and was driven by a significant ANOVA for the velocity of the COP trajectory in the ML direction, $F(2.42, 65.44) = 4.479$, $p = .010$.

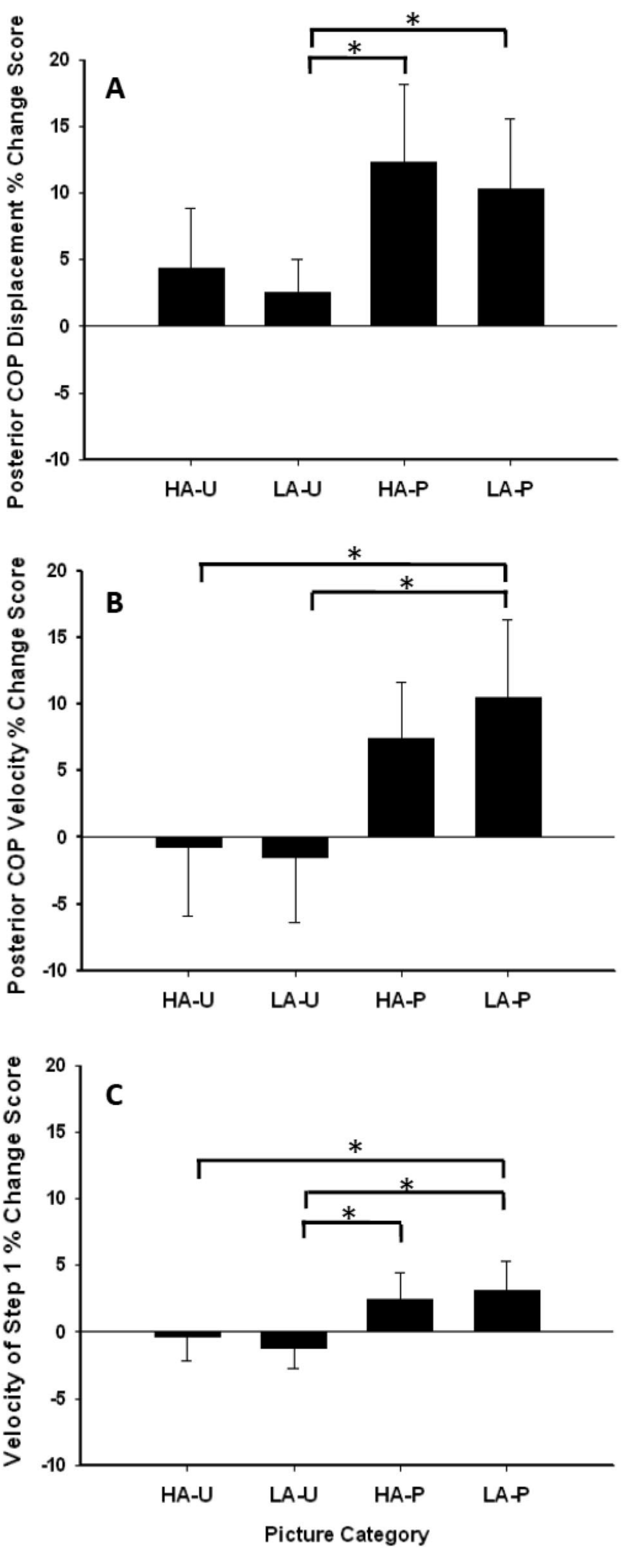

Figure 3. Mean and *SE* percent change scores across the picture categories for the (A) displacement of the COP data in the posterior direction during the S1 time period, (B) velocity of the COP data in the posterior direction during the S1 time period, and (C) velocity of the first step. HA-U = high arousal unpleasant; LA-U = low arousal unpleasant; HA-P = high arousal pleasant; LA-P = low arousal pleasant. $^{*}p < .05$.

S3 Period of the COP Trace

No significant effects were found during the S3 portion of the COP trajectory. Facilitation of gait would have been evidenced by faster movement of the COP in the anterior direction.

Step Length and Step Velocity of the First and Second Steps

Table 4 presents the raw step length and step velocity data for each level of valence. MANOVA revealed a significant effect of picture category for the dependent variables representing the execution of the first and second steps, *Wilks' lambda* = .702, $F(15.00, 212.964) = 1.938$, $p = .021$. The follow-up tests revealed a significant main effect of picture category for velocity of the first step only, $F(3, 81) = 3.797$, $p = .013$. Exposure to the low arousing pleasant pictures resulted in a significant increase in step velocity, compared to both categories of unpleasant pictures. Additionally, exposure to the high arousing pleasant pictures led to greater step velocity relative to the low arousing unpleasant pictures (see Figure 3c).

SAM

Valence ratings for the selected IAPS pictures varied significantly, $F(2.89, 95.24) = 170.50$, $p < .001$. As expected, participants rated the low and high arousing pleasant pictures as more pleasant than the low and high unpleasant pictures and neutral pictures. The neutral pictures were also rated as being more pleasant than both unpleasant picture categories (see Figure 4a). We also found a significant effect of picture category for arousal, $F(3.13, 87.56) = 28.64$, $p < .001$. As demonstrated in Figure 4b, (a) the high arousing pleasant and unpleasant pictures were rated as more arousing than the low arousing pleasant and unpleasant and neutral pictures and (b) the low arousing pleasant and unpleasant pictures were rated as more arousing than the neutral pictures. The SAM results support our division of the pleasant and unpleasant pictures into high and low arousing categories.

Discussion

We sought to determine how emotional state impacts GI in healthy young adults. Participants initiated gait and continued to walk forward at a self-selected pace for several steps after the presentation of affective pictures varying in emotional valence and arousal. Three novel contributions emerged from these findings: (a) High arousing unpleasant stimuli speeded reaction time of the motor response on the GI task relative to all other affective conditions; (b) high and low arousing pleasant stimuli facilitated the velocity and displacement of the COP movement needed to initiate gait, particularly during the anticipatory postural adjustment period; and (c) high and low arousing pleasant stimuli generally increased the velocity of the first step of GI. Each of these seminal findings is specified below and discussed in the context of contemporary theories of emotion and motivation.

Our first aim was to determine how emotional state influenced the latency from picture offset to the initiation of the motor response when executing an unambiguous approach-oriented behavior. The motivational direction hypothesis indicates pleasant conditions speed approach-related movements, whereas unpleasant

Table 3
Summary COP Data During the S1, S2, and S3 Phases of GI for Each Picture Category

Valence	HA-U		LA-U		HA-P		LA-P		Neutral		Catch	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
S1												
x displacement	4.16	.25	4.11	.22	4.25	.20	4.24	.22	4.02	.23	4.34	.22
y displacement	3.78	.21	3.70	.18	3.66	.21	3.86	.21	3.74	.20	3.85	.21
Velocity *x*	5.87	.47	5.57	.38	6.10	.36	6.17	.43	6.04	.42	6.41	.45
Velocity *y*	5.43	.44	5.21	.34	5.20	.31	5.75	.38	5.58	.36	5.77	.42
S2												
x displacement	.55	.28	.66	.31	.44	.36	.53	.24	.73	.34	.86	.34
y displacement	−12.57	.52	−12.20	.55	−12.33	.55	−12.63	.56	−12.49	.54	−12.56	.55
Velocity *x*	.72	.35	.93	.38	.76	.47	.88	.31	1.08	.40	1.30	.43
Velocity *y*	−15.12	.73	−14.27	.64	−15.07	.71	−15.43	.74	−14.84	.70	−15.78	.75
S3												
x displacement	−15.38	.53	−15.37	.56	−15.53	.58	−15.58	.55	−15.42	.57	−15.69	.50
y displacement	−.62	.34	−.60	.32	−.57	.29	−.46	.33	−.45	.33	−.52	.35
Velocity *x*	−9.24	.31	−9.19	.33	−9.37	.35	−9.39	.33	−9.32	.34	−9.46	.29
Velocity *y*	−.41	.21	−.39	.20	−.37	.18	−.30	.19	−.31	.21	−.34	.21

Note. *x* = AP direction; *y* = ML direction; displacement = cm; velocity = cm/s; HA-U = high arousal unpleasant; LA-U = low arousal unpleasant; HA-*p* = high arousal pleasant; LA-*p* = low arousal pleasant.

conditions speed withdrawal-related movements (Chen & Bargh, 1999; Duckworth et al., 2002). However, recent evidence has also emerged suggesting that threatening cues prime the motor system for action and expedite a motor response for nondirectional movements (Coombes et al., 2005, 2007a, 2007b, 2009). Our reaction time results support and extend the latter hypothesis. A 10% reduction in reaction time was observed after exposure to the highly arousing unpleasant pictures relative to the neutral pictures. Thus, exposure to the unpleasant highly arousing pictures speeded the initiation of the motor response on the GI task relative to all other affective pictures, even though the ensuing movement was approach-oriented. The current project is the first known attempt to examine how unpleasant and pleasant emotional stimuli influence a movement that places the whole body in closer proximity to the previously presented affective stimuli. Exposure to the threatening/aversive stimuli is known to activate the defensive response system (Gray, 1990; Öhman & Soares, 1998). Therefore, the speeded RT in response to attack pictures may have reflected the rapid initiation of an overt "fight or flight" response (Crenna & Frigo, 1991; Hillman et al., 2004). Qualifying and extending the motivational direction hypothesis, our RT results indicate that faster movements, regardless of direction, are primed in threatening situations.

We also anticipated that pleasant emotional states would facilitate the movement of the COP trajectory during GI. Our COP data supported this hypothesis and corroborate previous evidence that pleasant emotional cues facilitate approach-related movements (Chen & Bargh, 1999; Duckworth et al., 2002). As predicted, exposure to high and low arousing pleasant pictures relative to the unpleasant pictures led to greater displacement and velocity of the posterior and lateral movements during the S1 period. During the S1 period, the posterior displacement of the COP propels the COM forward, producing the forward momentum needed to initiate gait (Polcyn, Lipsitz, Kerrigan, & Collins, 1998). Exposure to pleasant pictures increased this posterior displacement and the speed of this backward shift, thus facilitating GI, compared to the unpleasant pictures. Another important aspect of the S1 period is the generation of stance side momentum, in which forces shift the COP laterally toward the swing limb (Polcyn et al., 1998) to propel the COM toward the stance limb and preserve lateral stability. Exposure to the low arousing pleasant pictures increased the velocity of this lateral COP movement, likely facilitating the

Table 4
Summary Step Execution Data for the First and Second Step of GI for Each Picture Category

Valence	HA-U		LA-U		HA-P		LA-P		Neutral		Catch	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Step 1												
Length (cm)	56.83	1.42	56.55	1.30	57.42	1.31	56.35	1.25	56.55	1.30	56.53	1.35
Velocity (cm/s)	61.25	2.25	60.60	2.06	62.63	1.97	63.14	2.18	61.68	2.24	63.70	2.07
Step 2												
Length (cm)	59.61	1.16	60.49	1.00	60.40	1.14	60.17	.95	59.24	1.06	59.82	1.02
Velocity (cm/s)	95.11	2.35	96.35	2.19	96.57	2.48	96.14	2.14	94.61	2.18	95.18	2.73

Note. HA-U = high arousal unpleasant; LA-U = low arousal unpleasant; HA-*p* = high arousal pleasant; LA-*p* = low arousal pleasant.

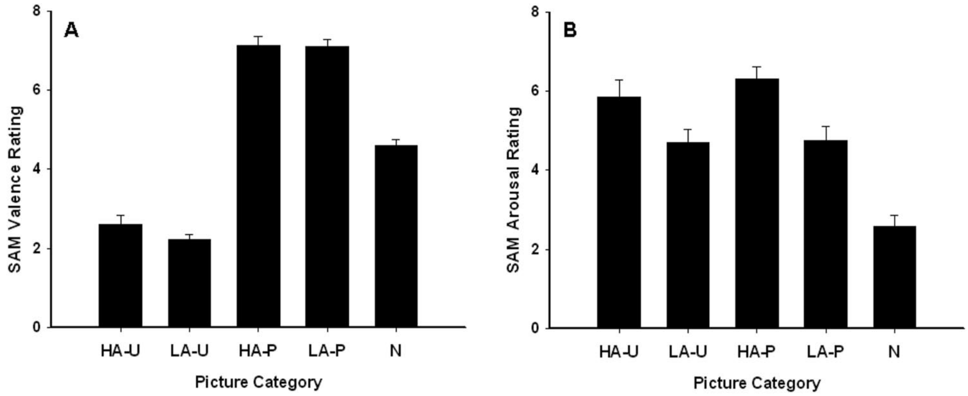

Figure 4. (A) Mean and *SE* SAM valence ratings for each picture category. The higher a participant's rating, the more the participant perceived the picture as being pleasant. (B) Mean and *SE* SAM arousal ratings for each picture category. The higher a participant's rating, the more arousing the participant perceived the picture. The SAM scale for valence and arousal is 1–9. HA-U = high arousal unpleasant; LA-U = low arousal unpleasant; HA-P = high arousal pleasant; LA-P = low arousal pleasant.

momentum of the center of mass toward the stance limb. Collectively, therefore, the data showed that exposure to the pleasant stimuli facilitated the dynamic postural adjustments during the S1 period of GI. Although COP data alone do not allow for *direct* inferences to be made regarding the relation between the COP and COM, substantial evidence supports the interaction of the COP and COM movement during the anticipatory phase of GI (Breniere et al., 1987; Hass et al., 2005; Martin et al., 2002). As such, strong inference can be made from the COP data regarding the influence of emotion on dynamic postural control.

Concerning the preparatory phase of GI, our data suggest that exposure to emotional stimuli has the strongest impact on the anticipatory postural adjustment period (S1), compared to the weight shift (S2) and locomotor periods (S3). This finding is in line with evidence showing that the anticipatory postural adjustments are controlled by brain areas (e.g., SMA, premotor cortex, basal ganglia: Massion, 1992; Rocchi et al., 2006; Yazawa et al., 1997) with known connections to limbic structures (Takakusaki, Tomita, & Yano, 2008), whereas stepping is regulated primarily by brain stem and spinal processes and thus less likely to be influenced by emotion. Additionally, prior work has shown that other factors, such as age and pathology (e.g., Parkinson's disease: Burleigh-Jacobs, Horak, Nutt, & Obeso, 1997; Crenna et al., 1990; Halliday et al., 1998), have greater impact on the anticipatory postural adjustments relative to the other components of the COP trajectory during GI.

The third aim of the study was to investigate how emotional state altered execution of the first and second steps of GI. As hypothesized, exposure to the pleasant conditions increased the velocity of the first step, compared to the unpleasant conditions. This finding supports the motivational direction hypothesis and further validates the notion that pleasant emotions prime approach behaviors (Cacioppo et al., 1993; Chen & Bargh, 1999; Duckworth et al., 2002) using a clearly approach-oriented whole body movement. As evidenced by smaller percent change values, emotion's influence was more pronounced in participants' RTs and COP movements relative to the execution of the first step. Further, emotion did not influence the velocity or length of the second step. This result is in apparent contrast to prior work showing an effect of mood (sad vs. happy) on gait velocity (Michalak et al., 2009). Importantly, the impact of emotion on lower body kinematics may depend on the component of gait being evaluated (i.e., initiation vs. ongoing regulation).

Two potential explanations may account for the reduced effect of emotion on the step execution component of GI relative to reaction time and COP movement. First, the effects of emotion may have "washed through" the motor system as the movement progressed. However, previous physiological evidence has shown that whereas affective modulation is typically greatest immediately after picture offset, increased defensive and appetitive activation endures long after the offset of the affective stimuli (Larson, Nitschke, & Davidson, 2007; Smith, Bradley, & Lang, 2005). While acknowledging this diminishing effect of emotion over time as a potential explanation, we argue that it is highly unlikely, given that execution of the first and second steps occurred within 1–3 s following picture offset. A second possible explanation is that the instructions given to participants caused them to focus more on the planning of the movement (i.e., initiation phase of the GI process), rather than the locomotor task (i.e., step execution phase). Participants were instructed to "begin walking immediately after offset of the picture and walk at your normal pace." If directions had focused more on the step execution process and instructed participants to walk as quickly as possible after picture offset, perhaps emotion would have exerted a greater influence on step execution.

Generally, both the high and low arousing pleasant pictures facilitated COP movement during GI, suggesting that the pleasant valence of the picture was more important than its intensity in driving this approach-oriented movement. However, the COP movement and step execution data after the two unpleasant categories were not consistently altered in the same manner. Exposure to the low arousing unpleasant pictures most often resulted in a slight decrease in the velocity and displacement in movement relative to the neutral pictures. However, this pattern was not strictly adhered to after the highly arousing unpleasant pictures. Specifically, exposure to the highly arousing unpleasant pictures, compared to the neutral pictures, resulted in a slight increase in the

AP displacement of the COP movement during S1. Additionally, COP differences were most often found between the pleasant conditions and the low arousing unpleasant condition, compared to the pleasant conditions and the high arousing unpleasant condition.

We propose two explanations to account for the COP findings after exposure to the highly arousing unpleasant pictures in particular. First, it is possible that the speeded reaction times after exposure to the highly arousing unpleasant pictures had a carry-over effect on the COP movement. Accordingly, the momentum produced from the accelerated initiation of the motor response could have enhanced the distance and velocity of the COP movement. Second, highly aversive threatening stimuli elicit activation of the "fight or flight" response. Thus, an imposing threat has the potential to invoke conflicting motivations in humans: Do I flee (withdrawal motivation) or do I engage and fight (approach motivation)? In short, the threatening pictures may not have unitarily evoked a withdrawal response. Indeed, previous research has shown that not all aversive stimuli facilitate avoidance-related behavior (e.g., anger: Harmon-Jones & Allen, 1998; Harmon-Jones et al., 2009). Future work could examine the effect of more specific unpleasant emotion categories (e.g., anger, threat, and sadness) on GI as an approach-, as well as withdrawal-oriented, behavior.

Previous research has indicated that females react to highly arousing unpleasant stimuli with greater activation of the defensive system, compared to males (Bradley, Codispoti, Sabatinelli, & Lang, 2001; Hillman et al., 2004). However, our preliminary analyses showed that no significant differences existed between males' and females' movement in response to any of the picture categories. Moreover, we discovered specific effects of emotion on gait even after the affective stimuli were no longer visible. Future research could explore the temporal dynamics of emotion's effect on forward gait initiation by varying the interval at which participants begin walking during and following picture onset. These efforts would allow a more precise specification of how emotion modulates GI and step execution.

Our findings show that the highly arousing unpleasant conditions accelerated the initiation of a motor response, but as the direction of the movement emerged, the pleasant conditions, relative to the unpleasant, clearly facilitated the initiation of gait. A growing corpus of literature suggests that individuals with depression/apathy experience blunted physiological and motor responses to pleasant stimuli (Naugle, Coombes, & Janelle, 2010; Kaviani et al., 2004; Larson et al., 2007). Future research should investigate whether pleasant stimuli facilitate GI (given that it is a behavioral marker) in these populations despite other indices of affective blunting. Perhaps, this apparent emotion-movement relationship evidenced on our gait task in healthy controls would be absent in the depressed and apathetic.

Finally, we encourage future research efforts to investigate the impact of emotion on voluntary GI in populations with abnormal gait. For example, individuals with (PD) frequently experience postural instability and difficulty initiation gait (Halliday et al., 1998; Hass et al., 2004, 2005). The GI parameters in persons with PD are characterized by increased movement preparation time, decreased velocity and magnitude of COP displacement, and reduced step length and velocity relative to healthy individuals. These gait problems are often highly disabling and pharmacologically unresponsive (Frank, Horak, & Nutt, 2000; Horak, Frank, & Nutt, 1996). Manipulating emotional state may be an effective way to significantly enhance these GI parameters in PD that is additive to the standard pharmacological interventions.

In conclusion, our findings provide further specification of how emotional state predictably modulates motor action. Emotional reactivity robustly manifested in the parameters that regulate whole body movements. Considering implications for ameliorating the comorbid affective and motor sequelae of numerous clinical health problems, future researchers are strongly encouraged to integrate these behavioral findings when considering the genetic, biological, and neurological mechanisms that drive such alterations in overt motor actions.

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