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Emotional influences on locomotor behavior

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Emotional responses to appetitive and aversive stimuli motivate approach and avoidance behaviors essential for survival. The purpose of the current study was to determine the impact of specific emotional stimuli on forward, approach-oriented locomotion. Steady state walking was assessed while participants walked toward pictures varying in emotional content (erotic, happy people, attack, mutilation, contamination, and neutral). Step length and step velocity were calculated for the first two steps following picture onset. Exposure to the mutilation and contamination pictures shortened the lengths of step one and step two compared to the erotic pictures. Additionally, step velocity was greater during exposure to the erotic pictures compared to (1) the contamination and mutilation pictures for step one and (2) all other picture categories for step two. These findings suggest that locomotion is facilitated when walking toward approach-oriented emotional stimuli but compromised when walking toward aversive emotional stimuli. The data extend our understanding of fundamental interactions among motivational orientations, emotional reactions, and resultant actions. Theoretical and practical implications are discussed.

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1. Introduction

Human behavior is fundamentally motivated by the propensity to approach appetitive stimuli while avoiding aversive stimuli and situations. Emotional responses to these stimuli serve as action dispositions, directing approach and avoidance behaviors (Carver et al., 2000; Frijda, 2009; Lang et al., 1998). Pleasant emotions theoretically activate appetitive circuits that prime approach behaviors whereas unpleasant emotions activate defensive circuits that facilitate avoidance behaviors (Cacioppo et al., 1993; Centerbar and Clore, 2006; Chen and Bargh, 1999). How interactions of approach and avoidance oriented emotions and behavioral outcome manifest in overt movement alterations, however, remains largely unspecified.

Attempts to address such theoretical notions have been limited by empirical investigations using a small range of upper extremity movements (e.g., flexion vs. extension) that do not clearly represent directional behaviors (Eder and Rothermund, 2008; Lavender and Hommel, 2007). Furthermore, such findings have been exclusively based on simple reaction time measures that fail to capture the complexity of human motor function. In contrast to the upper extremity tasks that have been implemented to date, whole body movements can be manipulated to yield clear approach and avoidance actions, thereby permitting direct evaluation of theoretical postulates. Herein, we sought to determine how an unambiguous approach oriented whole body movement, specifically forward locomotion, was altered under different emotional conditions that theoretically motivate directionally opposite action tendencies. This unique approach permitted us to explicitly evaluate fundamental interactions of motivational orientations, emotional state, and resultant actions.

Naugle et al. (in review) recently investigated the influence of emotional state on forward gait *initiation*. Participants initiated gait in response to the offset of pleasant and unpleasant valenced emotional stimuli and continued to walk toward the location of the presented stimuli. Exposure to the pleasantly valenced stimuli compared to unpleasant stimuli facilitated the anticipatory postural adjustments needed to initiate forward gait and increased the velocity of the first step. However, exposure to highly arousing unpleasantly valenced (attack) stimuli speeded the initial motor response, despite the movement being clearly approach-oriented. This finding supports the notion that faster movements, regardless of movement direction, are primed in threatening situations. (Coombes et al., 2007b, 2009). The result also clearly illustrates how sole reliance on reaction time measures, as in prior work, may produce misleading conclusions (i.e., unpleasant cues facilitate approach behaviors). While Naugle et al.'s work addressed the question of how emotional conditions affect the *planning* of the initiation of forward gait, whether emotion impacts the *regulation* of ongoing gait remains unknown.

A controversial issue in the emotion and movement literature involves the congruence of unpleasant stimuli with withdrawal motivation. Much of the extant data has been confounded by the

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errant assumption that approach and withdrawal responses are driven solely by emotional valence. The evidence against this assumptions is clearly exemplified in several lines of research showing that anger, although negative in valence, elicits approach motivational tendencies (see Carver and Harmon-Jones, 2009 for review). Additionally, confusion exists regarding the categorization of certain emotions, such as fear. Although fear is generally associated with a withdrawal response, it can also elicit approach to safe places or an approach-related "fight" response to threatening stimuli (Blanchard and Blanchard, 1994). As such, categorization of affective stimuli into emotion-specific categories, (i.e., attack, mutilation, and contamination) rather than broad valenced categories (pleasant, unpleasant), is essential for a comprehensive understanding of how emotion influences approach/avoidance movement.

The purpose of the current study was to determine how exposure to specific emotional stimuli impacts the regulation of steady state forward, approach-oriented locomotion. To achieve this aim, locomotor parameters associated with steady state walking were assessed while participants walked toward pictures varying in emotional content. We hypothesized that exposure to the approach-oriented pictures of erotica and happy people would facilitate forward locomotion as evidenced by enhanced step length and velocity compared to the contamination, mutilation, and attack pictures. We also predicted that exposure to contamination and mutilation pictures (the unpleasant pictures likely invoking the strongest withdrawal motivation) would compromise forward locomotion as indexed by reduced step length and velocity relative to images of erotica and happy people.

2. Methods

2.1. Participants

Thirty-four undergraduate students (17 males, *M* age=20.35, *SD*=1.17; 17 females, *M* age=20.12, *SD*=1.05) participated in this study. All participants reported no lower extremity injuries in the past six months that would affect movement and reported moderate to low levels of trait anxiety [State Trait Anxiety Inventory (STAI: Spielberger, 1983): males=33.18, *SD*=7.80; females=29.65, *SD*=4.77]. Three participants who were behavioral outliers (i.e., 3 SD from the mean for each picture category) were removed from the step length analysis, and two were removed from the step velocity analysis.

2.2. Emotion manipulation

Picture viewing was used to induce emotional states during the experimental trials. Presented stimuli included 30 digitized photographs selected from the International Affective Picture System (IAPS: Lang et al., 2005) representing six affective categories: (1) erotica, (2) happy people, (3) attack, (4) mutilation, (5) contamination, and (6) neutral. All pictures were chosen according to affective norms (NIMH, CSEA, 2005). We also included five catch trials, in which no picture was presented. Pictures were projected onto a 3.3 m × 2 m screen using NEC VT 670 digital projector. The screen was located 8 m in front of participants. Pictures were 127 cm × 91 cm and1024 × 768 pixels. Stimulus presentation and order were randomized and counterbalanced across participants. A custom LabVIEW program (LabVIEW 8.1; National Instruments, Austin, TX) controlled trial onset, offset, and visual stimulus presentation.

2.3. Instrumentation and task

Upon arrival to the Applied Neuromechanics Laboratory, volunteers completed an informed consent form approved by the University of Florida's Institutional Review Board. Participants were then fitted with the retro-reflective markers, familiarized with the protocol, and completed four practice trials using unique neutral images. Ground reaction forces (GRF) were collected at 1200 Hz using three force plates (Bertec, Newton, MA; size $60 \times 40\ cm^2$). The kinematic characteristics of the locomotor tasks were sampled at a rate of 120 Hz using a fourteen-camera Optical Motion Capture system (Vicon Peak, Oxford, UK).

Retro-reflective markers were placed on the lower body bilaterally on the anterior superior iliac spine (ASIS), posterior superior iliac spine, lateral epicondyle of the knee, lower lateral 1/3 surface of the thigh, lateral malleolus, tibia, second metatarsal head, and calcaneus. Participants then stood bare-footed in a comfortable stance at a designated location approximately 2.5 m behind the force platforms. Participants were informed that each trial would begin with the presentation of a fixation cross on the video screen (3 s duration), which would be replaced by an image (4 s duration) while they were walking. At the onset of the fixation cross, participants were instructed to begin walking at a self-selected pace. Starting position was selected so that picture onset occurred just prior to heel contact on the first force plate. Participants were instructed to look at the image on the screen for the duration of the trial. Following completion of the locomotor trials, participants completed the computerized 9-point version of the self-assessment manikin (SAM: Lang, 1980) to provide an arousal and valence rating (scale: 1–9) for each picture previously viewed.

2.4. Data reduction

Dependent measures included step length, stride length, and the average and instantaneous step velocity of the first two steps following picture onset. Length of the first step was calculated as the displacement (m) of the heel position at first heel strike following picture onset to the heel position of the swing leg at heel strike. Step length of the second step was calculated as the displacement (m) from the heel position of the initial swing leg at first heel strike to the heel position of the initial stance leg at heel strike. Stride length was calculated as the sum of the length of steps 1 and 2. An average and instantaneous velocity was calculated from the ASIS marker for each step. The average step velocity was calculated as the change in position for each step divided by the corresponding change in time (m/s). The instantaneous step velocity at heel strike of the swing leg for each step was calculated using the central difference method.

A single index was created for each dependent variable, representing the change in movement due to each affective category relative to the neutral category (calculated as affective category—neutral category, per Fox, 2002). A positive score indicates greater values during an emotional category relative to the neutral category, while a negative score indicates reduced values for the dependent variable during the emotional category relative to the neutral category. The bias scores served as the bases for all statistical analyses involving movement outcomes.

2.5. Statistical analysis

Preliminary analyses indicated that gender did not have a significant effect on any dependent variable, thus gender was not included as a factor on any consequential statistical analyses. Bias scores for step and stride length, average step velocity, and instantaneous step velocity were analyzed with separate repeated measures 1-way MANOVAs with five levels of picture category. For each MANOVA, separate analyses of variances (ANOVAs) were performed for follow-up testing when appropriate. We also conducted one-way ANOVAs on the SAM valence and arousal ratings. Follow-up analyses were conducted using Tukey's HSD procedure. For all analyses, the probability value was set at $p<.05$.

3. Results

All three MANOVAs detected significant effects of picture category [(1) step length bias score: *Wilks' Lambda*=.773, $F(12,\ 312.49)=2.66$, $p=.002$, $\eta^2=.082$; (2) average step velocity bias score: *Wilks' Lambda*=.841, $F(8,\ 246)=2.77$, $p=.006$, $\eta^2=.083$; and (3) instantaneous step velocity bias score: *Wilks' Lambda*=.764, $F(8,\ 246)=4.43$, $p<.001$, $\eta^2=.126$]. Table 1 presents summary data for the first and second step for each picture category.

3.1. Step length bias scores

The respective follow-up ANOVAs were significant for the length of step 1 ($p=.047$), length of step 2 ($p=.001$), and stride length ($p=.003$). Exposure to erotic pictures led to significantly greater length of the first step following picture onset compared to contamination ($p=.016$), mutilation ($p=.026$), and happy people pictures ($p=.022$; see Fig. 1a). For the second step following picture onset, exposure to contamination and mutilation pictures resulted in reduced step length compared to erotic ($p=.001$ and 032, respectively) and happy people pictures ($p=.001$ and .031, respectively; see Fig. 1b). Additionally, the length of the second step was reduced during exposure to contamination pictures relative to attack pictures ($p=.015$). Similarly, stride length following picture onset was (1) reduced

Table 1
Summary step execution data for the first and second step following picture onset for each picture category.

Valence	Attack		Mutilation		Contamination		Erotica		Happy people		Neutral	
	M	SE	M	SE	M	SE	M	SE	M	SE	M	SE
Step 1												
Length (m)	.617	.009	.611	.010	.615	.009	.620	.009	.615	.009	.618	.010
Ave. velocity (m/s)	1.088	.022	1.086	.023	1.078	.023	1.094	.022	1.087	.022	1.089	.023
Inst. velocity (m/s)	1.262	.025	1.250	.027	1.249	.028	1.269	.026	1.254	.026	1.261	.027
Step 2												
Length (m)	.609	.009	.606	.009	.605	.008	.613	.009	.616	.009	.615	.009
Ave. velocity (m/s)	1.125	.025	1.125	.023	1.116	.023	1.137	.023	1.122	.023	1.129	.025
Inst. velocity (m/s)	1.262	.022	1.258	.023	1.248	.022	1.282	.024	1.272	.023	1.276	.024

Note: Ave.—Average; Inst.—Instantaneous.

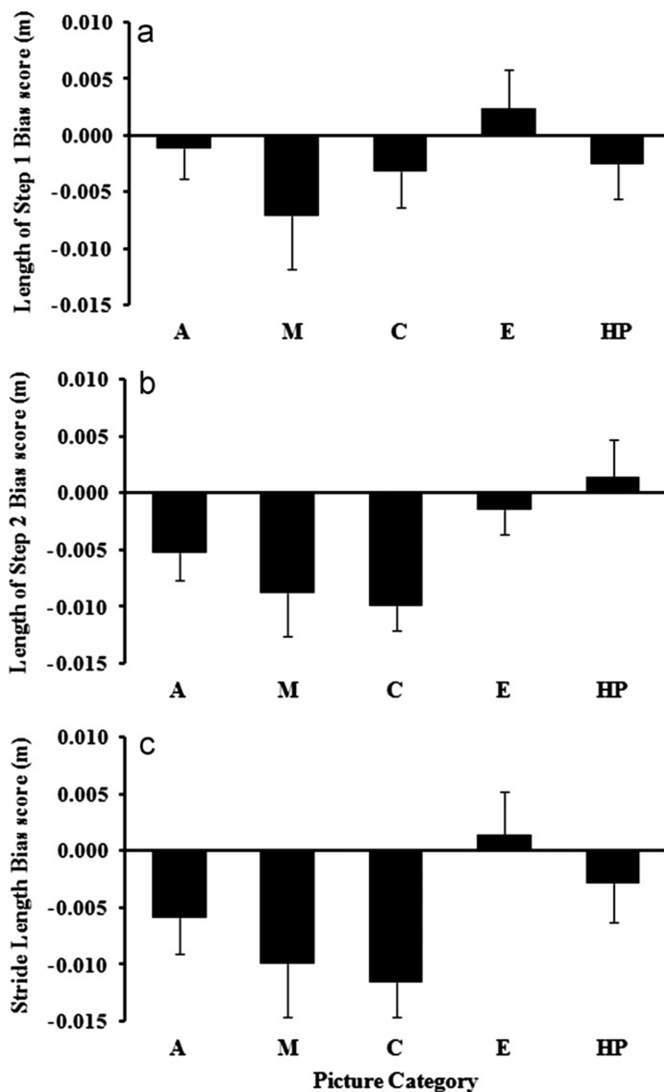

Fig. 1. Mean (and standard error) bias scores across the picture categories for (a) length of the first step following picture onset, (b) length of the second step following picture onset and (c) stride length following picture onset. A=attack; M=mutilation; C=contamination; E=erotica; HP=happy people.

during exposure to contamination compared to erotic (p=.001), happy people (p=.009), and attack pictures (p=.039), and (2) greater during exposure to erotic pictures compared to attack (p=.038), mutilation (p=.010), and contamination pictures (p=.001; see Fig. 1c).

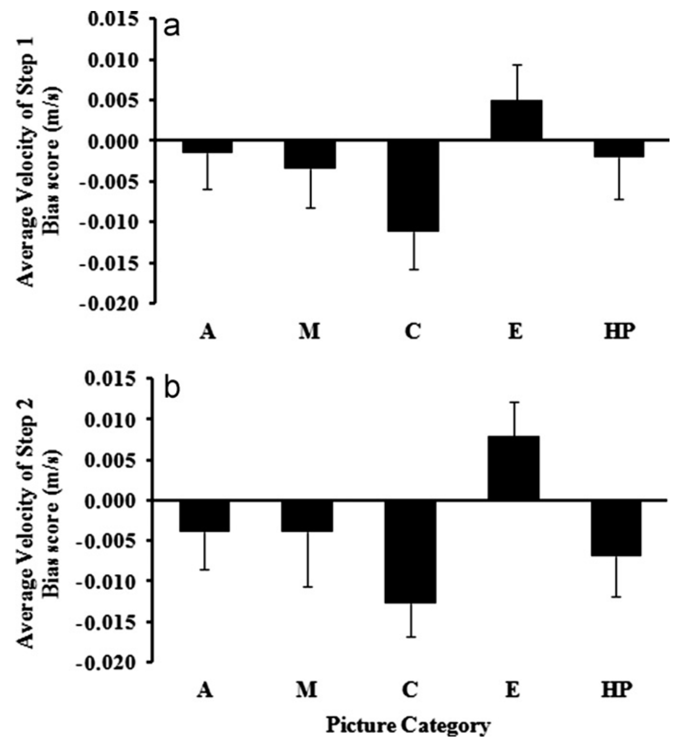

Fig. 2. Mean (and standard error) bias scores across the picture categories for (a) the average velocity of the first step following picture onset and (b) average velocity of the second step following picture onset. A=attack; M=mutilation; C=contamination; E=erotica; HP=happy people.

3.2. *Step velocity bias scores*

Average: The average step velocity bias scores significantly differed between picture categories for step 1 (p=.017) and step 2 (p=.004) following picture onset. Exposure to the erotic pictures lead to significantly enhanced step velocity: (1) compared to the mutilation (p=.032) and contamination (p=.001) pictures for the first step (see Fig. 2a) and (2) compared to all other picture categories for the second step (attack, p=.019; contamination, $p<.001$; mutilation, p=.049; happy people, p=.005; see Fig. 2b).

Instantaneous: The instantaneous velocity bias scores of step 1 (p=.005) and step 2 ($p<.001$) following picture onset also significantly differed between the affective picture categories. Complementing the average velocity results, the instantaneous velocity at heel strike of the swing leg for the first step was greater during exposure to erotica compared to the contamination (p=.005), mutilation (p=.010), and happy people pictures (p=.014; see Fig. 3a). Additionally, the instantaneous velocity

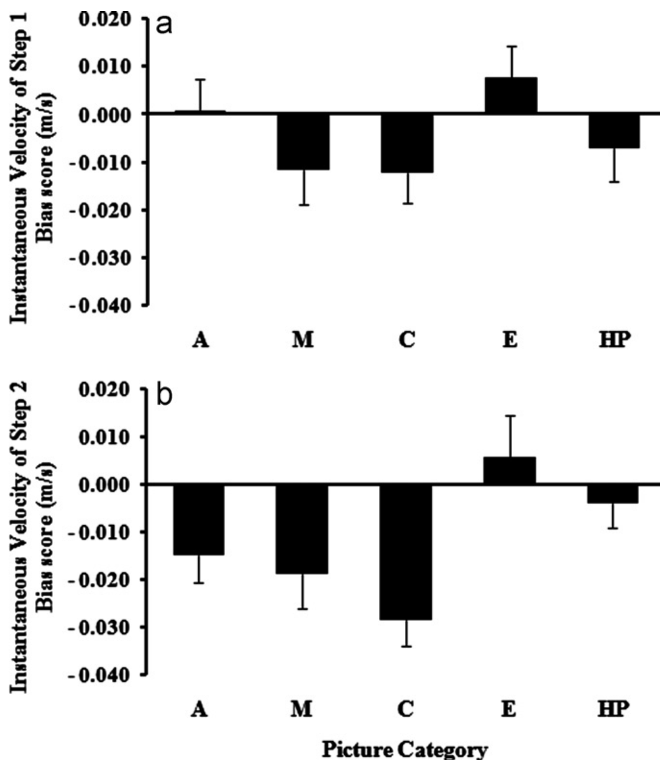

Fig. 3. Mean (and standard error) bias scores across the picture categories for (a) the instantaneous velocity of the first step following picture onset and (b) instantaneous velocity of the second step following picture onset. A=attack; M=mutilation; C=contamination; E=erotica; HP=happy people.

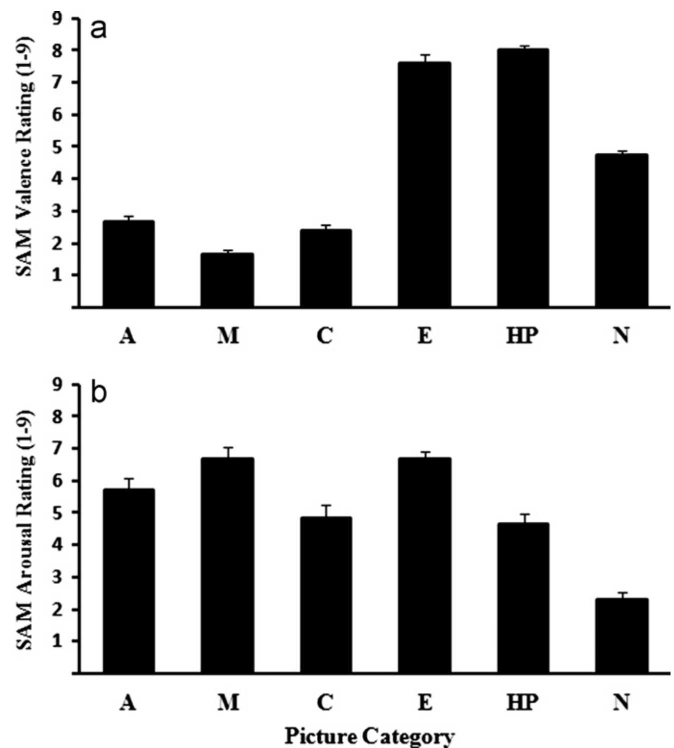

Fig. 4. Mean (and standard error) SAM valence ratings for each picture category (a). The higher a participant's rating, the more the participant perceived the picture as being pleasant. Mean (and standard error) SAM arousal ratings for each picture category (b). The higher a participant's rating, the more arousing the participant perceived the picture. A=attack; M=mutilation; C=contamination; E=erotica; HP=happy people; N=neutral.

for step 2 was reduced (1) during exposure to contamination pictures relative to erotic ($p < .001$), happy people ($p < .001$), and attack pictures ($p = .010$) and (2) during exposure to mutilation compared to erotica pictures ($p = .012$; see Fig. 3b).

3.3. SAM ratings

The picture categories significantly differed according to valence ($p < .001$) and arousal ($p < .001$) ratings on the SAM. As expected, participants rated erotica and happy people pictures as the most pleasant, followed by neutral pictures. Mutilation pictures were rated significantly more unpleasant than all other categories (see Fig. 4a). Erotica and mutilation categories were rated significantly more arousing than all other categories. Attack pictures were rated more arousing than happy people and neutral pictures. Contamination and happy people pictures were rated more arousing than neutral pictures (see Fig. 4b).

4. Discussion

The goal of the current study was to determine how exposure to specific emotional stimuli affects forward locomotion. The implementation of a protocol involving voluntary, whole body movements allows direct evaluation of the influence of emotional reactivity on approach-oriented behavior. Two principle findings emerged from the data. First, viewing intensely pleasant pictures thought to elicit approach orientations enhanced step velocity during forward walking. Second, viewing unpleasant pictures theorized to elicit avoidance behavioral orientations led to shortened step lengths and slower step velocities when walking toward such aversive stimuli.

Affective scientists postulate that pleasant emotions motivate behavioral responses to approach pleasant stimuli and situations (Frijda, 2009; Frijda et al., 1989; Lang, 1995). In line with this prediction, exposure to the erotica pictures facilitated forward locomotion. The greatest step lengths and velocities for the first and second steps following picture onset were displayed during exposure to erotica pictures. These data corroborate previous work showing that pleasant emotional conditions facilitate gait initiation (Naugle et al., in review) as well as upper extremity approach-oriented movements (Eder and Rothermund, 2008; Lavender and Hommel, 2007). Contrary to our prediction, exposure to happy people pictures (babies, children, and happy couples) did not facilitate locomotion. Indeed, these stimuli, although rated as pleasant as erotica stimuli, appeared to only have a small effect compared to neutral stimuli. Couples engaging in erotic acts may induce a stronger approach motivation than pictures of babies, children, and happy couples in this population. Additionally, happy people pictures were rated less arousing than erotica pictures and thus may not have been sufficiently arousing to affect motivated behavior. These findings corroborate previous work showing that high activation emotions (anger and joy) induced through recalling emotional experiences resulted in greater gait velocity, while low-activation emotions (i.e., content) had no impact on gait velocity (Gross et al., 2007).

Our second hypothesis was based on the notion that approach movements are inhibited when executing such movements after experiencing aversive stimuli (Chen and Bargh, 1999; Markman and Brendl, 2005). Exposure to contamination and mutilation pictures inhibited forward locomotion when approaching these stimuli. Encountering stimuli that are known to motivate disgust emotional responses shortened step lengths and slowed step velocity during steady state walking. Additionally, as particularly evidenced by the instantaneous velocity data, the magnitude of the withdrawal effect on movement appeared to strengthen as individuals moved closer to the stimuli (contamination) that are known to elicit a disgust response.

Exposure to the attack pictures generally lead to reduced step length and velocity relative to the pleasant categories; however, the magnitude of this effect was consistently smaller compared to the mutilation and contamination categories, and often non-significant. Pictures of contaminated food and toilets and mutilated bodies likely evoke a more pure withdrawal response than attack pictures. Attack pictures have the potential to motivate a ''flight'' withdrawal-related response, as well as a ''fight'' approach-related response to threatening stimuli (Bradley et al., 2001). Thus, locomotion appears to be more reactive to unpleasant stimuli that motivate an unambiguous and more intense withdrawal response. Moreover, as evidence by the instantaneous velocity data, the withdrawal response appears to be enhanced by the proximity of the aversive stimuli.

Evidence from this investigation could hold important implications for the treatment of hypokinetic gait disorders (e.g., reduced stride length and velocity). Steady state walking is widely accepted to be largely regulated by subcortical structures such as the basal ganglia, cerebellum, brainstem, and spinal cord (Takakusaki et al., 2004). Hypokinetic gait deficits, present in disorders of the basal ganglia (e.g., Parkinson's disease), are thought to be caused by excessive inhibitory output from the basal ganglia to the thalamo-cortical system and brainstem, leading to reduced activation of locomotor centers (Takakusaki et al., 2003). Animal work suggests that limbic and motor circuits may be integrated via a striato-nigro-striatal network or cortico-cortical pathways (Haber and Calzavara, 2009). It is plausible that activation of affective circuits could bypass impaired basal ganglia systems and provide an alternative route to ''energize'' locomotor centers and drive the CPGs. The addition of emotion manipulations to therapeutic gait training may provide a valuable adjunct to the traditional pharmacological treatment. From a clinical standpoint, while the acute effects noted here are small (albeit significant and reliable), the cumulative (or chronic) effects of these movement alterations could lead to more clinically significant and observable overt behavioral changes over time.

In conclusion, our results support the view that emotions prime action tendencies to yield efficient behavioral responses based on the unique environmental factors that trigger specific emotional responses. Our findings also support prior work showing that the categorization of affective stimuli into emotion-specific rather than broad valenced categories is necessary for a comprehensive understanding of emotion modulated movement (Coombes et al., 2007a). Indeed, picture categories rated similar in valence (i.e., erotic vs. happy people; attack vs. contamination) did not exert similar impacts on the regulation of forward locomotion. In addition, our data may hold important therapeutic implications for those suffering from gait and emotional disorders. Continued work in this area will permit more comprehensive understanding of how emotions affect movement, thereby leading to practical recommendations to optimize human performance.

Conflict of interest statement

The authors of this manuscript do not have any financial or personal relationships with other people or organizations that could inappropriately influence their work.

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