Gait & Posture 41 (2015) 159–163

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Biomechanical organization of gait initiation depends on the timing of affective processing

John F. Stins *, Linda M.A. van Gelder, Laura M. Oudenhoven, Peter J. Beek

MOVE Research Institute Amsterdam, Faculty of Human Movement Sciences, VU University Amsterdam, The Netherlands

ARTICLE INFO

Article history:
Received 21 September 2013
Received in revised form 16 September 2014
Accepted 24 September 2014

Keywords:
Gait initiation
Emotion
Center-of-pressure
Balance

ABSTRACT

Gait initiation (GI) from a quiet bipedal posture has been shown to be influenced by the emotional state of the actor. The literature suggests that the biomechanical organization of forward GI is facilitated when pleasant pictures are shown, as compared to unpleasant pictures. However, there are inconsistencies in the literature, which could be due to the neural dynamics of affective processing. This study aimed to test this hypothesis, using a paradigm whereby participants initiated a step as soon as they saw an affective picture (i.e., onset), or as soon as the picture disappeared from the screen (i.e., offset). Pictures were a priori categorized as pleasant or unpleasant, and could also vary in their arousing properties. We analyzed center-of-pressure and center-of-gravity dynamics as a function of emotional content. We found that gait was initiated faster with pleasant images at onset, and faster with unpleasant images at offset. Also, with offset GI the peak velocity of the COG was reduced, and subjects took smaller steps, with unpleasant images relative to pleasant images. The results are discussed in terms of current knowledge regarding temporal processing of emotions, and its effects on GI.

© 2014 Elsevier B.V. All rights reserved.

1. Introduction

Gait initiation (GI) from a quiet bipedal posture entails destabilizing postural equilibrium and propelling the body center of gravity (COG) forward. This highly coordinated activity involves lifting the swing leg (resulting in a rapid lateral weight shift), swinging the leg forward, and using the stance leg to create sufficient forward momentum. Analysis of COG and center-of-pressure (COP) dynamics has been employed to quantify key biomechanical parameters that constrain the step [1].

Recent studies investigated whether the control of GI is influenced by emotion. Posturographic studies have revealed that potent emotional triggers may activate innate behavioral tendencies, such as freeze, fight, or flight responses [2–4]. These responses may play into the neural control of balance, where they become visible as automatic postural adjustments. Recent studies [5–7] found that it took longer to initiate a forward step toward an unpleasant picture than toward a pleasant one, suggesting that it took longer to override the automatic avoidance tendency with unpleasant pictures. These results support the 'motivational direction hypothesis', which states that pleasant/desirable items trigger approach behavior, whereas unpleasant items prime avoidance behavior (see also [8]). Evidence for this hypothesis has been found in manual choice reaction time studies (e.g. [9]). Another study [10], however, found that highly arousing unpleasant pictures speeded up reaction time. They also found effects of emotional valence and arousal on other biomechanical features of the step, such as the anticipatory postural adjustments (APA) and step velocity. Findings were explained in terms of the arousing properties of unpleasant items.

It is unclear why some studies [5–7] found facilitation of forward steps toward pleasant pictures (compared to unpleasant items), whereas another study [10] found facilitation for unpleasant pictures. Reading of the literature reveals a subtle, but potentially crucial methodological difference: In earlier studies [5–7] participants had to initiate a step as soon as they saw and mentally classified the picture. In the divergent study [10] participants had to watch the picture for its entire duration (2–4 s), and initiate a step as soon as the picture disappeared, i.e., at stimulus offset. This could prove to be a key factor, since neural processing of affective proceeds via a highly stereotypical sequence of information processing 'stages', during which the stimulus is evaluated and endowed with meaning. The time course

* Corresponding author at: MOVE Research Institute Amsterdam, Faculty of Human Movement Sciences, VU University Amsterdam, van der Boechorststraat 9, 1081 BT, Amsterdam, The Netherlands. Tel.: +31 (0)20 5988543.
E-mail address: j.stins@fbw.vu.nl (J.F. Stins).

http://dx.doi.org/10.1016/j.gaitpost.2014.09.020
0966-6362/© 2014 Elsevier B.V. All rights reserved.

of affective processing is paralleled in physiological responses [8]. Moreover, especially unpleasant and threatening items may induce a short orienting phase during which the organism is immobile and hypervigilant, followed by selection of overt action. Hence, the manner in which a step is selected and organized may crucially depend on where along this neural chain of events the motor program for GI is activated.

We directly compared GI in response to the onset vs. offset of affective stimuli, and tested whether the biomechanical organization of GI depends on this factor. We predicted facilitation of GI for pleasant items in the onset condition (relative to unpleasant items) and facilitation of GI for unpleasant items in the offset condition. We further expected effects of emotion to become manifest in the APA and step size. We additionally assessed whether COG velocity provides information on how affective information processing couples to GI. Only one study [7] analyzed COG dynamics of GI in response to affective visual stimuli, but they did not vary arousal levels (a potentially crucial stimulus variable [10]). To this end, we tested the factorial combination of valence (pleasant/unpleasant) and arousal (high arousal vs. low arousal) of the affective content of the pictures.

2. Methods

2.1. Participants

Twenty-seven healthy individuals (11 males, 16 females; *M* age = 28.7 y, SD = 14.0) participated. None of the participants had lower extremity injuries that could hamper task performance. The local ethics committee approved the experiment. The participants signed an informed consent form prior to testing.

2.2. Material and methods

Posturographic data were recorded using a custom-made strain gauge force plate (1 m $\times$ 1 m; sampling frequency: 100 Hz). The force plate consisted of eight force sensors; four measuring forces in the *z* direction, and two each for the *x* and *y* directions. These signals were converted to forces (Fx, Fy, Fz) from which moments were (Mx, My, Mz) calculated. Mx and My were then used to calculate the point of application of the vertical force on the support surface (e.g. [11]). Pictures were shown on a 17-inch monitor, positioned at eye height 1.5 m in front of the participant.

The stimuli included photographs from the International Affective Picture System (IAPS [12]). The IAPS is a database of affective pictures with normative subjective scores for each picture on two continuous dimensions: valence (pleasant vs. unpleasant) and arousal (high arousing vs. low arousing). We selected 25 pictures, representing 5 affective categories: (1) High arousal, pleasant (HA-P; erotica), (2) Low arousal, pleasant (LA-P; children and animals), (3) High arousal, unpleasant (HA-U; attack and mutilation), (4) Low arousal, unpleasant (LA-U; contamination and famine), and (5) neutral (NEU; faces and abstract shapes) (see Appendix). Subjective valence and arousal were rated for each picture using the 9-point Likert version of the self-assessment manikin (SAM), with higher scores indicating positive (pleasant) valence and more arousal.

2.3. Procedure

At the beginning of each trial the participants stood still at one of the corners of the force plate, facing the monitor, which was positioned near the opposing corner. The pictures displayed on the monitor served as a cue for step initiation. Participants had to initiate and execute a step with their right leg in the direction of the monitor, diagonally across the plate, and stand still in this new position.[1] No instructions regarding step length and step velocity were given. We also presented 5 catch trials (a red cross), which signaled that participants had to refrain from stepping.

The timing of stimulus events was as follows. First, a black screen was presented for a variable 3–5 s duration, during which participants stood still. Next, an IAPS picture was shown for a variable 3–5 s duration. Participants in the *onset* condition had to initiate a step as soon as the picture appeared, whereas in the *offset* condition they had to initiate a step as soon as the picture disappeared from the screen. Next, a 4 s black screen was presented. Note that during this interval participants in the onset condition have already executed the step and stand in their new position, whereas those in the offset condition are still in the process of stepping. Finally, a 3-s message appeared on the screen with the words 'STEP BACK', during which participants assumed their initial position.

Participants were tested in both conditions (counterbalanced). During each condition the same 25 IAPS were shown, albeit in a different (randomized) order, plus the 5 catch trials. At the end of the experiment participants rated each picture.

Prior to each condition (onset and offset) there were 10 practice trials, showing pictures from each of the 5 picture categories plus 2 catch trials. These trials were not further analyzed.

2.4. Data reduction

The *x*-*y* COP time-series were rotated by 45° (due to the diagonal arrangement of the measurement setup), yielding a new time series involving an anterior–posterior (AP) component corresponding to the progression axis of the step, and a medio-lateral (ML) component corresponding to sideways excursions. In addition, we calculated the instantaneous acceleration of the COG in the AP-direction by dividing the ground reaction forces by the subject's mass. We analyzed the following GI parameters:

Reaction time: the time interval between t0 (stimulus onset, or stimulus offset) and the first discernible change in COG displacement. Step initiation was defined as the moment at which the acceleration of the COG trace in the anterior direction exceeded 4 times the standard deviation of the COG trace recorded in the 1-s quiet stance time window preceding the GI cue.

APA amplitude: the distance between the COP at t0 and the maximum posterior displacement of the COP.

APA velocity: the average velocity of the posterior COP shift (cf. [10]).

Swing heel-off time (HO): the moment where the APA ends and the execution phase starts. We calculated the time difference between t0 and the moment where the vertical impulse peaked downwards (cf. [13]). Vertical impulse was calculated by integrating the vertical ground reaction force, after subtraction of the subjects body weight.

Peak velocity of the COG trace: Through simple integration of the COG acceleration trace we obtained the COG AP velocity [7,14]. Note that this procedure only yields amplitude information about the COG acceleration; not its directional position (see also [15]). The maximal excursion of this signal following GI corresponded to the peak velocity.

Step size: the distance along the AP-axis between the COP of the initial stance position prior to step initiation and the final stance position.

A COP trace of a representative step in shown in Fig. 1.

[1] This diagonal arrangment was chosen so as to prevent constraints on step length and step velocity that could be induced by the margins of the force plate.

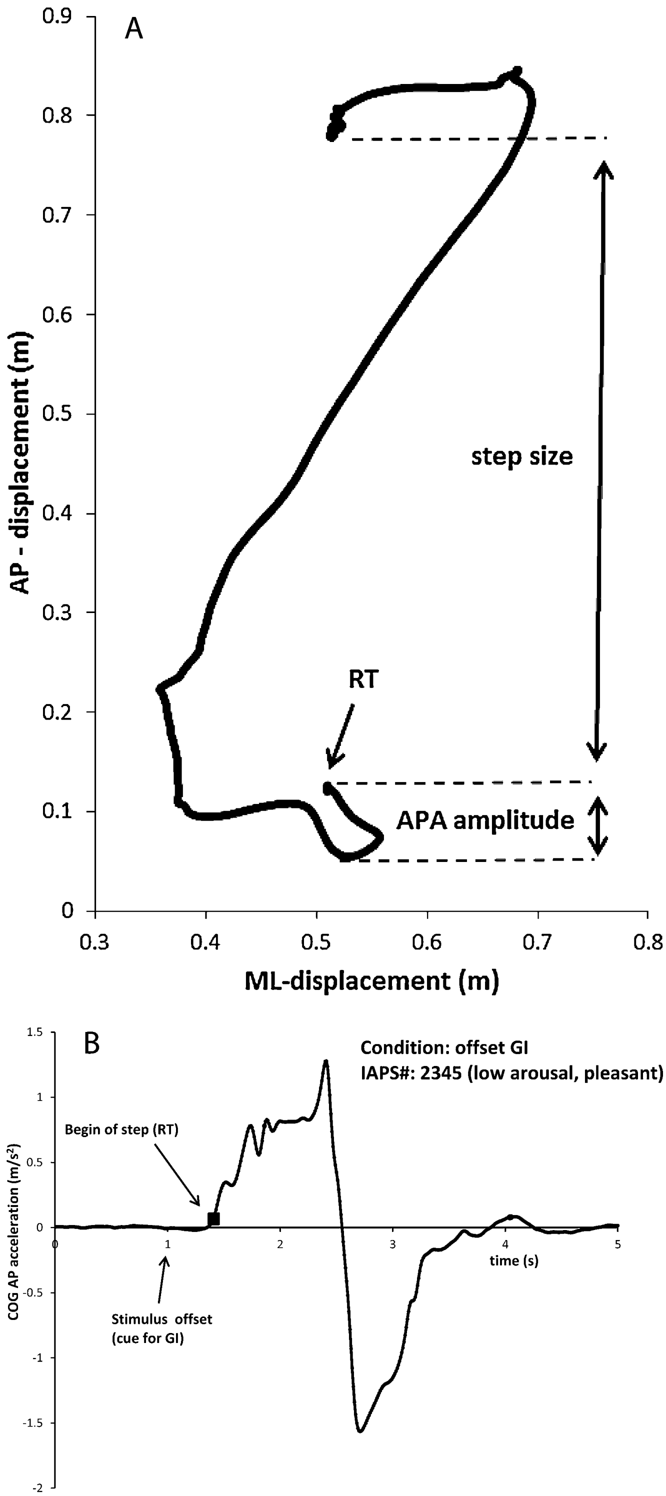

Fig. 1. (A) COP trace of a representative step (offset GI; LA-P), displaying the characteristic S-shaped profile. For illustrative purposes, RT, APA amplitude and step size are indicated in the graph. (B) Time trace of the ensuing acceleration of the COG in the AP direction.

2.5. Statistical analysis

SAM valence ratings were analyzed by collapsing valence across the 2 arousal levels (high vs. low), yielding 3 valence levels (pleasant, unpleasant, neutral) and entering these means in a one-way analysis of variance (ANOVA). Arousal ratings were analyzed by collapsing the ratings across the 2 valence levels (pleasant vs. unpleasant), yielding 3 arousal levels (high arousal, low arousal, neutral).

For the analysis of GI we did not analyze the neutral pictures. All six COP and COG variables were first entered in a three-way repeated measure multiple-analysis of variance (MANOVA), thus controlling for type-I error. The factors were condition (onset vs. offset GI), valence (pleasant vs. unpleasant images) and arousal (high vs. low arousing images). When significant, follow-up testing was done using separate ANOVAs. Interaction effects were explored using *t*-tests.

3. Results

We discarded 52 trials (out of 675), due to (a) stepping with the left leg, (b) not executing a step at all, (c) stepping too early (RT < 150 ms), or (d) stepping too late (RT > 2000 ms).

3.1. SAM

The picture categories differed significantly with respect to valence ($F(2, 50) = 165.2$, $p < .001$) and arousal ($F(2, 50) = 70.64$, $p < .001$). Pleasant pictures were rated as more pleasant than neutral pictures, which in turn were rated as more pleasant than unpleasant ones. High arousing pictures were rated as more arousing than low arousing pictures, which in turn were rated as more arousing than neutral ones (Table 1). No effects involving gender were significant.

3.2. MANOVA

The MANOVA revealed a significant effect of condition, $F(6, 21) = 4.83$, $p < .01$, a significant interaction of condition and valence, $F(6, 21) = 2.70$, $p < .05$, and a significant interaction of arousal and valence, $F(6, 21) = 4.01$, $p < .01$. Means for all variables and conditions are shown in Table 2.

3.3. Reaction times

The main effect of condition was significant ($F(1, 26) = 17.09$, $p < .001$); steps were initiated faster in the offset condition (451 ms) than the onset condition (552 ms). The interaction between condition and valence was significant ($F(1, 26) = 5.64$, $p < .05$) as was the interaction between valence and arousal ($F(1, 26) = 7.70$, $p < .01$). Fig. 2 (left) shows that there was an RT advantage for pleasant pictures compared to unpleasant pictures for the onset condition ($t(26) = 2.56$, $p < .05$), but that this contrast was not significant for the offset condition. The latter interaction revealed that there was an RT advantage for pleasant pictures compared to unpleasant ones when the pictures were low arousing ($t(26) = 2.61$, $p < .05$), whereas this contrast was not significant when the pictures were highly arousing (right panel).

We performed separate ANOVAs for onset vs. offset GI. For the onset condition only the main effect of valence was significant ($F(1, 26) = 6.57$, $p < .01$); steps were initiated faster to pleasant than to unpleasant items (534 vs. 570 ms). For the offset condition the interaction between valence and arousal was significant ($F(1, 26) = 5.26$, $p < .05$). High arousing unpleasant items yielded faster RTs (430 ms) than high arousing pleasant items (459 ms; $t(26) = 2.35$, $p < .05$). This same contrast was not significant for low arousing stimuli.

3.4. APA amplitude

The main effect of condition ($F(1, 26) = 9.98$, $p < .01$) indicated that offset stepping yielded larger posterior APAs (4.7 cm) than onset stepping (4.0 cm). Also, the interaction between valence and arousal was significant ($F(1, 26) = 6.60$, $p < .05$). For low arousal pictures the pleasant items yielded larger APAs (4.5 cm) than unpleasant items (4.2 cm; $t(26) = 2.97$, $p < .01$). The same contrast for high arousal pictures was not significant.

3.5. APA velocity

The main effect of condition, $F(1, 26) = 13.29$, $p < .001$, indicated that APA velocity was higher in the offset condition (16.3 cm/s) than the onset condition

Table 1
Mean (+ standard deviation) valence and arousal scores for each picture category.

	Valence	Arousal
High arousing, pleasant (HA-P)	6.11 (1.28)	5.29 (1.37)
Low arousing, pleasant (LA-P)	7.40 (.97)	3.61 (1.64)
High arousing, unpleasant (HA-U)	2.22 (.90)	5.49 (1.83)
Low arousing, unpleasant (LA-U)	2.55 (.97)	5.09 (1.82)
Neutral (NEU)	5.21 (.78)	3.33 (1.41)

Table 2
Mean (+ standard deviation) values of the COP variables for onset and offset gait initiation for the five picture categories.

Picture category	HA-P		LA-P		HA-U		LA-U		NEU	
	Onset	Offset	Onset	Offset	Onset	Offset	Onset	Offset	Onset	Offset
RT (ms)	552 (156)	459 (67)	516 (118)	453 (85)	566 (147)	430 (86)	575 (139)	462 (112)	637 (172)	465 (100)
APA amplitude (cm)	4.04 (1.57)	4.66 (1.85)	4.16 (1.45)	4.81 (1.71)	4.11 (1.58)	4.80 (1.87)	3.88 (1.50)	4.63 (1.73)	4.24 (1.62)	4.43 (1.53)
APA velocity (cm/s)	12.65 (5.34)	15.62 (6.25)	12.90 (5.45)	16.67 (7.02)	13.46 (6.65)	17.35 (8.17)	12.20 (4.64)	15.53 (5.97)	13.81 (5.59)	16.17 (6.76)
Swing heel off time (ms)	1034 (204)	935 (143)	1018 (175)	908 (163)	1044 (198)	905 (142)	1065 (171)	940 (183)	1104 (239)	907 (162)
Peak COG velocity (cm/s)	55.0 (12.2)	54.1 (13.5)	54.8 (12.3)	54.4 (13.2)	55.3 (12.2)	53.4 (13.2)	55.4 (11.7)	54.8 (12.8)	55.8 (11.9)	54.5 (13.0)
Step size (cm)	49.21 (8.20)	47.85 (8.03)	48.73 (8.35)	47.60 (8.30)	49.20 (8.31)	46.84 (7.97)	49.09 (8.40)	47.50 (8.65)	49.49 (8.33)	47.70 (8.71)

Note: HA-P, high arousal pleasant; LA-P, low arousal pleasant; HA-U, high arousal unpleasant; LA-U, low arousal unpleasant; NEU, neutral.

(12.8 cm/s). The interaction between valence and arousal was significant ($F(1, 26) = 7.42$, $p < .05$). The difference between LA-U (13.9 cm/s) and LA-P (14.8 cm/s) was significant, $t(26) = 2.36$, $p < .05$, as was the difference between HA-U (15.4 cm/s) and HA-P (14.1 cm/s), $t(26) = 2.19$, $p < .05$.

3.6. Heel-off time

The main effect of condition, $F(1, 26) = 13.97$, $p < .001$, indicated that HO was faster in the offset (922 ms) than the onset condition (1040 ms). The interaction between valence and arousal was significant ($F(1, 26) = 9.57$, $p < .01$). The difference between LA-U (1002 ms) and LA-P (963) was significant, $t(26) = 2.96$, $p < .001$, whereas the difference between HA-U (975 ms) and HA-P (985 ms) was not significant.

3.7. Peak COG velocity

The only significant effect was the interaction between condition and valence ($F(1, 26) = 5.48$, $p < .05$). For the offset condition the difference between pleasant and unpleasant items was significant ($t(26) = 2.81$, $p < .05$; 54.6 vs. 53.7 cm/s, respectively), whereas the same contrast for the onset condition was not significant.

3.8. Step size

The interaction between condition and valence was significant ($F(1, 26) = 5.63$, $p < .05$). In the offset condition participants took larger steps toward pleasant pictures (47.7 cm) than toward unpleasant ones (47.1 cm), $t(26) = 2.25$, $p < .05$. For the onset condition this contrast was not significant.

4. Discussion

We examined how emotion impacts on the biomechanical organization of GI. We contrasted two paradigms; in one paradigm participants initiate a step as soon as an affective visual cue is presented (onset-GI), while in another paradigm participants initiate a step as soon as the cue disappears from the screen (offset-GI). A crucial difference between these paradigms is that in the latter case participants had ample time to mentally process the affective material before engaging in GI. Emotion researchers [8] have demonstrated that physiological and behavioral systems (e.g., related to heart rate, or to sweat production) behave in a characteristic manner when presented with potent stimuli, especially related to threat. This rationale motivated us to examine whether the organization of GI varies according to onset vs. offset GI.

We found an RT-advantage for pleasant pictures compared to unpleasant pictures for the onset condition. This finding replicates earlier studies [5–7], and confirms that a forward step toward pleasant items is more readily initiated than toward unpleasant ones, as the default reaction to unpleasant items is likely defensive (avoidance). In the offset condition, however, steps were initiated fastest to high arousal unpleasant items, compared to all other picture categories, replicating an earlier study [10]. The seemingly divergent result for onset vs. offset GI might be explained by considering the temporal dynamics of affective processing. Neural processing of unpleasant and threatening items proceeds in a stereotypical manner; the initial response is typically postural immobility, during which the organism is hypervigilant (e.g. [2,16,17]). This response is then followed by overt action patterns. We believe that in the onset condition unpleasant items triggered a brief state of immobility, which made it harder to organize a transition from quiet standing to forward stepping. In the offset condition, in contrast, participants first viewed the items for some time, during which they processed the material to its full extent. Especially high arousal unpleasant pictures, displaying scenes of death and mutilation, likely triggered powerful action tendencies and mobilized energetic resources. Upon picture offset participants were in a state of heightened arousal and were quicker to initiate action. This explanation, though tentative, underscores the need to control for the temporal dynamics of affective processing when studying the influence of emotions on GI.

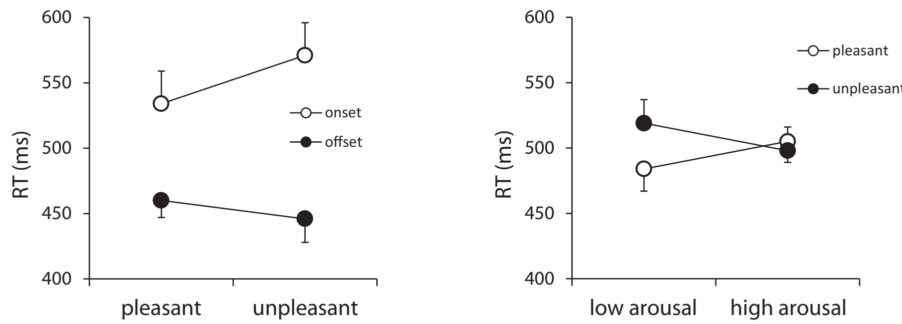

Fig. 2. Mean RT (+ standard errors of the mean) for gait initiation, for the various conditions. Left panel: RTs for onset vs. offset GI, separate for pleasant and unpleasant images. Right panel: RTs for pleasant vs. unpleasant images, separate for the low- and high arousal picture categories. RTs are averaged over participants and trial repetitions.

Second, there were clear differences between onset and offset GI with respect to step size, APA velocity, heel-off time and COG peak velocity. During offset (but not onset) GI, participants who had just viewed unpleasant items generated smaller steps, and with a smaller peak velocity of the COG, compared to pleasant items, suggesting a more 'cautious' step. Note that this more cautious step execution was accompanied by fast movement initiation (see above).

Third, we found effects of emotion on APA amplitude; for low arousal pictures, the pleasant items yielded larger posterior displacements than unpleasant items. A similar effect was reported previously [10], although in our study the effect was not significant for high arousal pictures. It could be that the decrease in amplitude of the APA for unpleasant items reflects a defensive behavioral tendency, such as postural immobility [1].

A possible limitation is that we did not control for state and trait anxiety, as anxiety can have strong impact on approach-avoidance tendencies [18].

We demonstrated that the biomechanical organization of GI is influenced by the valence and the arousing properties of affective visual stimuli. GI was strongly influenced by whether steps were initiated in response to the onset or offset of the stimuli. These effects are consistent with current knowledge regarding neural processing of emotions. Future studies will have to test this notion more directly by simultaneous recordings of psychophysiological and somatic variables related to emotion and arousal.

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.

Appendix. List of IAPS pictures

HA-P: 4607, 4659, 4670, 4687, 4694; LA-P: 1463, 1920, 2058, 2071, 2345; HA-U: 2683, 3010, 3069, 3400, 6250; LA-U: 2095, 2682, 2703, 2800, 9301; NEU: 2104, 2190, 2200, 2305, 7820.

Note that this list is nearly identical to the set of pictures used by [10].

References

[1] Yiou E, Caderby T, Hussein T. Adaptability of anticipatory postural adjustments associated with voluntary movement. World J Orthop 2012;3(6):75–86.
[2] Azevedo TM, Volchan E, Imbiriba LA, Rodrigues EC, Oliveira JM, Oliveira LF, et al. A freezing-like posture to pictures of mutilation. Psychophysiology 2005;42:255–60.
[3] Hagenaars MA, Stins JF, Roelofs K. Aversive life events enhance human freezing responses. J Exp Psychol Gen 2012;141:98–105.
[4] Horslen BC, Carpenter MG. Arousal, valence and their relative effects on postural control. Exp Brain Res 2011;215:27–34.
[5] Stins JF, Beek PJ. Organization of voluntary stepping in response to emotion-inducing pictures. Gait Posture 2011;34(2):164–8.
[6] Stins JF, Roelofs K, Villan J, Kooijman K, Hagenaars MA, Beek PJ. Walk to me when I smile, step back when I'm angry: emotional faces modulate whole-body approach–avoidance behaviors. Exp Brain Res 2011;212(4):603–11.
[7] Gelat T, Coudrat L, Le Pellec A. Gait initiation is affected during emotional conflict. Neurosci Lett 2011;497(1):64–7.
[8] Bradley MM, Codispoti M, Cuthbert BN, Lang PJ. Emotion and motivation. I. Defensive and appetitive reactions in picture processing. Emotion 2001;1:276–98.
[9] Chen M, Bargh JA. Immediate behavioral predispositions to approach or avoid the stimulus. Pers Soc Psychol B 1999;25(2):215–24.
[10] Naugle KM, Hass CJ, Joyner J, Coombes SA, Janelle CM. Emotional state affects the initiation of forward gait. Emotion 2011;11(2):267–77.
[11] Duarte M, Freitas SM. Revision of posturography based on force plate for balance evaluation. Rev Bras Fisioter 2010;14:183–92.
[12] Lang PJ, Bradley MM, Cuthbert BN. International affective picture system (IAPS): affective ratings of pictures and instruction manual. In: Technical Report A-6. Gainesville, FL: University of Florida; 2005.
[13] Caderby T, Yiou E, Peyrot N, Bonazzi B, Dalleau G. Detection of swing heel-off event in gait initiation using force-plate data. Gait Posture 2013;37:463–6.
[14] Yiou E, Do MC. Control of mediolateral stability during rapid step initiation with preferred and non-preferred leg: is it symmetrical? Gait Posture 2010;32(1):145–7.
[15] Kirtley C. Clinical gait analysis: theory and practice. Edinburgh: Elsevier Health Sciences; 2006.
[16] Roelofs K, Hagenaars MA, Stins JF. Facing freeze: social threat induces bodily freeze in humans. Psychol Sci 2010;21:1575–81.
[17] Adkin AL, Frank JS, Carpenter MG, Peysar GW. Fear of falling modifies anticipatory postural control. Exp Brain Res 2002;143:160–70.
[18] Buetti S, Juan E, Rinck M, Kerzel D. Affective states leak into movement execution: automatic avoidance of threatening stimuli in fear of spider is visible in reach trajectories. Cogn Emot 2012;26:1176–88.