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COMPREHENSIVE REVIEW

Postural responses to emotional visual stimuli

Thierry Lelard[a,*], **John Stins**[b], **Harold Mouras**[c]

[a] EA 3300, Adaptations Physiologiques à l'Exercice et Réadaptation à l'Effort, UFR des Sciences du Sport, Université de Picardie-Jules-Verne, allée P. Grousset, 80025 Amiens, France
[b] Department of Human Movement Sciences, Faculty of Behavioural and Movement Sciences, Vrije Universiteit, Van der Boechorststraat 9, 1081 BT Amsterdam, The Netherlands
[c] EA 4559, Laboratoire de Neurosciences Fonctionnelles et Pathologies, Centre Universitaire de Recherche en Santé, rue René-Laennec, 80054 Amiens cedex 1, France

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Summary Postural control is a motor skill that allows individuals to interact with their environment. Indeed, in all species, development of postural control is a prerequisite for acquiring further motor abilities. In humans, the maintenance of a bipedal posture plays an important role in interaction with the environment, as it provides a stable postural basis allowing upper limbs and hands to be used to manipulate objects. On the other hand, this bipedal posture induces a constraint in terms of balance, as individuals have to deal with a relatively small base of support enclosed by the surface of the two feet. Biomechanical principles underlying postural control have been studied in great depth, but the effect of emotion on postural control seems to be an emergent topic. Over the last two decades, an exponential number of studies have been published at the interface of affective and social neurosciences. Moreover, the interactions between motor and affective processes are increasingly documented in the scientific literature. In this article, we try to synthetize main recent empirical results that have allowed exploration of the link between body posture and emotional processing.

Introduction

Charles Darwin previously described the relationship between emotional and motor systems. Indeed, Darwin argued that emotional stimuli induce adaptation of behavioral responses according to the environmental context triggering the emotion [19]. However, these relationships between emotional and motor systems were not extensively characterized until quite recently, whereas the relationships between cognitive and motor functions had been studied in greater depth [18]. Over the last twenty years, breakthroughs particularly in the field of functional neuroimaging

* Corresponding author.
E-mail address: thierry.lelard@u-picardie.fr (T. Lelard).

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have made it possible to approach the functioning of the brain and associated psychological processes from a new angle. In neuroimaging for example, it is possible to observe specific brain activity across different perceptual, cognitive or motor paradigms. In addition to considerable progress in the knowledge of brain circuits involved in general cognitive processes, two particularly active research areas have emerged: so-called affective neuroscience [58], which focuses on the cerebral foundations of emotional and motivational processes, and so-called social neuroscience [41], crystallized around the neural correlates of the processing of information of social nature. Neuroanatomical data have helped to highlight the interface between limbic and motor circuits. For example, the basal ganglia are involved in voluntary movements (such as gait and posture), but also in the physiological expression of emotions [44]. Henceforth, it is now thought that interaction between the motor systems and the limbic system could explain why emotion influences motor behavior, including postural adjustments.

In evolutionary theories, it is assumed that the automatic responses triggered by emotional stimuli played a central role for survival of the species. These automatic responses can be viewed as instinctual responses [59] allowing rapid response to a threat (e.g., [4]). It is generally assumed that emotional processes affect behavioral responses at central, cognitive and motor preparation stages [11,33,45,70,71]. Recent research in experimental psychology has shown that emotions influence motor processes, such as the control and initiation of manual and postural behaviors [7,17,25,53,56,65]. For example, force production seems to be dependent of the emotional context [17,65] or speed execution [33].

Several authors have adopted the so-called biphasic model in which emotional stimuli are considered to activate appetitive or defensive brain circuits [46], which in turn might trigger approach-withdrawal behavioral responses. This model argues that behavior is governed by motivational circuits as a function of the stimuli's valence and intensity, with pleasant events (appetitive stimuli) triggering an approach response, and unpleasant events (defensive stimuli) triggering withdrawal [10,12,38,46,47].

In this review, we will focus only on the effects of the emotional context on the maintenance of a static posture. We believe that this apparently simple motor task can be highly informative for our understanding of emotional processing, for the following reasons: first, as argued above, the postural task of quiet upright standing can be considered a physical basis for further emotion-guided behaviors, such as increasing/decreasing the distance between the self and items in the environment, or supplying the stable support for social behaviors, such as attacking an enemy, or comforting someone in pain. Second, the time course of quiet standing can be recorded with high spatial and temporal accuracy, thus potentially providing a window into subtle postural adjustments that are indicative of changes in emotional states.

The postural control system

The postural control system is involved in the maintenance of a stable posture by regulation of the relationship between the center of mass and the base of support. Moreover, it serves as a reference frame for perception and action with respect to the external world. Postural control is thus a motor skill that allows animals or humans to interact with their environment. Indeed, in all species, development of postural control is a prerequisite to the acquisition of more specialized motor abilities [49] such as walking and grasping.

Postural control is supported by 3 components: the neural, sensory, and musculoskeletal systems. Sensory cues are involved in the representation of the body in its environment (postural alignment in regard to the gravity vector), and permit detection of postural deflections from postural verticality, which could trigger loss of stability. Cortical and subcortical structures are involved in the selection of adaptive responses to changes (predictable or unpredictable) in the environment, while muscle activity produces motor responses that act on the environment.

Posturography: a tool to evaluate static balance

In order to evaluate the integrity of the postural control system, clinical or instrumental recording tools can be used. Posturography quantifies the postural responses (body sway) in terms of area and velocity of the center of pressure (COP) displacement. In healthy young adults, information from the soles of the feet and from the muscle spindles in leg muscles make a major contribution to maintenance of stance [26]. Posturography evaluates displacements of the center of pressure (COP) and is appropriate to demonstrate postural changes and to quantify body movements [8,29,40]. This technique determines the COP position from the body mass distribution on at least 3 pressure sensors. Many contemporary force plates have 4 sensors, measuring vertical force distribution. To ensure good reproducibility of the measurement, the recording conditions are typically standardized: participants stand barefoot in the middle of the posturographic platform and are asked to maintain a comfortable bipedal stance with their arms hanging relaxed at their sides, with their feet pointing slightly outwards. As all sensory cues are involved in the maintenance of a static bipedal stance, great attention is paid to the presence of the information provided by the environment. The measurements are made in a quiet place, without auditory stimulation or unwanted disturbance in the visual field of the individual.

Postural changes and body movements can be described posturographically by analyzing the trajectory of the COP over a certain time frame. When recorded for several seconds, the displacement of the center of pressure in the anteroposterior and medio-lateral plane can be described by several parameters: average position of the center of pressure, the standard deviation of this position (in either direction), the area on which this center of pressure has moved, etc. The mean COP position in the anteroposterior axis is, at first sight, a suitable index for objectively studying approach-withdrawal behaviors [21,64], because spontaneous forward displacements of the mean COP may signal an approach tendency, whereas spontaneous backward displacements of the mean COP may signal an avoidance tendency. However, it is equally interesting to study the dynamics of the postural response in response to an emotional stimulus [54,60].

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Postural responses to emotional stimulation

While postural control is evaluated under standardized conditions limiting external stimulation, posturography has also been used to evaluate the effects of various stimuli on postural control. Indeed, behavioral responses appear to be context-dependent, as illustrated by the example of the defensive response to an aversive stimulus (e.g. fear behavior in animals). Animal and human research have demonstrated that the defensive behavior system can produce different responses (e.g. freezing or aggression) [9,24,31,66]. The type of defensive response depends on the level of experienced fear, which in turn may depend on the proximity and intensity of the triggering stimulus, and on the subject's own unique history and action capabilities.

Thus, several studies have reported postural changes in response to emotional stimulation. The relationship between postural control and emotional contents could be characterized by the displacements of the COP when presenting different stimuli. Most studies have focused on the effects of pleasant versus unpleasant emotion stimuli, thus demonstrating approach- withdrawal behaviors according to the valence of the stimulus (pleasant or unpleasant). However, many studies also reported freezing behavior in response to high arousal stimulation. Freezing can be characterized by posturographic data as a decrease of the amplitude, area and standard deviation of COP displacements. Freezing behavior corresponds to a defensive response expressed as a brief immobility phase [31].

Impact of emotional state on postural control

Several studies have shown the impact of the participant's emotional state on postural performance. Anxiety [6,22] and especially fear of falling [52] were among the first emotional states studied that linked postural parameters with emotion. Experimental studies were then developed to modify the emotional state of the participant.

Modulation of postural threat

An innovative experimental procedure allowed modulation of the state of the participant by changing the environment in which the postural task was performed [1]. The participants performed a posturographic test standing on an elevated surface (80 cm, or higher in more recent studies) above the ground [2,3,13—15,39]. This experimental procedure reliably modifies the state anxiety of an individual. In this setup, the participant is aware that a fall from that height would likely cause some degree of injury. The researchers listed above hypothesized that standing at the edge of an elevated surface would modify the participant's emotional state. Increasing postural threat was referred to as ''fall anxiety'' or ''postural anxiety''. Physiological responses to postural threat attested to the increased postural anxiety. When the participant was standing on the elevated surface, increased skin conductance evidenced a change in psychophysiological state [50,57]. Some authors hypothesized that the participant might experience reduced balance confidence, being less stable and more anxious about falling when standing on an elevated surface [1]. Indeed, even though the biomechanical constraints for maintaining postural balance on the stable, elevated surface are the same as those involved in maintaining postural balance on the ground, the results evidenced a change in the balance control strategy. Regardless of the age of the participants, standing on the edge of an elevated surface modified postural control behavior. Specifically, the subjects were generally found to sway less in the postural threat condition than when standing on the ground. Although bipedal stance on the elevated surface was stable and safe, the subjects nevertheless sought to minimize the amount of sway in this condition. This was interpreted as the adoption of a ''freezing'' behavior in response to postural anxiety. Considering the 'inverted pendulum model' of quiet standing, an ankle strategy applies in the anteroposterior direction [72]. Activation of lower leg muscles (especially tibialis anterior (TA) and soleus (SOL)) reflect forward or backward leaning of the whole body. Synchronous activation of these muscles, reflecting co-contraction, does not yield postural displacement but leads to a stiffer stance, including higher frequencies in the signal. Carpenter et al. (2001) also reported changes in TA or SOL activation during a postural threat condition that was attributed to a freezing response [15,68]. Likewise, EMG data reflect the adoption of a strategy of rigidification in response to increased postural threat as expressed by significant increases in mean TA activity and muscle co-activation (described as increased muscle stiffness).

Postural reaction to emotional visual stimuli

Several researchers have studied psychophysiological, behavioral and neuro- physiological reactions in response to visual affective stimuli [12]. Lang et al. developed an emotional picture database called the ''International Affective Picture System'' (IAPS), encompassing semantic categories such as mutilation, threat, erotica [46] commonly used to explore emotional responses. In terms of subjective judgment, the highest agreement among observers is obtained for pictures depicting mutilation, which are consistently rated as evoking disgust, by both men and women [12]. In terms of physiological changes, electrodermal activity (EDA, reflecting sympathetic nervous system activity) was greater when viewing pleasant or unpleasant pictures than when viewing neutral pictures. These findings suggest that a measurable change in EDA merely corresponds to high motivational activation and may not be sufficient to differentiate between responses to appetitive and defensive stimuli. In contrast, heart rate (HR) responds specifically to pleasant and unpleasant visual stimuli [28]. Greater initial heart rate deceleration was associated with viewing unpleasant contents [10]; this suggests that regardless of arousal, unpleasant contents prompt greater initial attention (relative to appetitive stimuli).

Recent studies have focused on the effects of emotional visual stimulation on postural control [5,23,37,38,50,51,55,67]. Motor responses and related postural responses to an emotional stimulus have been mainly observed during the presentation of aversive visual stimuli (i.e. stimuli corresponding to unpleasant content) [38]. Although human postural responses to visual emotional stimuli have been described in several recent studies, the findings showed two types of defensive responses [5,23,37,67]. All the studies clearly showed that the presentation of unpleasant pictures had an effect on postural control. However, the posturographic responses to unpleasant pictures differed from one study to another and thus were interpreted differently. Some researchers reported withdrawal behavior in response to unpleasant visual stimuli [37] while others reported freezing responses [5,23,67] and the absence of a withdrawal response, to similar stimuli. In most of these studies, the motor responses reported were the adoption of a freezing strategy in response to an aversive stimulus. However, this response does not seem to be specific to stimuli with negative valence. Indeed, similar responses were also reported in response to positive items [55]. This confirms Horslen's conclusions that postural responses seem to depend more on arousal than on valence [38].

From the findings presented above, the tentative conclusion could be reached that the presentation of emotional stimuli induces automatic postural and physiological responses that may be dependent on the emotional state of the participants. Interestingly, participants who had experienced aversive life events demonstrated amplified freezing responses [32], and even if postural responses to aversive stimuli are still observed in participants facing a postural threat, motor response seems to be tempered by the threat [50]. Indeed, when individuals were standing on an elevated surface, the withdrawal behavior in response to aversive visual stimulation was attenuated but nevertheless active as compared with the responses observed on the ground position.

Psychological state or trait may contribute to inter-individual variability of the results obtained in the general population. This could demonstrate the need to further characterize the population in terms of anxiety, trauma, etc., in order to improve our knowledge of the link between movement control and emotional information processing.

Modulation of postural responses

Postural responses to observation and mental simulation of visual scenes

The postural responses described above were observed in response to highly arousing stimuli such as aversive pictures depicting mutilation. However, Hagenaars et al. (2015) demonstrated that these highly automatic defense behaviors can be influenced by mental imagery manipulations [30]. These authors reported that bradycardia, as generally encountered in automatic responses, is modulated if individuals are asked to perform a passive viewing task or mental imagery of a situation [16].

Imagination of a visual situation experienced by us or simulation of another subject's behavior is based on the ability of an individual to simulate actions, to simulate perception [35,36], and involves simulation processes and activation of internal models [73]. The ability to simulate a situation seems to be an important mechanism by which we can understand another person's intentions and actions and the induction of the bodily expression of emotion [43]. During simulation processes, individuals may re-activate their own past experiences in order to gain access to pleasurable, motivational, or strictly informational properties [20]. Simulation of a situation seems to be realized by mirror neurons that increase their discharge frequency both during action production and during observation of the same action performed by another person [27,63]. For example, a similar fronto-parietal network was activated in pianist participants when they played music and when they imagined playing the same music. Hardwick et al. (2018) showed that motor imagery and action observation recruit similar premotor-parietal cortical networks. However, motor imagery recruits a similar subcortical network to movement execution while action observation does not activate any subcortical areas [34]. Jeannerod stated that ''the motor system is part of a simulation network that is activated under a variety of conditions in relation to action, either self-intended or observed from other individuals'' [42].

Embodiment of the situation?

Several studies have been conducted to better understand the mechanisms of embodiment. Simply put, the embodied cognition model states that cognitive and affective information processing is deeply grounded in the sensory and motor experiences of the physical body. Embodiment is an automatic process, subject to individual differences (such as bodily characteristics like size and motor skill), is flexible, and can be activated following simple manipulations of motor activation or attention to body parts. Embodiment is made possible by the ability to imagine oneself in a particular situation, and can be considered as sensorimotor simulation. For example, Stins et al. (2015) reported that during kinesthetic motor imagery, individuals produced unintentional postural adjustments [69] that were specific to the mental contents.

It seems likely that the development of empathic skills depends on this ability to simulate another person's emotional response. In this regard, the model of empathy for pain may be promising to investigate in greater depth, because pain involves a clear affective component (a mental subjective experience) and a clear motor component (avoidance of the exposure to the noxious stimulation) [62]. According to the ''motor'' theory of empathy, the perception-action linkages of empathy activate somatic and autonomic responses [61]. Simulation of a painful situation may therefore be an efficient functional context because our study showed that postural responses could be modulated by mental imagery of painful situation. Differential motor responses were observed when participants were asked to imagine themselves in painful situations as compared to non-painful situations [51]. Interestingly, an effect of mental simulation was also reported, as differential postural responses were reported when subjects were instructed to imagine themselves in a painful as compared to a simple passive observation of the same images [48].

To conclude with this part, it appears that postural and physiological automatic responses to visual stimulation may reflect an instance of embodiment. That is, both perceiving and imagining emotional scenes, especially of a social nature, could re-activate the associated motor responses,

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including responses involving postural adjustments. This mechanism can be used to understand another person's intentions. However, it appears that these responses can be modulated according to the degree of commitment in the situation established by mental simulation.

Conclusion

Current knowledge of the influence of emotional context on motor output shows that the presentation of emotional stimuli induces consistent automatic responses. Most recent studies have found that emotion can alter static postural control dynamics, likely reflecting ''defensive responses''. Future studies can help us better understand the inter-individual variability (e.g. experienced aversive life events, threat, anxiety) and identify the parameters influencing the task (set point, image size, sounds in the environment, etc.) and involvement in the situation represented (mental imagery or embodiment). The interpretation of phasic postural responses to emotional stimuli as approach-avoidance behavior needs to be further explored in order to better understand the variability between individuals (according to emotional state, personality characteristics and so on).

More attention should thus be paid to the psychological profile of the populations studied. This could demonstrate the need to characterize the populations in order to improve our knowledge of the link between movement control and emotional information processing such as that described in patients presenting post-traumatic stress disorder (PTSD).

It seems that emotional stimuli induce a robust dynamical pattern in the time course analysis [54,60]. In addition, this characteristic response seems to indicate that attentional processes may play a role in human postural responses to emotional stimuli [60]. The quiet standing paradigm could be advanced in the future by looking more at attentional effects of emotion, and also by introducing fine-grained temporal analyses of physiological data. Thus, a simultaneous collection of EEG, ECG (bradycardia), and eye movement data would provide a better understanding of the coordination of such responses, which jointly make up the full emotional experience.

Disclosure of interest

The authors declare that they have no competing interest.

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