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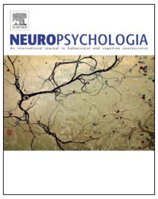

Dance expertise modulates visual sensitivity to complex biological movements

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ABSTRACT

Motor resonance processes that occur when observing an individual perform an action may be modulated by acquired visuomotor expertise. We used the event-related potential (EEG/ERP) technique to investigate the ability to automatically recognize a subtle difference between very similar novel contemporary dance movements. Twelve professional dancers and twelve non-dancers were shown 212 pairs of videos of complex whole-body movements that lasted 3 s. The second of each pair was the repetition of the previous movement or a slight variation of it (deviance). The participants were engaged in a secondary attentional task. Modulation of a larger centro-parietal N400 effect and a reduction of the Late Positivity amplitude (repetition suppression effect) were identified in response to deviant stimuli only in the dancers. Source reconstruction (swLORETA) showed activations in biological motion, body and face processing related areas, and fronto-parietal and limbic systems. The current findings provide evidence that acquired dance expertise modifies the ability to visually code whole-body complex movements.

1. Introduction

It is well established that observing a familiar action performed by another individual leads to the activation of brain regions that are also involved in its execution. A matching between the perceived action and the motor programme required to perform it is thought to occur to prepare the observer to execute or imitate the action (Rizzolatti and Craighero, 2004; Kilner et al., 2007), as well as understand its goal (Carmo et al., 2012; Catmur, 2015; Hamilton and Grafton, 2008; Iacoboni et al., 2005; Umiltà et al., 2001). The ventral premotor cortex (vPM), the inferior parietal lobule (IPL), the inferior frontal gyrus (IFG), and the posterior portion of the superior temporal sulcus (pSTS), part of the fronto-parietal system (also referred to as the human mirror neuron system, MNS), are thought to be at the base of this resonance process (Buccino et al., 2001, 2004a, 2004b; Holz et al., 2008; Rizzolatti et al., 1996; Rizzolatti and Sinigaglia, 2010). Several additional regions (part of the Action Observation Network, AON) are active when we observe a moving person (Bonini, 2016), including regions devoted to biological motion (Grèzes et al., 2001; Peelen et al., 2006) and face and body processing (Haist and Anzures, 2016; Haxby et al., 2000; Murata et al., 2016; Peelen and Downing, 2007), namely, the fusiform face (FFA) and body area (FBA), the middle temporal area (MT/V5), and the extrastriate body area (EBA). Moreover, several studies have shown that the activity of the MNS/AON may be modulated by changing the familiarity level with the observed action (Buccino et al., 2004a, 2004b) and the visuomotor expertise with a specific repertoire of movement, as in the case of professional musicians (Candidi et al., 2014; Karpati et al., 2017) and athletes (Calvo-Merino et al., 2005; Smith, 2016).

In particular, dance has proven to be an excellent framework (Bläsing et al., 2012; Sevdalis and Keller, 2011) for comparing groups of volunteers with different expertise (e.g., highly skilled experts vs. naïve controls) during the execution (Brown et al., 2006; Brown and Parsons, 2008; Cruz-Garza et al., 2014), observation (Calvo-Merino et al., 2005; Cross et al., 2011; Orgs et al., 2008) and imagination (Cross et al., 2006; Laland et al., 2015) of complex movements. It is assumed that years of daily training and rehearsals lead professional dancers to achieve improved motor skills, awareness of their body, and attention to the details of movements. In particular, increased visuomotor expertise would result in structural and connectivity changes in the sensorimotor brain regions of dancers (Giacosa et al., 2016; Hänggi et al., 2010; Hüfner et al., 2011; Karpati et al., 2017; Nigmatullina et al., 2015). In addition, the investigation of how dance moves are perceived and codified may be useful to investigate complex body motion per se for numerous reasons. For example, dance actions generally engage the whole-body of a dancer, vary in terms of complexity and difficulty, and differ from other sport actions with respect to the lack of tools as sport equipment

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(e.g., balls, clubs, or rackets). It is also possible to compare well-trained steps with non-trained steps and create a novel set of movements on the basis of the rules of a specific technique.

To investigate how dance expertise specifically affects brain plasticity, Calvo-Merino et al. (2005) compared ballet and capoeira dancers during the observation of technical steps belonging to ballet and capoeira repertoire. Enhanced activities of the PM cortex, intraparietal sulcus (IPS), right superior parietal lobule (SPL) and left pSTS were identified when dancers observed movements from their own technique (i.e., ballet dancers watching ballet) compared with kinematically similar movements from the other technique (i.e., ballet dancers watching capoeira). It should be noted that training a motor ability potentially implies not only the acquisition of motor skills but also of visual awareness through the observation of our own body or that of other dancers. In this regard, evidence has crucially dissociated the role of visuomotor expertise from visual familiarity (Cross et al., 2009; Jola et al., 2012; Gardner et al., 2015) in modulating the activity of the AON. In a study conducted by Calvo-Merino et al. (2006), dancers were shown dance moves belonging to male and female ballet technique. The observation of steps from the same-gender technique (e.g., male watching steps from male technique) compared with the opposite-gender technique (e.g., male watching steps from female technique) resulted in a greater activation of the left PM cortex, intraparietal cortex (IPC) and cerebellum bilaterally (Calvo-Merino et al., 2006). Similarly, in an fMRI study by Cross et al. (2006), motor imagery of extensively rehearsed movements (compared with non-rehearsed) resulted in a greater activation in the STS, vPM, inferior parietal sulcus, cingulate (CG) and supplementary motor areas in the brains of dancers (Cross et al., 2006). In another fMRI study by Kirsch and Cross (2015), participants were taught dance sequences via an auditory, audiovisual or audio-visuomotor training. A pattern of increasing activity in the left PM, left STG and right IPC was identified when observing movement from untrained to uni-modal, bimodal and tri-modal trained conditions (Kirsch and Cross, 2015). Overall, this evidence appears to suggest that motor resonance processes are directly related to the knowledge of the specific motor programme of an action.

A similar modulation of the AON in anticipating the outcome of an action was identified in studies involving skilled athletes (Smith, 2016; Tomeo et al., 2012). For example, in a TMS (transcranial magnetic stimulation) study by Aglioti et al. (2008), professional basketball players, expert watchers and control volunteers were presented basket shots to predict their outcome. TMS stimulation over the left primary motor cortex (M1) resulted in an enhanced corticospinal excitability only in professionals, when comparing incorrect and correct shots, which confirms that motor practice was necessary for a fine-tuning of resonance processes (Aglioti et al., 2008). Moreover, in an fMRI study by Abreu et al. (2012), the prediction of the outcome of basket shots was associated with the engagement of the IFG, vPM, IPL and somatosensory cortices. When comparing participants with different expertise, activity in the EBA was only shown in the brains of professional basketball players, which was likely the result of a larger amount of body-related kinematics information required to perform the task. Moreover, in this study, correct action prediction led to greater activity in the posterior insular cortex and left STG in experts and the medial orbital gyrus in non-experts (Abreu et al., 2012). At this point, it is important to note a study by Babiloni et al. (2008) that showed how the outcome of golf putts could be predicted by the modulation of the fronto-central high-frequency alpha rhythm power (10–12 Hz) during the execution of these actions. A reduction (event-related desynchronization, ERD) of alpha power for successful (compared with unsuccessful) actions was found. Moreover, ERD was linearly related to the amount of error (cm from the hole) made during the execution of unsuccessful putts (lower error was associated with a stronger ERD). In another study, Denis et al. (2017) found ERD in the central high mu rhythm band (11–13 Hz) during the observation of tennis shots when experienced (vs. less experienced) tennis players were instructed to predict the final direction of the ball. A lack of expertise-related difference in posterior attentional alpha components was also identified, which strengthened the assumption of action anticipation processes based on the engagement of sensorimotor regions.

The ability to detect errors in movements performed by other individuals has been broadly investigated in sport experts and musicians. Musical training leads to structural and functional connectivity changes in sensorimotor regions of the brain involved in musical gesture execution and its integration with the produced sound, as well as in auditory cortices (Giacosa et al., 2016; Palomar-García et al., 2017). Candidi et al. (2014) reported that TMS delivered over the left M1 led to an enhanced corticospinal excitability in pianists (vs. non-pianists) during passive observation of fingering errors. Moreover, this effect was specific for the muscle of the thumb involved in the incorrect movement and occurred 300 ms after the onset (Candidi et al., 2014), which thus indicates a monitoring process of action based on motor simulation. Moreover, Proverbio et al. (2012) determined that incorrect basketball actions (images of body postures or techniques that violated the rules of a sport game) were automatically detected by skilled basketball players (vs. non-players), which led to a more negative event-related potential (ERP) response (N400) over anterior sites of the scalp. Source reconstruction of the N400 component showed a greater involvement of the MNS, EBA, STS and cerebellum during the observation of incorrect/ineffective (vs. correct) actions in this study. Overall, the previously described literature has scarcely investigated the ability to detect subtle variations (instead of macroscopic errors) between movements and the relative role of expertise in this capacity. An attempt in this direction was made through a behavioural study by Calvo-Merino et al. (2010). Point light animations were obtained from eight standard ballet steps and presented to participants in pairs in upright and upside-down orientations. Professional dancers and non-dancers were instructed to discriminate whether the second stimulus was identical or different from the first stimulus. Experts were more accurate in discriminating upright stimuli only, whereas there were no differences for upside-down stimuli in both groups of volunteers (Calvo-Merino et al., 2010).

On this basis, the present electrophysiological (EEG) investigation aimed to investigate the neural correlates of the ability to automatically recognize subtle differences between two very similar movements and recognize action similarity for repeated actions in the skilled brains of professional dancers (vs. controls), by means of the EEG/ERP technique. Several EEG studies have been conducted to investigate the time course of brain processing during the execution and perception of actions that involve selected body parts, such as the hand, lower limb, finger, and oro-facial movements, or during simple actions, such as walking (Cochin et al., 2008; Holz et al., 2008). In these studies, a reduction of the mu rhythm (8–13 Hz) power was identified over sensorimotor central sites of the scalp when an action was performed or observed, an index of the MNS activity (Fox et al., 2016). Orgs et al. (2008) used ERD to investigate the MNS activity during the observation of daily trained dance movements (vs. common human actions) in groups with different expertise. The observation of dance moves resulted in a significant reduction of power in alpha (7.5–13 Hz) and low beta (13–18 Hz) frequency bands only in dancers, whereas there was no modulation in controls (Orgs et al., 2008).

In our study, professional contemporary dancers and control volunteers were recruited and shown 212 video pairs of whole-body complex movements during EEG recording. The first video of each pair (Pre) showed a dancer performing a novel move created by a choreographer, whereas the second video (Post) was a repetition of the previous video or a slight variation of it. The participants were instructed to detect static target images (secondary attentional task) and respond to them by pressing a key. The use of novel dance actions, which have never been practised as such by all participants, enabled us to exclude that the deviant movements could be codified as incorrect.

Considering the previous electrophysiological literature, we hypothesized that a larger negativity (N400 effect) would be identified