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I CAN'T REACH IT! FOCUS ON THETA SENSORIMOTOR RHYTHM TOWARD A BETTER UNDERSTANDING OF IMPAIRED ACTION–PERCEPTION COUPLING

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Abstract—It is known that anxiety (ANX) impairs action–perception coupling. This study tests whether this impairment could be associated with an alteration of the sensorimotor function. To this aim, the cortical activities underlying the sensorimotor function were recorded in twelve volunteers in a reach-to-grasp paradigm, in which the level of ANX and the position of a glass were manipulated. The experimental manipulation of the ANX-related somatosensory state was expected to prompt participants to underestimate their reaching-to-grasp capabilities while the sensorimotor-related oscillatory brain activities around the 6-Hz (θ) frequency over motor-related and parietal regions were expected to be modulated. We also investigated the oscillatory brain dynamics around the 11.5-Hz (fast-α) frequency as a neural hallmark of ANX manipulation induced by the breath-restriction. Results indeed showed that participants underestimated their reaching-to-grasp maximal performance. Concomittantly, θ-EEG synchronization over the motor cortex contralateral to the dominant hand was higher during glass presentation under breath-restriction condition (+20.1%; $p < 0.05$), and when the glass was perceived as non-reachable (+20.0%; $p < 0.05$). Fast-α-EEG desynchronization was reduced under breath-restriction (−37.7%; $p < 0.05$). The results confirm that ANX-related impairment of action–perception coupling co-modulates with theta-sensorimotor rhythm. This finding is discussed as an altered "readiness state" in the reaching-related cortical network, while individuals are anxious.

Key words: action–perception coupling, sensorimotor function, motor region, parietal region, theta activity.

INTRODUCTION

It is widely accepted that the neuronal processes involved in action and perception interact, making the action–perception coupling a crucial component in achieving efficient visuomotor actions (Prinz and Hommel, 2002). These neural processes includes the encoding and association of visuospatial and somatosensory (including sensorimotor) afferences during the preparation and initiation phase of the movement, and their update when motor running until the action is achieved (Cruikshank et al., 2012).

But the action–perception processes occurring when the goal of the action is visually identified can be impaired with changes in somatosensory state, as reported under anxiety (ANX) state with misestimated reaching capabilities (Pijpers et al., 2006; Graydon et al., 2012; Daviaux et al., 2016). Despite the fact that action–perception coupling in reaching tasks is well investigated so far (e.g., Wamain et al., 2016), only few study focused on the cortical correlates for such an impaired action–perception coupling in the context of emotional valence (Valdés-Conroy et al., 2014). Yet this issue is crucial to understand and prevent movement disorders in the field of public health (*e.g.*, Lee et al., 2001; Higuchi et al., 2009; Guardia et al., 2010, 2012; Smith et al., 2011; Hackney and Cinelli, 2013; Sakurai et al., 2013). We thus examined the effect of ANX state on participants' perceived reach-to-grasp abilities while the electroencephalographic (EEG) brain activities were recorded.

To ease the understanding, we refer here to "action–perception coupling" as a perceptual occurrence, and "sensorimotor function" as the neurophysiological processing of motor- and body-representation-related afferences which is part of the processes underlying the action–perception coupling.

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Abbreviations: actual-D_{max}, maximal actual reach-to-grasp performance; ANX, experimental breathing restriction (anxiety); CTL, experimental control condition; NON-REACH, non-reachable-to-be-grasped experimental condition; perceived-D_{max}, maximal perceived reach-to-grasp performance; REACH, reachable-to-be-grasped experimental condition.

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ACTION–PERCEPTION COUPLING AND THE SENSORIMOTOR FUNCTION

Previous studies have shown that impaired action–perception coupling occurs in patients with conditions that encounter sensorimotor disorders (*e.g.*, body spatial awareness) such as Parkinson's disease (Lee et al., 2001; Smith et al., 2011) or anorexia nervosa (Guardia et al., 2010, 2012). The same applies in older healthy individuals who experience progressive regression of sensorimotor functions (Luyat et al., 2008; Noël et al., 2011; Hackney and Cinelli, 2013; Sakurai et al., 2013). These findings raised the question of whether the alteration of somatosensory state, such as under ANX, is associated with an alteration in sensorimotor function leading to the impairment of action–perception coupling (Graydon et al., 2012; Daviaux et al., 2016).

NEUROPHYSIOLOGICAL CONTEXT OF THE ACTION–PERCEPTION COUPLING

The reaching-to-grasp paradigm, which involved hand–object interactions, is the main task used in behavioral studies to investigate the relationship between ANX and action–perception coupling (*e.g.*, Pijpers et al., 2006; Graydon et al., 2012; Daviaux et al., 2016). Such a perceptual task potentiates visuomotor transformations partitioned in the brain into sub-sensorimotor-components (Ellis and Tucker, 2000; Borghi and Riggio, 2009). It specifically involves the fronto-parietal network and the motor-planning-related regions (Fogassi, 2007; Binkofski and Buxbaum, 2012; Bartolo et al., 2014). The exchanges of multimodal information between the premotor and posterior-parietal regions allow the sensorimotor representation of individuals' body and its awareness regarding the environment (Graziano and Botvinick, 2002; Thurm et al., 2011). In such a cortical network, modulations of the EEG activity ~6 Hz, so-called the theta (θ) rhythm, can be used to reflect the sensorimotor function as it was thought to allow the motor and sensory systems to update each other and coordinate their activities (Klimesch, 1999; Bland and Oddie, 2001; Caplan et al., 2003). In a motionless context where a to-be-reached target is visible, an increasing level of event-related θ-EEG activity spectral power over the motor and parietal regions is suggested to *"initiates a series of sensory transformation and activates cortical sensorimotor networks*" for motor planning (Cruikshank et al., 2012, p.69). Given that achieving reaching behaviors requires an efficient sensorimotor function, studies have particularly focused on the motor regions and the posterior-parietal regions to assess their involvement in pointing-reaching tasks when spatial cues were manipulated (Curtis et al., 2004; Praamstra et al., 2009; Tombini et al., 2009; Cruikshank et al., 2012; Rawle et al., 2012). Moreover, Bartolo et al. (2014) have shown that reachability judgements involve motor-related brain processing, with an involvement of fronto-parietal cortical network including the motor cortex and the cerebellum. Taken together, these findings provide evidences that judging reachability cannot be considered as a simple visual task, and rather requires to investigate the activity of the motor-related cortical regions to understand impairment in perception of reaching capabilities.

WORKING HYPOTHESIS

According to the aforementioned background, the present study examines the θ-EEG activities over the motor and posterior-parietal regions as a marker of altered sensorimotor function for impaired action–perception coupling. Participants were required to *estimate* whether a glass could be reached-and-grasped while their EEG brain activities was recorded. An underestimation of their reaching-to-grasp capabilities was expected when individuals were breathing-restricted, which corresponded to a validated situation to manipulate ANX (Graydon et al., 2012; Daviaux et al., 2016). As the main hypothesis of this work, we hypothesized that the underestimation of the reaching-to-grasp capabilities under ANX would be associated with altered sensorimotor functioning. This latter should be revealed by a co-modulation in θ-EEG synchronization over the motor-related and posterior-parietal regions. We also focused on contralateral and ipsilateral motor regions; previous studies have indeed found simultaneous activation during the preparation phase prior to reaching movement with the dominant hand (Tombini et al., 2009; Cruikshank et al., 2012).

Also, it has to be noted that ANX impairs the performance of the attentional system: the individuals' attentional resources can shift from a task-relevant stimulus to an eventual threat-relevant stimulus in stressful situations, or individuals can enhance the attentional effort to maintain their performance (Eysenck et al., 2007). The amplitude of the EEG activity ~10 Hz [alpha rhythm (α)] reflects the amount of the neural populations involved in the attentional processes (Niedermeyer and Lopes da Silva, 2005). Ascending level of α-EEG desynchronization accounts for ascending task-engagement due to the task's attentional demands (Stipacek et al., 2003). This α rhythm is classically divided into two sub-rhythms, namely slow-α and fast-α rhythms (Klimesch, 1999). The slow-α rhythm accounts for general, non-specific attention over broad regions of the brain, whether the fast-α rhythm is especially sensible to task-related attentional modulation over the parietal regions (Gevins et al., 1997; Klimesch, 1999; Stipacek et al., 2003). Thus, in complement to the main hypothesis regarding the sensorimotor θ-EEG activity, we also focused on the fast-α-EEG activity over the parietal regions as a task-related indication of the brain activity that could account for an effective manipulation of the brain ANX-network state – from the hypothalamic–pituitaryadrenal axis to the activation of brainstem nuclei (Steimer, 2002) – related to the breathing restriction.

METHODS

In this study, we replicated the experimental setup, experimental conditions, and task procedure reported in Daviaux et al. (2016). The main features are briefly reported here in order to improve the readability of the present work while optimizing its understanding. Readers