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Effects of anticipation certainty on preparatory brain activity and anticipatory postural adjustments associated with voluntary unilateral arm movement while standing

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ABSTRACT

We examined the effects of anticipation certainty concerning which voluntary movement is required in response to a stimulus while standing on preparatory brain activity and anticipatory postural adjustments (APAs). Ten right-handed adults abducted their left or right arm rapidly in response to a visual imperative stimulus, based on the type of stimulus. A warning cue, which did or did not contain information about the side of arm abduction, was presented 2000 ms before the imperative stimulus. Preparatory brain activity before arm abduction was quantified by the mean amplitude of the contingent negative variation 100 ms before the imperative stimulus (late CNV amplitude). Compared with the low anticipation condition, in the high anticipation condition the following results were obtained only in the case of right arm abduction: (1) larger late CNV amplitude, (2) earlier postural muscle activities with respect to the focal muscle of arm abduction, and (3) smaller peak displacement of center of pressure during the abduction. These findings suggest that high anticipation of voluntary movement of dominant arm to a stimulus while standing influences preparatory brain activity before the movement, resulting in earlier APAs and thus smaller disturbance of postural equilibrium during the movement.

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1. Introduction

When humans voluntarily move their limbs and trunk while standing, they compensate for internally induced postural disturbances caused by the movement in order to maintain postural equilibrium. This compensation is achieved by activation of postural muscles of the trunk and lower limbs that control standing posture in advance of the focal muscles of voluntary movement (Belen'kiĭ, Gurfinkel, & Pal'tsev, 1967). This type of postural control, known as anticipatory postural adjustments (APAs), reduces the effects of forthcoming perturbations on posture and equilibrium (Bouisset & Do, 2008). Since APAs are initiated before voluntary movement, the anticipatory postural muscle activities of the trunk and lower limbs are believed to be controlled by centrally preprogrammed motor commands (Bouisset & Zattara, 1981; Friedli, Hallet, & Simon, 1984; Horak, Esselman, Anderson, & Lynch, 1984).

The timing and/or magnitude of APAs are modulated according to which postural disturbances are induced by voluntary movement (Massion, 1992). Previous studies have revealed that changes in biomechanical parameters of voluntary movement, e.g., speed of the movement (Mochizuki, Ivanova, & Garland, 2004) and standing posture before the movement, e.g., initial standing position (Benvenuti, Stanhope, Thomas, Panzer, & Hallett, 1997; Fujiwara, Toyama, & Kunita, 2003), are related to such APA modulation. Furthermore, even though these biomechanical parameters are identical, APAs are also modulated by several high-level cognitive processes, such as anticipation (Brown & Frank, 1987; Fujiwara, Tomita, Maeda, & Kunita, 2009; Maeda & Fujiwara, 2007), attention (Shen, Fujiwara, & Tomita, 2009; Tomita & Fujiwara, 2008), and anxiety (Adkin, Frank, Carpenter, & Peysar, 2002). These studies suggest that changes in the central set, which is defined as a state of readiness to receive a stimulus or make a movement within the central nervous system (CNS) (Prochazka, 1989), play an important role in APA modulation.

It is known that performance of a voluntary response to a stimulus improves when humans know which response is likely to be required by the stimulus before its presentation (i.e., high anticipation certainty) (Jennings & van der Molen, 2005). In such circumstances, several brain areas related to sensory-perceptual processing of the stimulus and motor processing of the response are activated in advance of presentation of the stimulus (Brunia, 1999). Such preparatory modulation of activation in motor and sensory areas, which is assumed to be controlled by the frontoparietal cortical networks (Fuster, 2000), is believed to optimize subsequent sensory and motor processing, improving performance of the voluntary response (Talsma, Mulckhuyse, Slagter, & Theeuwes, 2007).

In the case of voluntary arm movement in response to a stimulus while standing, the certainty of anticipation concerning the types of response also influences performance of the response, at least in part as a result of modulation of the associated APAs (Brown & Frank, 1987). Although central organization of APAs associated with arm movement has been examined mainly in behavioral studies (e.g., Benvenuti et al., 1997) and patient studies (e.g., Viallet, Massion, Massarino, & Khalil, 1992), neurophysiological studies using electroencephalography (EEG) (Fujiwara, Tomita, Maeda, & Kunita, 2009; Jacobs, Henry, & Nagle, 2010; Maeda & Fujiwara, 2007; Shen et al., 2009; Tomita & Fujiwara, 2008; Yoshida, Nakazawa, Shimizu, & Shimoyama, 2008) and transcranial magnetic stimulation (Petersen, Rosenberg, Petersen, & Nielsen, 2009) over the last decade have revealed the mechanisms in greater detail. We recently reported that APAs associated with voluntary arm movement in response to a visual stimulus while standing are influenced by modulation of sensory-perceptual processing of the stimulus, which was quantified by visual event-related brain potentials (ERPs) (Tomita & Fujiwara, 2008). However, since this previous study recorded ERPs after the stimulus, it remains unclear whether changes in preparatory modulation of brain activity before a response stimulus (i.e., changes in the central set) according to certainty of anticipation regarding the type of voluntary response influence the associated APAs during standing.

Contingent negative variation (CNV), an ERP originally reported by Walter, Cooper, Aldridge, Mccallum, and Winter (1964), is a potential measurement of preparatory brain activity. The CNV is a slow negative shift in EEG amplitude, which is obtained by averaging EEGs during the period between the warning cue and imperative stimulus. Many previous studies have demonstrated that the late component of CNV (late CNV) represents preparatory brain activity (Brunia, 2003). In this paradigm of warning cue–imperative stimulus–motor response, the certainty of anticipation concerning