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BRAIN RESEARCH

Research Report

Neural evidence for impaired action selection in right hemiparetic cerebral palsy

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ARTICLE INFO

Article history:
Accepted 22 June 2010
Available online 28 June 2010

Keywords:
Hemiparetic cerebral palsy
Motor planning
Action selection
Event-related potentials
P2

ABSTRACT

Recent studies suggest that in addition to low-level motor impairments, individuals with hemiparetic cerebral palsy (HCP) are characterized by anticipatory action planning deficits as well. In the present EEG study we investigated the neural and temporal dynamics of action planning in participants with right-sided HCP ($n = 10$) and in left-handed control subjects ($n = 10$). An anticipatory planning task was used in which participants were required to grasp and rotate a hexagonal knob over different angles (60°, 120° or 180°). At a behavioral level, participants with HCP were slower in their movements and often selected an inappropriate grip when grasping the object. At a neural level, individuals with HCP showed a strong reduction in the amplitude of the P2 component, likely reflecting an impaired process of action selection. In addition, a strong correlation was observed between the P2 amplitude and grasping and rotation times. The P2 component was localized to sources in the dorsal posterior cingulate cortex (dPCC), an area that is known to be involved in orienting visual body parts in space. Together these findings suggest that anticipatory planning deficits in cerebral palsy arise mainly due to an impaired process of action selection.

1. Introduction

Individuals with cerebral palsy (CP) are characterized by non-progressive disorders of movement and posture that are attributed to disturbances in the fetal or infant brain (Bax et al., 2005). Clinical studies have shown large individual variability in terms of the brain areas affected, ranging from lesions in both gray and white matter, brain malformations to no detectable brain abnormalities at all (Korzeniewski et al., 2008; Wu et al., 2006). About 20–33% of the individuals with CP are categorized with hemiparetic CP (HCP), a form of CP affecting the left or right lateral side of the body (Koman et al., 2004; Wuet al., 2006).

In addition to low-level problems with motor execution, one recurring finding is that individuals with HCP are characterized by deficits in anticipatory action planning as well (for review, see Steenbergen & Gordon, 2006). These action planning deficits are occurring in both the affected and the (relatively) unaffected arm, and as such these problems have a major impact on activities in daily life. Previous studies have indicated that action planning deficits are especially apparent when the right body side is affected (Craje et al., 2009; Mutsaarts et al., 2007), in line with the proposed role of the left hemisphere in action planning (Haaland & Harrington, 1996; Vingerhoets, 2008). Support for the notion that action planning deficits are a

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doi:10.1016/j.brainres.2010.06.055

characteristic feature of HCP comes mainly from behavioral studies. Whereas healthy participants typically grasped objects with a grip that allows a comfortable posture at the end of a movement (Rosenbaum Vaughan et al., 1992), individuals with HCP often grasped objects with an initial comfortable grip, even if that resulted in an awkward end posture or task failures (Mutsaarts et al., 2005, 2006; Steenbergen et al., 2004). In addition, it has been found that HCP participants failed to anticipate the fingertip forces required for smoothly grasping an object (Duff & Gordon, 2003). Other studies indicate that people with HCP show less efficient grasping kinematics that – in contrast to healthy controls – are not influenced by later task demands (Chen & Yang, 2007; Steenbergen & van der Kamp, 2004). Although these studies provide tentative support for the notion that participants with HCP are characterized by anticipatory planning deficits, the neural and functional mechanisms underlying these impairments remain poorly understood.

An important aspect of action planning involves the selection of the correct motor program (Andersen & Cui, 2009). If you are grasping a pen, for instance, depending on your action intention you need to select a specific grip that allows you to use the object in a proper way (e.g. writing with a pen requires a different grip than moving a pen; cf. Daprati & Sirigu, 2006). Accordingly, in the present study we hypothesized that action planning problems in individuals with HCP may be related to an impaired process of action selection.

To investigate this hypothesis we used an action planning task in which subjects were required to make a rotating movement with their unaffected hand (cf. Mutsaarts et al., 2006). We measured subjects' EEG while they were preparing actions of varying difficulty (i.e. preparing to rotate a disk over 60°, 120° or 180°) and effects of task difficulty were explored by measuring event-related potentials (ERPs). Due to their high temporal resolution and the limited restrictions on subjects' hand and arm movements, ERPs provide the opportunity to capture the time-course of visuo-motor processing.

Based on our interest in early action planning, ERP analysis focused on the action preparation interval and more specifically on the anterior P2 (also labeled P2a or P3f; Makeig et al., 1999; Potts, 2004), which is a positive deflection over fronto-central sites with a peak latency of about 200 ms after the onset of a stimulus. Typically a larger P2 amplitude is observed for stimuli with a to-be-attended feature (Kenemans et al., 1993; Potts, 2004; Smid et al., 1999) and accordingly the P2 has been associated with the evaluation of task-relevant stimuli. In addition the P2 amplitude is larger for trials that require an overt response (Gajewski et al., 2008; Makeig et al., 1999; Potts et al., 1996) and the P2 has been associated with the anticipation of action consequences as well (Nikolaev et al., 2008). Interestingly, in a recent study we found a stronger P2 component (as reflected in a frontal selection positivity; FSP) when subjects were required to grasp compared to when they had to point towards a 3D target object (van Elk et al., in press). This task-specific modulation of the P2 was only found when subjects were required to actually perform the movement, but not when they withheld from a response. In sum, these studies suggest that the P2 reflects an action selection mechanism, enabling the coupling of relevant visual information to specific responses (Kuhn et al., 2009; Smid et al., 1999).

In the present study, it was hypothesized that motor planning deficits in participants with HCP should become apparent in slower reaction and movement times, less accurate rotations and more awkward grips compared to control subjects. Based on previous studies (Smid et al., 1999; van Elk et al., in press), we expected that the planning of more complex actions (i.e. rotating a disc over a larger angle) might be accompanied by a stronger anterior P2 component. In addition, differences in action planning between individuals with HCP and control participants may be reflected in a smaller amplitude of the anterior P2 for HCP compared to control participants.

2. Results

2.1. Behavioral results

The RT analyses revealed a main effect of rotation, $F(2, 17)=6.5$, $p<.01$, $\eta^2=.43$, reflecting that RTs increased with increased rotation angles (see Fig. 2). There was a marginal trend for direction, $F(1, 18)=3.7$, $p=.07$, $\eta^2=.17$, suggesting slower RTs for counter-clockwise rotations (777 ms, SE = 119 ms) than for clockwise rotations (738 ms, SE = 104 ms; see Fig. 1). No effect of group was found ($F<1$).

The analyses of grasping times showed a main effect of rotation, $F(2,17)=9.1$, $p<.005$, $\eta^2=.52$, reflecting slower grasping times with increased rotation angles (see Fig. 1). A main effect of direction, $F(1,18)=4.7$, $p<.05$, $\eta^2=.21$, reflected slower grasping times for counter-clockwise (2077 ms, SE = 190 ms) compared to clockwise rotations (1925 ms, SE = 188 ms; see Fig. 1). A marginally significant effect of group, $F(1,18)=4.2$, $p=.056$, $\eta^2=.19$, indicated slower grasping times for HCP subjects (2381 ms, SE = 263 ms) than for control subjects (1621 ms, SE = 263 ms; see Fig. 1).

As expected, the analyses of rotation times showed a main effect of rotation, $F(2, 17)=9.8$, $p<.001$, $\eta^2=.54$, reflecting longer rotation times with increased rotations (see Fig. 1). A main effect of direction, $F(1,18)=12.2$, $p<.005$, $\eta^2=.40$, reflected slower rotation times for counter-clockwise (3471 ms, SE = 196) compared to clockwise rotations (3198 ms, SE = 176 ms; see Fig. 1). A main effect of group, $F(1,18)=6.6$, $p<.05$, $\eta^2=.27$, reflected slower rotation times for HCP subjects (3801 ms, SE = 258 ms) than for control subjects (2869 ms, SE = 257 ms; see Fig. 1).

With respect to rotation errors (difference between instructed and realized rotation angle), a main effect of rotation, $F(2,17)=4.4$, $p<.05$, $\eta^2=.34$, reflected larger rotation errors with increased rotations (see Fig. 1). No effect of group was found, $F(1,18)=2.2$, $p=.15$.

In the analysis of the selection of initial grip types for grasping the hexagon it was found that HCP subjects more often grasped the hexagon with an initial comfortable hand grip (average number of selection of Grip 3 per category = 6.1) compared to control subjects (average number of selection of Grip 3 per category = 2.5), $F(1,18)=4.1$, $p=.059$. In an additional analysis based on the coding of anticipatory grips, a marginally significant interaction was found between direction and rotation, $F(2,17)=2.9$, $p=.08$. This interaction reflected that – overall – subjects showed anticipatory grip selection for 180° rotations. Importantly, a significant interaction between