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Action planning in typically and atypically developing children (unilateral cerebral palsy)

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ABSTRACT

In the present study, we investigated the development of action planning in children with unilateral Cerebral Palsy (CP, aged 3–6 years, $n = 24$) and an age matched control group. To investigate action planning, participants performed a sequential movement task. They had to grasp an object (a wooden play sword) and place the sword in a hole in a wooden block. Our main dependent variable was the grip type that participants used, i.e., did they adapt their initial grip choice such that they would reach a comfortable posture at the end of the action? This end-state comfort effect has been abundantly shown in research on action planning, and is taken as evidence for anticipatory planning. The first aim of the study was to investigate the development of action planning in the unilateral CP group and the control group. Our hypothesis was that action planning improves with age in the control group, but not in the unilateral CP group. The results showed that planning was impaired in the unilateral CP group compared with the control group. Consistent with our hypothesis, we found an age effect in the control group, but not in the unilateral CP group. In the control group 5 and 6 years olds showed more anticipatory planning compared with the 3 and 4 years olds. The second aim of this study was to examine whether an intervention for children with unilateral CP (i.e., constrained induced movement therapy combined with bimanual training) affected action planning. The children with unilateral CP were therefore measured on the experimental task before and after an 8-week intervention period. The results showed that planning improved after the intervention. This finding suggests that action planning ability in young children with unilateral CP may be sensitive to improvement. These findings are discussed within the context of typical and atypical development of action planning and further guidelines for intervention in children with unilateral CP are given.

1. Introduction

The age span between 3 and 10 years is critical for the development of motor control in children, as evinced by both behavioural studies (Ferrel, Bard, & Fleury, 2001; Hay, 1979; Hay, Bard, Ferrel, Olivier, & Fleury, 2005; Smyth & Mason, 1997; Thibaut & Thoussaint, 2010) as neuroimaging studies (Casey, Galvan, & Hare, 2005). In this age period, motor and sensory

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areas develop first, followed by higher order areas, such as the prefrontal cortex, which develop later (Casey, Tottenham, Liston, & Durston, 2005). An important aspect of motor control is motor planning. Motor planning can be defined as the ability to take the upcoming task demands into account when first taking hold of an object (Johnson-Frey, McCarty, & Keen, 2004; Mutsaarts, Steenbergen, & Bekkering, 2005, 2006; Steenbergen, Meulenbroek, & Rosenbaum, 2004). For example, a cup that is placed upside down and that needs to be turned over is initially grasped with an uncomfortable posture (thumb down, supination of forearm), such that the arm is in a comfortable posture (thumb up, pronation of the forearm) when the cup is turned over, i.e., at the end of the task. This phenomenon implies that participants planned the end of the action. Several studies showed that (adult) participants prefer to end an action with a 'comfortable end posture' and sacrifice comfort of the initial posture in order to attain this goal (e.g., Rosenbaum, Vaughan, Barnes, & Jorgensen, 1992).

Until now, the development of action planning in sequential tasks in children has only received limited attention, and results have been inconclusive. For example, Adalbjornsson, Fischman, and Rudisill (2008) studied two cohorts of children (2–3 and 5–6 years) that had to rotate a cup in order to pour water in it. They found that only a minority (11 of 40) of the children adapted their start posture in order to end the movement in a comfortable posture. No differences between these age groups were found. These findings suggest that action planning does not develop until age 6 (for consistent findings, see also Manoel & Moreira, 2005). In contrast, Smyth and Mason (1997) found that end posture planning developed in children between 3 and 8 years of age. Children had to rotate a bar, placed in different start orientations, into a target orientation. It was observed whether the children showed anticipatory planning, i.e., if they adapted the initial hand posture in order to reach a comfortable end posture. Planning improved with age, suggesting action planning develops between 3 and 8 years of age, although it has not yet reached adult levels at age 8. Consistently, Thibaut and Thoussaint (2010) showed that action planning increased from age 4 and till age 10. At age 10, a pattern of results similar to adults was observed.

Cerebral Palsy (CP) is a developmental disorder of movement and posture (Bax, Goldestein, Rosenbaum, Leviton, & Paneth, 2005). With a prevalence of 2.0–2.5 per 1000 living births, CP is the most common cause of severe disability in childhood (Blair & Watson, 2006). One of the most frequently occurring forms of CP is unilateral CP, where one vertical body side is affected, as a consequence of brain damage that primarily affects one hemisphere. Recently it has been proposed that the compromised action performance of children with unilateral CP is not only due to problems in action execution, but is also related to problems with action planning (Steenbergen & Gordon, 2006; Steenbergen, Verrel, & Gordon, 2007). Participants with unilateral CP were shown to be compromised in their capacity to be engaged in anticipatory action planning when using their unaffected arm (Mutsaarts et al., 2006; Steenbergen, Hulstijn, & Dortmans, 2000; Steenbergen et al., 2004). Instead of planning the end of the action they were shown to use a step-by-step planning strategy. That is, they first plan the movement towards the target object, and only after having grasped the object the next movement is subsequently planned (Mutsaarts et al., 2005; Steenbergen & Van der Kamp, 2004). This is in contrast with control participants that plan the entire action sequence prior to the start of the first movement. Rehabilitation efforts in children with unilateral CP are predominantly aimed at facilitation of the motor execution problems of the affected side. The beneficial effects of rehabilitation programs are often established by measures of movement *execution*, for example, the assessment of wrist flexion and extension, motor proficiency and speed, or ratings of movement quality (Charles & Gordon, 2007; Eliasson & Gordon, 2000; Gordon, Charles, & Wolf, 2006; Taub, Ramey, DeLuca, & Echols, 2004). However, the potential beneficial effects of therapeutic programs on motor *planning* have never been scrutinized.

The first aim of the present study was to investigate action planning in young children (aged 3–6) with and without unilateral CP as this age range is critical for the development of planning in typically developing children. Based on previous literature we expected to find an increase in end posture planning with age in the typically developing children. In contrast, as ample evidence suggests that action planning is impaired in adolescents with unilateral CP (Crajé, Van der Kamp, & Steenbergen, 2009; Mutsaarts et al., 2005, 2006), we expect no developmental improvement in action planning in the children with unilateral CP.

The second aim of our study was to examine whether action planning in children with unilateral CP is prone to change after intervention. Until now, it has not been investigated whether action planning capacities can be improved by therapeutic programs. This is surprising given the constraining effects of compromised planning on action performance (Steenbergen & Gordon, 2006). Therefore, our second aim of the present study was to explore the potential beneficial effect of an 8-week period of intensive hand function training on motor planning in children with unilateral CP (Aarts, Jongerius, Geerdink, Van Limbeek, & Geurts, in press). Despite the fact that the training was mainly focused on the affected side, we hypothesize that it may alleviate motor planning of the less-affected side based on two lines of evidence. First, anticipatory planning is based on previous manipulatory experience with an object (Salimi, Hollender, Frazier, & Gordon, 2000) and variability of practice, a facet that is central in CIMT, may further promote anticipatory planning (Schmidt & Wrisberg, 2000). Second, anticipatory planning can be transferred between both body sides in both healthy children and adults (Gordon, Forssbergh, & Iwasaki, 1994; Westling & Johansson, 1984). Specifically, weight and friction information of an object gained during previous lift with one hand can be used to scale the fingertip forces during subsequent manipulations with the contralateral hand. More importantly, in a recent study, Gordon, Charles, and Steenbergen (2006) studying children with unilateral CP, showed that performance related to anticipatory fingertip force control can be improved in the less-affected side if movements are first performed with the affected hand. Based on these two lines of evidence we hypothesize that intensive and variable upper limb training may be beneficial for motor planning of the less-affected side.