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Impaired anticipatory vision and visuomotor coordination affects action planning and execution in children with hemiplegic cerebral palsy

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ABSTRACT

Background: Action-planning and execution deficits in children with hemiplegic cerebral palsy (HCP) are potentially due to deficits in the integration of sensory information, such as vision, with motor output.

Aims: To determine differences in anticipatory visual patterns in children with HCP compared to typically developing (TD) children, and to assess visuomotor coordination in children with HCP.

Methods and procedures: We included 13 children with HCP (Age = 6.8 ± 2.9 yrs) and 15 TD children (Age = 5.8 ± 1.1 yrs). The experimental task used in this study is a valid action-planning task, which consisted of initially reaching and grasping an object placed at a fixed position, followed by placing the object in a random target position. Visual patterns were recorded using a head-mounted eye-tracker system and arm movements were recorded using motion capture (120 Hz).

Outcomes and results: Children with HCP had delayed anticipatory gaze time and longer latency than TD children during the planning and execution phases. Children with HCP also had a higher frequency of gaze shifts, longer reaction times (RT) and movement times (MT) than TD children.

Conclusions and implications: Children with HCP may have deficits in anticipatory vision, which potentially affected planning and executing a goal-directed action. Therapeutic interventions focusing on improving visuomotor coordination may improve the motor performance in children with HCP.

What this paper adds

The role of vision in planning and executing a goal-directed action in children with hemiplegic cerebral palsy (HCP) is not well understood. This study specifically evaluated the differences in visual anticipatory patterns, and integration of vision with motor output for controlling the upper extremity movement in children with HCP as compared to typically developing (TD) children. The asynchrony between eye and hand was measured during different stages of a goal-directed motor action. We found that children with

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HCP have delay in the onset of gaze timing on the goal in response to a starting stimulus, identified by a cue. Potentially, the impaired anticipatory visual control in children with HCP affected their ability to plan the goal-directed action since vision is a precursor for forward planning of movement. Moreover, the delay in gaze onset timing further delayed the initiation of arm movement and execution of the goal-directed action in children with HCP. This asynchrony in temporal coupling between eye and hand potentially also impacted the final execution of goal-directed action. This study demonstrates a critical role of vision in successful planning and execution of goal-directed actions and further suggests the need of incorporating therapeutic interventions that specifically focuses on improving visuomotor coordination to improve motor performance of children with HCP.

1. Introduction

Hemiplegic cerebral palsy (HCP) is one of the most common forms of cerebral palsy, with a prevalence of almost one in every thousand live births in the United States (Yeargin-Allsopp et al., 2008). Due to various sensorimotor dysfunctions, children with HCP have difficulty using the affected upper extremity for activities of daily living, specifically reaching, grasping, releasing, and manipulating objects. Along with sensory deficits, such as proprioception and tactile perception (Cooper et al., 1995; Sarlegna & Sainburg, 2009; Valvano & Newell, 1998), children with HCP have central deficits in integrating sensorimotor and visuo-perceptual modalities, which potentially affects the ability to execute motor actions (Gordon et al., 2006; Wann, 1991). Emerging evidence also suggests that impaired motor performance in children with HCP may be related to impaired forward control and deficits in planning goal-directed actions (Kurz et al., 2014; Steenbergen & Gordon, 2006; Surkar et al., 2018a; Surkar et al., 2018b).

Action planning is the ability to anticipate forthcoming perceptual-motor demands of an action goal (Kaller et al., 2010), and involves higher levels of cognitive and visual processes (Glover, 2004; Glover et al., 2012). Studies investigating planning deficits in children with HCP have for the most part been based on object manipulation and anticipatory fingertip forces (Gordon et al., 2006; Gordon, Charles, & Duff, 1999). These studies suggested possible deficits in the integration of sensory information, such as vision, with motor output in children with HCP. Although vision plays a critical role in planning an action, it has been largely overlooked in children with HCP.

Vision, along with dynamic integration with various sensorimotor systems, plays a critical role in the successful execution of goal-directed actions (Goodale, 2011; Land et al., 1999; Mackrous & Proteau, 2016; Neggers & Bekkering, 1999; Sarlegna & Sainburg, 2009). To achieve the end goal of a goal-directed action, visual scanning is first required for the identification and location of a target. This visual information then contributes to appropriate motor commands. When the task is complex, vision is engaged to closely monitor actions, update an action plan, and amend action execution (Desmurget & Grafton, 2000; Franklin et al., 2012). Collectively, a motor command is sent to a forward model that anticipates sensorimotor consequences, predicts the movement endpoint, and issues corrective motor commands to accomplish an accurate goal-directed action if necessary. The forward model is updated during movement execution by incoming proprioceptive and visual inputs (Shadmehr et al., 2010).

Visual and proprioceptive information contributes to the control of limb coordination (Sarlegna & Sainburg, 2009). Integration of visual and proprioceptive signals from the periphery is required to estimate the position of the arm while planning a goal-directed action (Desmurget & Grafton, 2000). Vision provides extrinsic information and is used to accommodate the spatial features of movements toward visual targets, whereas proprioception provides intrinsic information about limb configuration and movement. This information is used to transform the spatial plan into neural/motor commands (Sarlegna & Sainburg, 2009).

One such example of visual and proprioceptive coupling is eye-hand coordination. Studies on eye-hand coordination of visual targets in healthy adults have shown that saccadic eye movements are much shorter and quicker than goal-directed hand movements, and that the eyes first fixate on the target before a hand movement begins (Bekkering et al., 1995; Abrams et al., 1990; Bekkering et al., 1994). Moreover, movements are more accurate when the person is able to see while making them (Desmurget et al., 1997; Elliott et al., 1991; Ghez et al., 1995). Furthermore, movement errors occur when visual feedback of the initial position is distorted (Bagesteiro et al., 2006; Holmes & Spence, 2005; Sainburg et al., 2003; Sarlegna & Sainburg, 2007; Sober & Sabes, 2003). The results of these studies suggest that vision precedes hand movements and is a precursor for anticipatory control of goal-directed actions. To ensure that movement is spatially accurate, the control system requires rapidly computed visual representations. Thus eye movements seem to be tightly coupled, both temporally and spatially, to the motor actions of a specific task (Adam et al., 2012). Potentially, the eyes are mainly involved in "forward planning," or seeking out objects for future use and setting up the operations to be performed on them.

It has been shown that forward planning is affected in children with HCP (Mutsaarts et al., 2006; Duff & Gordon, 2003; Mutsaarts et al., 2005). However, studies investigating the contribution of vision in action planning deficits in children with HCP are very limited. Studies that have investigated eye-hand coordination demonstrated that children with HCP closely monitor the actions of the affected hand during object manipulation and transportation (Verrel, Bekkering, & Steenbergen, 2008). Steenbergen and colleagues also anecdotally noted increased visual attention to the affected hand (Steenbergen et al., 1996). These observations suggest that online visual monitoring of movements is potentially used to compensate for underlying sensorimotor deficits. Although a strategy of close visual monitoring might be beneficial for online control of action, such strategy may compromise the planning process as a whole. This may impair the ability to scan the visual scene and identify task-relevant landmarks in advance, which is necessary for appropriate prospective control of an action. Therefore, investigating anticipatory visual strategies in children with HCP is crucial to understanding the nature of planning deficits in children with HCP.

The purpose of this study was a) to determine differences in anticipatory visual patterns in children with HCP compared to typically developing (TD) children and b) to assess visuomotor coordination in children with HCP. Our first hypothesis was that children with HCP would have delayed anticipatory gaze patterns, which may impact the action planning and execution of goal-

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