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CHILDREN WITH DEVELOPMENTAL COORDINATION DISORDER ARE DEFICIENT IN A VISUO-MANUAL TRACKING TASK REQUIRING PREDICTIVE CONTROL

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Abstract—The aim of this study was to examine how feedback, or its absence, affects children with Developmental Coordination Disorder (DCD) during a visuo-manual tracking task. This cross-sectional study included 40 children with DCD and 40 typically developing (TD) children between 6 and 10 years old. Participants were required to track a target moving along a circular path presented on a monitor by moving an electronic pen on a digitizing tablet. The task was performed under two visibility conditions (target visible throughout the trajectory and target intermittently occluded) and at two different target velocities (30° and 60° per second). Variables reflecting tracking success and tracking behavior within the target were compared between groups. Results showed that children with DCD were less proficient in tracking a moving target than TD children. Their performance deteriorated even more when the target was occluded and when the target speed increased. The mean tracking speed of the DCD group exceeded the speed at which the target rotated which was attributed to accelerations and decelerations made during tracking. This suggests that children with DCD have significant difficulties in visuo-manual tracking especially when visual feedback is reduced. It appears that their impaired ability to predict together with impairments in fine-tuning arm movements may be responsible for poor performance in the intermittently occluded visuo-manual tracking task.

Key words: developmental coordination disorder, visuo-manual tracking, manual pursuit, feed forward control, predictive control.

INTRODUCTION

Children with Developmental Coordination Disorder (DCD) are reported to have difficulties executing everyday manual tasks that require visual information (visuo-manual coordination) such as writing, tying shoelaces, aiming and reaching for objects or catching a ball (Wang et al., 2009; Magalhaes et al., 2011; Ferguson et al., 2014). In comparison to their peers, the motor performance of children with DCD during these tasks lacks fluency and precision. Their inaccurate and error-prone movements have been attributed to variability in controlling the temporal and spatial aspects of movement and to inconsistencies in force production and regulation, all pointing toward an underlying deficit in motor control (Piek and Skinner, 1999; Smits-Engelsman et al., 2003a; Van Waelvelde et al., 2006).

Motor control includes the use of a combination of both feed-forward and feedback control strategies (Wolpert and Miall, 1996). The feedback system is reliant on adequate sensory information, error detection and integration (Scott, 2012). Impairments in one or more of these processes may be regarded as a source of poor motor performance. Feed-forward motor control is defined as the ability to estimate the temporal and spatial requirements of a motor task and predict the sensory consequences of the impending action (Wolpert and Miall, 1996). It is hypothesized that feed-forward control is sub-served by internal forward models (Blakemore and Sirigu, 2003; Kawato et al., 2003). Limb state-estimation (i.e., estimating the location and position of a limb at any given moment), target-state estimation (i.e., estimating the coordinates of external objects or targets) and information related to the relationship between limb and object/target are all inputs into an internal model (Scott, 2012). This information is then used to organize and monitor movements. Information via internal models is available much more rapidly than afferent feedback signals, resulting in greater efficiency of the motor system (Wolpert et al., 1998).

To understand the extent to which deficits in motor control processes contribute to the poor motor

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Abbreviations: ADD, Attention Deficit Disorder; ADHD, Attention Deficit with Hyperactivity Disorder; APAs, anticipatory postural adjustments; DSST, Double Step Saccade Task; DCD, Developmental Coordination Disorder; fMRI, functional Magnetic Resonance Imaging; IMD, internal modeling deficit; LD, Learning Disorder; MABC-2, Movement Assessment Battery for Children-second edition; PPC, posterior parietal cortex; TD, typically developing; TV, tracking variability.

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performance that is seen in children with DCD, various studies have focused on the interaction between feed-forward and feedback control processes as the basis for efficient motor control (Wilson et al., 2004, 2013; Gabbard, 2009). In terms of the underlying motor control deficits associated with DCD, evidence from an information processing paradigm has implicated impairments in the use of feedback systems such as motion detection, tactile perception and visuo-spatial processing (Wilson et al., 2013). However, recent research, using computational neuroscience paradigms, proposes that impaired motor control in children with DCD may also be due to deficits in generating and using internal forward models, which is referred to as an internal modeling deficit (IMD) (Wilson et al., 2004; Williams et al., 2006; Hyde and Wilson, 2011).

Evidence suggests that children with DCD are more reliant on online visual feedback information and that they take longer to utilize visual information for the generation and control of actions than their typically developing (TD) peers (Wilmut et al., 2006). Successful use of predictive control strategies may also be confounded by deficits in kinesthetic processing ability and by problems with error detection and correction which has been reported in children with DCD (Wilson and McKenzie, 1998; Kagerer et al., 2006). Hence, there is a need to re-examine these questions preferably by using a paradigm that allows various degrees of feedback and feed-forward control. Since DCD involves deficits in manual dexterity (Smits-Engelsman et al., 2001, 2003b, 2008), the choice was made to study specific visuo-manual tracking or manual pursuit tasks.

When tracking a slow-moving target that follows a predictable trajectory, feedback and feed-forward strategies may be used to prevent and correct errors. However, when target motion is faster, the use of feedback is more difficult and one has to rely more on feed-forward control (Wolpert et al., 1998). Making appropriate adjustments in a tracking task entails the detection of visual information about the current position of the target and making estimates of that position in the near future (referred to as prospective control). Prospective control is an essential component of effective motor control and has been reported to be impaired in children with DCD (Debrabant et al., 2013). In cases where the visual stimulus is removed or transiently occluded, then the most important source of feedback is lacking, thereby forcing the subjects further in the direction of enlisting feed-forward control.

Pursuit tasks with temporary occlusion of the target have been used primarily in oculomotor studies (Newsome et al., 1988; Mrotek and Soechting, 2007; Orban de Xivry et al., 2008). For example, Newsome et al. (1988) introduced an ocular pursuit task with visual occlusion in monkeys to demonstrate that certain cells in the middle temporal area continue firing after occlusion. They thus demonstrated that these cells used extraretinal input, most likely derived from an efference copy, produced by an internal model. Two recent studies have investigated ocular pursuit in children with DCD and found a reduced gain with regard to horizontal pursuit in a young DCD group (n = 8, 5–7 years) (Langaas et al., 1998). In a larger study with older children (n = 27, 8–12 years), it was shown that the vertical pursuit, not the horizontal one, is significantly impaired in children with DCD (Robert et al., 2014).

While the tasks used thus far in studies of pursuit in DCD have focused on *ocular* pursuit, the addition of *manual* pursuit tracking makes this paradigm directly related to functional visuo-manual skills used in daily life. However, studies using manual pursuit tasks in children are rare and they have focused either on TD children (van Roon et al., 2008) or children with learning disabilities (van Roon et al., 2010) and not on children with DCD. Recently, a functional Magnetic Resonance Imaging (fMRI) study, which adopted a visually guided tracking task, reported that children with DCD were significantly less accurate than control children when guiding a cursor toward an easy to track, continuously moving, horizontal target (Kashiwagi et al., 2009). More importantly, differences in brain activation were shown, in the left posterior parietal cortex (PPC) and left post-central gyrus. These areas are known to cause visuo-motor deficits affecting hand-eye coordination. Moreover, the PPC plays an important role in generating mental representations of movement (Sirigu et al., 1996).

In contrast to ocular pursuit, no study using a manual pursuit task with temporary occlusion in children with DCD was available at the time of our study. As it was expected that DCD subjects would be poor in tracking, it was hypothesized that their pursuit trace would be less optimal than that of the TD controls. To allow these differences to be revealed as clearly as possible, the pursuit task was executed at two speeds and with intermittent occlusion of the target. It was hypothesized that tracking would show even more deficits in DCD children under these more difficult conditions. The aim of this study was thus to examine how feedback, or its absence, affects visuo-manual tracking in children with DCD. The specific objectives were to examine the effect of visual information and target speed on (1) manual tracking performance, (2) parameters of the trajectory trace while in the target and (3) the differences between DCD and TD on these variables.

EXPERIMENTAL PROCEDURES

Participants

In this cross-sectional study, children between the ages of 6 and 10 years old were recruited from two mainstream primary schools situated in Cape Town, South Africa using convenience sampling.

Children were identified as having DCD by using the four criteria based on the Diagnostic and Statistical Manual-4th Edition (American Psychiatric Association, 2000). Children were included in the DCD group if they met all four criteria.

The Movement Assessment Battery for Children-2 (MABC-2) (Henderson et al., 2007) was used to evaluate the motor performance of the participants (criterion A). The MABC-2 is considered to be a reliable and valid measure for assessing motor performance in DCD