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Multisensory integration in children with Developmental Coordination Disorder

R.O.A. Coats, L. Britten, A. Utley, S.L. Astill *

School of Biomedical Sciences, Faculty of Biological Sciences, University of Leeds, Leeds LS2 9JT, United Kingdom

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ABSTRACT

This study examines how multisensory stimuli affect the performance of children with Developmental Coordination Disorder (DCD) on a choice reaction time (CRT) task. Ten children with DCD, identified using the Movement Assessment Battery for Children-2, aged 7–10 years (4F, M = 8 y 3 m, SD = 17 m) and 10 typically developing peers (TDC) (5F, M = 8 y 4 m, SD = 17 m) reached to unimodal (auditory (AO), visual (VO)) and bimodal (audiovisual (AV)) stimuli at one of three target locations. A multisensory (AV) stimulus reduced RTs for both groups ($p < 0.001$, $\eta^2 = 0.36$). While the children with DCD had a longer RT in all conditions, the AV stimulus produced RTs in children with DCD (494 ms) that were equivalent to those produced by the TDC to the VO stimulus (493 ms). Movement Time (DCD = 486 ms; TDC = 434 ms) and Path Length (DCD = 25.6 cm; TDC = 24.2 cm) were longer in children with DCD compared to TDC as expected ($p < 0.05$). Only the TDC benefited from the AV information for movement control, as deceleration time of the dominant hand was seen to decrease when moving to an AV stimulus ($p < 0.05$). Overall, data shows children with DCD do benefit from a bimodal stimulus to plan their movement, but do not for movement control. Further research is required to understand if this is a result of impaired multisensory integration.

1. Introduction

Developmental Coordination Disorder (DCD) is a neurodevelopmental disorder that is characterised by poor fine and/or gross motor coordination (APA, 2013). Depending on how the APA assessment criteria are interpreted and applied, prevalence in the UK is estimated at between 1.7% and 6% of primary school aged children (Lingam, Hunt, Golding, Jongmans, & Emond, 2009). Due to its high prevalence there is now a vast body of literature that has tried to understand the mechanisms of DCD in an attempt to optimise therapy.

Goal orientated upper limb tasks have been extensively studied as a window into movement deficits of children with DCD (Astill, 2007; Biancotto, Skabar, Bulgheroni, Carrozzi, & Zoia, 2011; Wilmut, Wann, & Brown, 2006) with the planning and execution of these tasks often measured using reaction time (RT) and Movement Time (MT) respectively. Research shows that children with DCD exhibit slower, more variable RTs than typically developing children (TDC) as a result of either slower processing speed, inefficient preparation of movement or both (Debrabant, Gheysen, Caeyenberghs, Van Waelvelde, & Vingerhoets, 2013; Henderson, Rose, & Henderson, 1992; Hyde & Wilson, 2011). Similarly, MTs are frequently reported as

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* Corresponding author.
E-mail address: s.l.astill@leeds.ac.uk (S.L. Astill).

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longer in children with DCD compared to TDC (Astill, 2007; Biancotto et al., 2011; Hyde & Wilson, 2011) perhaps as a result of a heavier reliance on visual information for movement control (Adams, Lust, Wilson, & Steenbergen, 2014).

The planning and execution of hand movements require information about the position of the hand and the location of the target, so that it can be transformed into signals activating the appropriate muscles in order for the hand to reach the respective target. This sensorimotor transformation represents the internal representation of the relationship between visual space and motor space, or the internal model (Wolpert & Ghahramani, 2000). Recently, it has been suggested that the currently available data point to children with DCD having an internal modelling deficit which can be behaviourally manifested in, for example, more variable and slower MTs (Wilson, Ruddock, Smits Engelsman, Polatajko, & Blank, 2013). Information about target location is critical to producing a viable forward model of action, and can be provided by multiple sensory modalities, as multisensory information. These sensory stimuli can provide information about where the object or target is and planning the action to intercept/interact with the target, and the object or target qualities themselves (Jeannerod, 2006).

There is a large body of research which suggests that children with DCD display visual processing deficits (Tsai, Wilson, & Wu, 2008; Van Waelvelde, De Weerdt, De Cock, & Smits-Engelsman, 2004; Wilson & McKenzie, 1998) and this directly impacts on a child with DCD in terms of being able to plan and execute simple aiming and reach to grasp actions (Biancotto et al., 2011). Multisensory integration has been implicated as a deficit in children with DCD, with past research shows that children with DCD have difficulty with cross modal transfer of information (Sigmundsson, Ingvaldsen, & Whiting, 1997) and the integration of information from multiple senses (Bair, Kiemel, Jeka, & Clark, 2012). More specifically, Bair et al., 2012 suggest that children with DCD weighted information from touch (haptic) and visual information differently while attempting to maintain a steady posture, and concluded that in children with DCD, multisensory integration or fusion is impaired, and this contributes to their general motor deficit.

While the Bair et al. (2012) study considered the fusion of touch and visual information there is no one study that has examined if children with DCD can fuse auditory and visual information and then make use of the multisensory enhancement that an audiovisual stimulus provides to aid planning and execution movement. In general, when visual and auditory stimuli are presented in close spatial and temporal correspondence they become ‘bound’ into a single perceptual entity, the result of which is an enhancement of the neural response to the stimuli (see Stein & Stanford, 2008 for a review). In healthy adults Hecht, Reiner, and Karni (2008) have shown that combinations of multisensory signals, e.g., audio and visual stimuli (bi-modal) could be detected faster (i.e., a shorter RT) than either of these signals presented separately (unimodal). A similar set of data are revealed when considering saccadic eye movements in that when saccades were made to visual and auditory targets their reaction times were decreased, and accuracy increased compared to those generated to unimodal stimuli (Bell, Meredith, Van Opstal, & Munoz, 2005; Frens, Van Opstal, & Van der Willigen, 1995). In children, postnatal development plays an important role in the maturation of multisensory facilitation. For example, Brandwein et al. (2011) showed that multisensory facilitation of behaviour (i.e., quicker RTs to an audiovisual task) is present in (typically developing) children as young 7, but adult levels are not reached until about 14 years of age.

While it has been shown that an audiovisual stimulus can drive shifts in attention to the target resulting in a decrease in RT, if the stimulus is seen as relevant to a movement goal it can also mediate the processes involved in movement execution (Talsma, Doty, & Woldorff, 2007). Evidence in humans and non-human primates suggests that other sensory information is integrated with auditory information in the auditory dorsal pathway, and taken together, research shows that motor and auditory information, once coupled, can be reciprocally activated by inputs to either end of the dorsal pathway (Warren, Wise, & Warren, 2005). Indeed, research shows that the advantages of multisensory information extend beyond planning to movement execution. For example, in adults a bimodal stimulus produced a more forceful response than a unimodal stimulus (Giray & Ulrich, 1993). This potential bi-sensory coactivation within the motor system was also supported by Plat, Praamstra, and Horstink (2000) who showed that while the modulation of force amplitude was not affected by bimodal stimulation, the time needed for the force signal to reach its maximum amplitude was shorter with a bimodal signal compared to a unisensory one. While Utley, Nasr, and Astill (2010) have previously shown that a ball (visual stimuli) that emitted broadband sound (audio stimuli) was more successful in aiding development of catching and throwing skills over a 4 week training period, research that has examined if combinations of stimuli aid movement control during execution, even in typically developing children is limited. It could be that multisensory information might support children with and without DCD in the generation or updating of internal models for executing upper limb movements, and this may be reflected in the movement kinematics of the limbs.

In light of the above, here we investigate the performance of children with DCD and age matched controls on a multisensory aiming task. The aim of this study was to examine whether multisensory enhancement asserts its effect on the perceptual/planning part of the movement (RT) or the execution of the movement (MT) or both, and how this differs in children with DCD compared to typically developing children (TDC).

2. Methods

2.1. Participants

Ten children (Males = 6) aged 7–10 years of age (M = 8 y 3 m; SD = ±17 m) who met the research criteria for DCD and 10 children (Males = 5, M = 8 y 4 m; SD = ±17 m) who are age matched (±0.3 m) to the children with DCD participated in the