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Reaching to throw compared to reaching to place: A comparison across individuals with and without Developmental Coordination Disorder

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ABSTRACT

When picking up an object, adults show a longer deceleration phase when the onward action has a greater precision requirement. Tailoring action in this way is thought to need forward modelling in order to predict the consequences of movement. Some evidence suggests that young children also tailor reaching in this way; however, how this skill develops in children with Developmental Coordination Disorder (DCD) is unknown. The current study compared the kinematics of reaching to an object when the onward intention was: to place the object on a target (either with high or low precision requirements), to throw the object or to lift the object vertically. Movements of both adults ($N = 18$) and children ($N = 24$) with DCD and their age-matched controls were recorded. The typically developing adults discriminated across all action types, the adults with DCD and the typically developing children only across the actions to place and throw and the children with DCD only between the actions to lift and throw. The results demonstrate developmental progression towards fine tuning the planning of reaching in relation to onward intentions. Both adults and children with DCD are able to plan movement using inverse models but this skill is not yet fully developed in early adulthood.

1. Introduction

Every action that we carry out during our daily lives is composed of a string of movements; drinking tea from a cup consists of reaching out and grasping the cup, lifting the cup, moving it towards our mouth, tipping it to an angle that allows us to drink and not spill the tea, and then placing the cup back down. The way in which we grasp the cup and where we place our hand allows both lifting and drinking; if we grasped the cup handle too far down we would need to re-assess our grip before continuing. Therefore, the grasping movement needs to take into account that the next movement is lifting and the one after drinking. This forward anticipation of movement whereby one movement is tailored to the onward action allows a spatially and temporally optimal movement, minimising fatigue, maximising comfort, lowering energy output and achieving accuracy (Haggard, 1998; Rosenbaum, Vaughan, Barnes, & Jorgensen, 1992).

One might imagine that aspects of the movement which are tailored to the onward action are the overt aspects of reach-to-grasp such as positioning of the hand and fingers on the object, type of grasp used and pressure of grasp. However, it would seem that this is not all that is planned. Marteniuk, MacKenzie, Jeannerod, Athenes, and Dugas (1987) reported that the onward action also effects the precise kinematics of the initial reach-to-grasp trajectory. They asked participants to either reach and fit an object into a hole or reach and throw the object. Initial demands of the reach component were identical

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across conditions. However, during the reach phase an elongated deceleration phase was seen for the fit as compared to the throw action and this resulted in a longer movement when grasping to fit compared to grasping to throw (Marteniuk et al., 1987). The authors suggest that the different precision requirements of the two onward actions could be used to explain this; the higher the precision requirements the higher the movement times and deceleration phase. Armbruster and Spijkers (2006) considered a greater range of actions: lifting, throwing and placing an object. They found that peak aperture of the hand was larger and peak deceleration was higher when the grasp was followed by either a throwing or a placing movement as compared to a lift movement. Unlike Marteniuk et al. (1987) they did not see a difference between reach characteristics for the place and the throw conditions. Findings such as these are not only seen for movement kinematics. For example Ansuini, Giosa, Turella, Altoe, and Castiello (2008) and Ansuini, Santello, Massaccesi, and Castiello (2006) considered the grasp preceding a lift movement, a place in a tight niche or a place in a large niche movement. They found that the degree of end-goal accuracy did affect hand shaping during the approach phase, with a distinctly different hand shape across the two 'place' movements. Once again this highlights movement precision as a key factor in the mechanism behind fine tuning a movement to an onward action.

These findings point towards the importance of tuning each sub-component of an action to optimise the transition from one component to another. This type of fine tuning has been previously demonstrated in co-articulation studies which have shown that sequences of actions are more than the positioning of action elements in succession (e.g., Rosenbaum, 1991). It has been suggested that this concatenation of actions could be explained in terms of inverse models (Ansuini et al., 2006). Inverse models anticipate the consequences of a motor plan prior to execution (Wolpert & Kawato, 1998) and as such could anticipate which specific reaching movement was needed given a subsequent action (Ansuini et al., 2006).

Tuning a reaching movement in this way seems to develop in early life, Claxton, Keen, and McCarty (2003) have demonstrated a difference in the initial grasp movement when 10-month-old infants are asked to throw a ball compared to place it in a tube. When reaching to throw, the infants demonstrated a higher peak velocity compared to when they were reaching to place. Furthermore, by 4 years of age children demonstrate an elongated deceleration period for a 'grasp to fit' action compared to a 'grasp to throw' action (Chen & Yang, 2007). Interestingly, Chen and Yang (2007) also considered children with Cerebral Palsy (CP; who were able to reach-and-grasp and hold an object with their less affected hand), these children did not seem to engage in forward planning their reach movement and showed no difference in reach kinematics across action types (a similar finding has been demonstrated elsewhere: e.g. Mutsaarts, Steenbergen, & Bekkering, 2006). The authors suggest that this may indicate that children with CP lack the ability to use inverse models to anticipate onward action and therefore, sub-movements are performed sequentially without an integrative plan. An alternative explanation is that the lack of difference may be caused by the limited repertoire of movements in the children with CP.

Within the population, approximately 2% of children present with difficulties in the execution and coordination of body movements which cannot be accounted for in terms of an intellectual impairment or identifiable physical or neurological disorder (Lingam, Hunt, Golding, Jongmans, & Emond, 2009). This condition is termed Developmental Coordination Disorder (DCD) and problems manifest in difficulties with fine motor tasks such as tracing, writing and fastening buttons, and/or in gross motor tasks such as jumping, hopping and riding a bike (Sugden & Wright, 1998). Many children with DCD continue to exhibit problems throughout adolescence (Cousins & Smyth, 2003; Losse et al., 1991), however, little is known about how these individuals develop into and throughout adulthood. Despite an increasing number of studies focusing on DCD, very little is known about the underlying cause of the movement problems (see Visser, 2003, for a review). However, several studies have highlighted poor motor planning (e.g. Schoemaker et al., 1994), which in part may be explained by a difficulty in the internal modelling of movement used to predict or anticipate the outcome of action (Maruff, Wilson, Trebilock, & Currie, 1999; Smits-Engelsman, Caeyenberghs, van Rood, & Swinnen, 2007; Williams, Thomas, Maruff, Butson, & Wilson, 2006). To date, no research has considered whether children with DCD are able to tailor an initial reaching movement to the end-goal. Therefore, this aspect of forward anticipation needs consideration in a DCD population.

The current study considers four different onward actions: throw, lift and two place actions (one with a high precision and one with a lower precision requirement) across children and adults, typically developing and with DCD. Based on previous research, the four actions chosen should give us the best chance of seeing a tailoring to onward intention effect in the typically developing group and whether precision requirements (as suggested by Marteniuk et al., 1987) can be used to explain the differential kinematics across reach movements for different onward actions. Previous studies have used a range of different objects, from tennis balls to disks, all of which have shown effects of onward action. In this study we chose to use a small cylinder. Given previous findings we would expect both typically developing populations to show some differences in the kinematics of the initial reach movement for the throw as compared to the other actions. This will most likely manifest in a longer deceleration phase for the higher precision movements (place vs. throw). The movement difficulties of children with CP are both quantitatively and qualitatively different to those in DCD. However, both populations have demonstrated a difficulty with using inverse models to forward anticipate movement (Maruff et al., 1999; Mutsaarts et al., 2006; Smits-Engelsman et al., 2007) and so we might expect to see a similar pattern of behaviour in the children with DCD as was seen in the children with Cerebral Palsy (Chen & Yang, 2007), whereby the children with DCD fail to tune an initial reaching movement to the onward action. However, the way in which this develops from childhood to adulthood is unknown. This is the first study to consider the exact nature of tailoring initial kinematics to onward action in a DCD population. As such it will provide a greater insight into the nature of motor planning in this population. This study is also one of the first to examine skill performance across children and adults with DCD. These two novel aspects of the study will help to further our understanding of the mechanisms underlying DCD.