A Test of Motor (Not Executive) Planning in Developmental Coordination Disorder and Autism

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Grip selection tasks have been used to test “planning” in both autism and developmental coordination disorder (DCD). We differentiate between motor and executive planning and present a modified motor planning task. Participants grasped a cylinder in 1 of 2 orientations before turning it clockwise or anticlockwise. The rotation resulted in a comfortable final posture at the cost of a harder initial reaching action on 50% of trials. We hypothesized that grip selection would be dominated by motoric developmental status. Adults were always biased towards a comfortable end-state with their dominant hand, but occasionally ended uncomfortably with their nondominant hand. Most 9- to 14-year-olds with and without autism also showed this “end-state comfort” bias but only 50% of 5- to 8-year-olds. In contrast, children with DCD were biased towards selecting the simplest initial movement. Our results are best understood in terms of motor planning, with selection of an easier initial grip resulting from poor reach-to-grasp control rather than an executive planning deficit. The absence of differences between autism and controls may reflect the low demand this particular task places on executive planning.

Keywords: motor planning, grip selection, bias, prehension, coordination, autism, DCD

The topic of “planning” has been of great interest in recent years. Planning skills are thought to be impaired in a range of neurodevelopmental disorders including attention deficit hyperactivity disorder (ADHD; Scheres et al., 2004), autism (Hill, 2004; Hughes, 1996) and developmental coordination disorder (DCD: cf. Smyth & Mason, 1997). But what exactly is “planning”? Planning seems to fall naturally into two basic categories within the research literature. The first, which we will call executive planning, categorizes planning as an executive function involving a sequence of choices or moves that must be arranged in order to achieve a desired end state (a goal). Methods for assessing executive planning include tasks such the Towers of Hanoi (e.g. Hill, 2004) and London (Shallice, 1982). The second category focuses on what we will refer to as motor planning (Cohen & Rosenbaum, 2004; Rosenbaum, Heugten, & Caldwell, 1996; Rosenbaum et al., 1990; Rosenbaum, Meulenbroek, Vaughn, & Jansen, 2001; Rosen-
baum, Vaughn, Jorgensen, Barnes & Stewart, 1993). Rosenbaum and colleagues have used tasks that measure the type of grip selected by participants (e.g. overhand vs. underhand) when asked to do a two-stage task (e.g. grasp-and-turn). Adults in these tasks tend to make a less comfortable initial grasp if it allows them to turn the object so as to end up in a comfortable posture (the “end state comfort effect”).

Motor and executive planning are often discussed as if they have a great deal in common. Indeed, it is likely that many movement tasks require both executive and motor planning (what we will call action planning). Nonetheless, there are important differences that need to be addressed. For example, the Towers of Hanoi and London involve several abstract, largely nonrepetitive, cognitive steps. These tests of executive planning often rely on the task being first performed in the imagination before commencement and depend upon executive processes such as working memory. In contrast, tasks that assess motor planning involve behavior that is often cognitively impenetrable and depends upon learned movement skills built up over developmental experience.

Smyth and Mason (1997) used Rosenbaum et al.’s handle task on children aged 4–8 years with and without DCD. They found that young children had a propensity to grasp the handle in a way that led to uncomfortable end states after rotation. This was interpreted as showing that the young children lacked planning skills during the task. Hughes (1996) administered a grip selection task to a group of children with autism. Hughes found children with autism were less likely to select a grip that favored end-state comfort (the adult pattern observed by Rosenbaum et al) and used this finding to suggest that the children lacked planning skills. The difficulty with interpreting these results as generic planning difficulties is the lack of distinction between motor and executive planning. We suggest that grip selection tasks may be problematic as a test of executive planning and that interpreting the results of Hughes (1996) or Smyth and Mason (1997) in these terms (or generic “planning” terms) is inherently unsatisfactory. For example, on such tasks adults only select a grip that results in end-state comfort (ESC) on 80%–90% of trials in two key handle locations (Rosenbaum, Vaughan, Jorgensen, Barnes, & Stewart, 1993). If we interpret ESC grip selection as evidence of executive planning then we must suppose that the adults lost their ability to cognitively plan on 10%–20% of the trials. This strange conclusion arises from assuming that the optimal solution to the problem is always the majority response and that any deviation implies impaired executive planning.

An alternative framework is to treat grip selection tasks as testing motor planning with motor status affecting motor planning. Rosenbaum’s handle turning task has two requirements to reach the end-state position: (1) reach-to-grasp the handle, and (2) turn the handle. Selecting a grip to maximize end-state comfort is only efficient if this is not outweighed by the extra costs of a difficult initial movement. Children who find the initial reach-to-grasp difficult may select the simplest initial movement even at the cost of an overall inefficient movement. Likewise they might be biased to select a constant grip despite this being less optimal in the second task component. Selection of this constant grip might then be subject to other biases, such as trying to minimize the required precontact rotation of the arm. Thus, observation of one type of grip selection cannot be taken as evidence for or against executive planning per se.

If we accept that grip selection tasks primarily evaluate motor rather than executive planning then we can begin to consider what factors influence (“bias”) motor planning. One possible bias is the previous movement. Repeating an action (perseveration or hysteresis) can be easier and therefore more likely than generating a new one (e.g. Cohen & Rosenbaum, 2004; de Lussanet, Smeets, & Brenner, 2001, 2002; van Bergen, van Swieten, Williams, & Mon-Williams, 2007). Two additional potential biases are: (1) precontact minimal rotation (MR; van Bergen et al, 2007), in which the hand is rotated through the minimum distance required to reach a final posture, resulting in an easier movement; and (2) end-state comfort (ESC; e.g. Rosenbaum et al, 1990), in which initial comfort is sacrificed in order to achieve a comfortable final position. We therefore modified the task used by Smyth and Mason (1997) to expose the potential influence of grip selection biases in groups at different developmental stages. The crucial aspect of our design was that (1) and (2) were placed in direct opposition with one another so that selecting maximal pre-contact rotation would increase end-state comfort on half the trials (and vice versa).

These biases help constrain a task to make it solvable; we therefore predicted that their influence would vary as a function of motor developmental status or competence. Adults reaching with their preferred hand would always be biased by ESC but might occasionally be biased by MR with their nonpreferred hand. Young children are likely to select an easier initial movement (because they have less well-developed prehension skills; Kuhlbuschbeek, Stolze, Johnk, Boczek-Funcke, & Illert, 1998; Mon-Williams et al., 2005; Tresilian, Mon-Williams, Coppard, & Carson, 2005), and so we predicted that young children would primarily show the MR bias. Children with DCD would be even more strongly biased by MR because of their fundamental difficulty with prehension. We also looked at grip selection in children with autism, as these children are known to have executive planning deficits (Hughes, Russell, & Robbins, 1994); we postulated, however, that this might not translate to a motor planning deficit. If any group showed any tendency to perseverate, this would also be clear in the current design.

**Methods**

**Participants**

There were four groups of participants. The first group consisted of 27 children (20 male) diagnosed with DCD by the *DSM–IV* criteria. The children were recruited from the Royal Aberdeen Children’s Hospital (RACH). The children were diagnosed by a history of coordination problems and performance assessed as being below the fifth percentile on the Movement ABC (MABC: Henderson & Sugden, 1992) by occupational therapists. The DCD population was examined by the relevant clinical services within the RACH for signs of known neurological disease and autism (the presence of which would have prevented a diagnosis of DCD under *DSM–IV* criteria). Most (24/27) of the children with DCD were right-handed as indexed by their writing hand. Their age ranged between 6 and 13 years. We split this group into two age bands that contained the bottom and top two age bands from the MABC (6–8 years, n = 16; mean BPVS normalized score 101.31, SD = 14.97; mean age equivalence 7.75; and 9–13 years, n = 11;
mean BPVS normalized score 114.72, SD = 22.99; mean age equivalence 12.23). The second group consisted of 20 children with autism (17 male) aged between 9 and 14 years (mean 11.9 years; mean BPVS normalized score 95.78, SD = 14.15; mean age equivalence 10.76) recruited through the Department of Child and Family Mental Health of the RACH, having been diagnosed using the Autism Diagnostic Interview – Revised (ADI-R; Lord, Rutter, & Le Couteur, 1994), the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000) and clinical observation (all patients were known clinically to one of the authors, JHGW). None had any diagnosed learning difficulties. Most (15/20) of the children were right-handed. The third group consisted of 70 typically developing children from Scottish primary schools (35 male, 35 female). We classified these children into two groups. The first consisted of 26 children ages 5–8 years. The second group consisted of 44 children ages 9–14 years. The typically developing children had no history of neurological or ophthalmological deficit and were reported to be performing satisfactorily within their mainstream education setting. Most (61/70) of the children were right-handed. The fourth group consisted of 40 normal adults (16 male) aged between 19 and 32 years (mean 21.5 years) classified into two groups (half reached with their preferred hand, half with their nonpreferred hand). Most (36) were right-handed. Both clinical groups had normal verbal IQ as assessed with the British Picture Vocabulary Scale (BPVS). Children with autism are well known to have difficulties with tasks measuring cognitive planning (e.g. the Tower of Hanoi or London) and executive function (e.g. the Wisconsin Card Sorting task), but we needed to establish whether children with DCD showed any difficulties on a test of executive level planning; we therefore tested a sample of 18 children with DCD (16 males, 2 female; ages 7–11, average age 9.91 years) on the Tower of London. For each child, we computed their scaled score from the appropriate age tables in the NEPSY Manual (Korkman, Kirk, & Kemp, 1998); these scaled scores have a mean of 10 and a standard deviation of 3. All of the children scored within or above 1 SD from the mean (scores ranged from 8–16, M = 11.83). There is therefore no evidence to suggest that children with DCD have any specific executive function difficulties in planning. All adult participants provided their informed consent prior to their inclusion in the study and parental consent was obtained for all of the children. The study was approved by a University ethics committee and NHS Grampian Local Research Ethics Committee.

Procedure

Stimuli were presented on a 14.1” computer screen (Toshiba Tecra M4 tablet laptop) with its screen rotated 180° from the keyboard so that the screen was upright and facing the participants. A Perspex sheet held within a wooden frame was placed in front of the screen. A small axle (0.5 cm in diameter, 4 cm in length) protruded from the Perspex sheet. A piece of wooden dowelling (length of 5 cm, diameter of 2 cm) was mounted on the axle at the centre of the long axis of the dowelling. This meant that the dowelling could freely rotate 360° in the frontoparallel plane. One end of the dowelling was colored red, differentiating it clearly from the other end. The participants were asked to always grasp the object so that their thumb was located at the red end. A red sticker was placed on the participant’s thumbnail as an aide mem-

![Figure 1.](image-url) The four different configurations for right-handed participants (reversed for left-hand). The grey pieces (dot and one end of dowelling) were red in the experiment. Participants started with their hand pinching a molded grip so their thumb was at 9 o’clock—degrees of rotation are measured with respect to this. The top pictures show the combinations where minimal rotation bias allowed end state comfort after turning the dowelling. The bottom pictures show the combinations in which these two biases were placed in opposition.
which you can grasp the object” and were asked to think about which of the two ways they were going to use. On each trial, participants reached out and grasped the object as fast as possible, then turned it. They were asked to hold their final posture until the stimulus disappeared. The participants did eight practice trials where the experimenter ensured that the participants had followed the instructions (grasp the object with the thumb at the red end of the dowelling and turn it following the white arrow). The practice trials were followed by a three-minute rest where the participants were distracted by questions regarding their daily lives, then the experiment was run. The experimenter coded each reach as pronation or supination as it happened.

Results

Data Analysis

If there were no biases affecting grip selection then the participants should randomly select a grasp (pronation or supination) on each individual trial and there should be no discernable pattern across the trials. If participants were using pronation and supination more systematically, then we might expect participants to select the MR grip (smaller rotation is faster and easier), pronating on half the trials and supinating on the other half. However, on half of all trials, selecting a MR grip would entail an awkward final position after the rotation. On these trials, participants might select the longer rotation grip in order to produce ESC. There were two additional variations; it was possible that we might see ESC dominate for one dowelling position and MR dominate at the other and second that there may be some hysteresis (repeating an initially performed action independently of these other biases. In this case, a younger child might consistently pronate or supinate their hand irrespective of condition).

In order to analyze grip selection, we looked at the four conditions (depicted in Figure 1) separately and listed the grip selected for each of the eight trials. In the majority of cases, the same grip was selected throughout the condition. Thus, we could label the response to each condition as being either pronation or supination. Consequently, there were 16 possible response patterns but we anticipated seeing only 6 of these: If participants show repetition, then all four conditions (a, b, c, and d in Figure 1) should show either (1) a consistent pronation response or (2) a consistent supination response depending on the initial reach. If participants show an “end-state comfort” effect, they should (3) supinate their hand when reaching to grasp the dowelling in Position 1 and turn it anticlockwise (Figure 1a) but pronate their hand when rotating the dowelling clockwise from this position (Figure 1b) with the opposite effect occurring when the dowelling is in Position 2 (Figure 1, c and d). If participants show a minimal precontact rotation effect then they should (4) supinate their hand when reaching to grasp the dowelling in Position 1 (Figure 1a and b) and pronate their hand to Position 2 (Figure 1, c and d) regardless of the direction of the subsequent turn. It was also possible that we might observe (5) a minimal rotation effect at Position 1 (Figure 1, a and b) but an end-state effect at Position 2 (Figure 1, c and d) or (6) vice versa. In order to explore grip selection, we simply determined the category of response pattern for each individual and then determined the frequency with which each response pattern was found within the populations under investigation.

Grip Selection

For the majority of participants (103/117 children and all the adults), the grasp they selected on the first trial of a given condition was repeated on all other trials of that condition. In 14 children (10 typically developing and 4 with DCD), we observed a (single) shift from one pattern to another in the middle of the experiment. In order to analyze the data across all participants, we considered the initial pattern shown by these 14 children (as being more representative of their underlying initial competence) together with the stereotypical (consistent) pattern shown across all trials by the other children. Figure 2 shows the relative frequency with which the different groups selected the different grasp patterns. We found that all of the adults who grasped with their preferred hand showed ESC across all of the trials, replicating the results of Rosenbaum et al. (1993). We found that when adults grasped with their nonpreferred hand, 20% showed a MR bias. The difference between the two adult groups (preferred vs. nonpreferred hand) was statistically reliable (Fisher’s exact test; p < .05).

It can be seen immediately that the children (who all grasped with their preferred hand) showed a different pattern when compared to the adults who used their preferred hand. A small number (5/26, 19.2%) of the youngest typically developing children showed the ESC bias across both target positions, but 50% of the children showed the ESC bias for at least one of the positions (8/26, 30.8% of children showed the ESC bias at one position and the MR bias at the other position). Seven (26.9%) of the youngest children were biased to select an MR grip at both target locations. In contrast, 81.8% (36/44) of the older typically developing children showed an ESC bias for at least one of the positions (34.1% of these children showed the ESC bias at one position and the MR bias at the other position). Only 6.8% of the older typically developing children showed the MR at both target locations. We used Fisher’s exact test to test whether the developmental trend away from MR and towards ESC bias was statistically reliable, which it was (p < .05).

Figure 2 shows that both the younger and older children with DCD were biased to select an MR grip to grasp the dowelling even though this resulted in a more awkward second action. Fisher’s exact test confirmed that the difference in grip selection between younger children with DCD and younger typically developing children was statistically reliable (p < .05), and the same difference occurred when older children with DCD were compared to the older typically developing group (p < .05). The difference in grip selection bias (MR against ESC) across the younger and older children with DCD was not statistically different (p = .61). Figure 2 also shows that some children within all those groups had a tendency towards perseveration/repetition (i.e. they generated a pronation or supination movement in all four conditions). There is a clear tendency for this behavior to disappear with increasing age and none of our adult participants showed such a response. The repetition effect appeared to be present in children with and without DCD. Figure 2 also shows the data from the children with autism, which was completely indistinguishable from the typically developing data. Thus, children with autism showed the same pattern of grip selection as typically developing children and differed from the DCD population in this respect.
We have replicated previous research showing that adults are biased towards selecting a grip that results in a comfortable end-state posture after a subsequent secondary movement when using their preferred hand (Rosenbaum et al., 1990, 1993, 1996). We found that adults who used their nonpreferred hand showed a different pattern of grip selection, supporting the hypothesis that a lower prehension skill level would influence behavior away from ESC. We hypothesized that children might therefore be biased towards selecting a grip that decreased the difficulty of the initial movement, given that children have a lower skill level in reach-to-grasp behavior than adults (Kuhtz-Buschbeck et al., 1998; Mon-Williams et al., 2005; Tresilian et al., 2005). We found a clear developmental trend in line with this hypothesis where younger children (ages 5–8 years) showed a greater bias towards selecting an MR grip than older children (ages 9–14 years). We had also hypothesized that a group of children with DCD would be biased towards MR at all ages due to their known prehension difficulties (Smyth, Anderson, & Churchill, 2001; Mon-Williams et al., 2005). The children with DCD showed the predicted bias towards MR, and the proportion of children with DCD who showed the MR bias was higher than even the youngest group of typically developing children. Moreover, there was no statistical evidence of a decrease in the proportion of older children with DCD showing this bias. Finally, we investigated whether children with autism would also show different grip biases, postulating that their executive planning deficits might not translate into a motor planning deficit. The children with autism performed identically to age-matched controls.

Our finding that children with DCD show a different grip selection bias is at odds with the study by Smyth and Mason (1997) who found no differences between their groups. Our results also appear at variance with the study by Hughes (1996) who found that children with autism were different from controls. Nevertheless, the differences can be readily explained in terms of the experimental designs. The difficulty with the designs used by Smyth and Mason (1997) and Hughes (1996) is that potential biases that affect grip selection were not well controlled and were not documented. For example, Smyth and Mason used eight different target positions and allowed children to turn the handle either clockwise or anti-clockwise from uncontrolled hand starting locations. In the present study, the task was simplified and the potential motor planning biases were carefully controlled (and documented), which allowed us to identify different subtle grip selection biases across the groups.

Differences in grip selection between adults and children have been interpreted elsewhere as indicating a deficit in planning (see Smyth & Mason, 1997; Hughes, 1996). The problem with such an interpretation is that a clear distinction between motor and executive planning has not been drawn. The fact that young children are biased towards selecting a grip that minimizes the initial difficulties cannot be taken as evidence that they have a deficit in “thinking ahead” (somewhat implicit within the generic descriptor of “planning deficit”). Indeed, all of the children with DCD possessed

### Figure 2

The relative frequency with which the different grasp patterns were selected by the different groups.

<table>
<thead>
<tr>
<th>Grip Selection</th>
<th>Adult Preferred Hand</th>
<th>Adult Non Preferred Hand</th>
<th>Typical 5-9yrs</th>
<th>Typical 9-14yrs</th>
<th>DCD 5-9yrs</th>
<th>DCD 9-13yrs</th>
<th>ASD 9-14yrs</th>
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<tr>
<td>All pronation or all supination (Patterns 1 &amp; 2)</td>
<td>100%</td>
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<td>End state comfort (Pattern 3)</td>
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<td>Minimal Rotation (MR) (Pattern 4)</td>
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<td>End state comfort + MR (Patterns 5 &amp; 6)</td>
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normal IQ and showed no evidence of cognitive problems, and the children with DCD we tested performed within the normal range on the Tower of London test. In contrast, there is compelling evidence that children with autism have executive planning deficits (e.g. Hughes et al., 1994). Nevertheless, there was no evidence of different grip selection in the autistic population. While it is clear that these planning tasks (gripping, Tower of Hanoi, etc) all entail both executive and motor elements, these dissociations strongly suggest that the tasks primarily tap different processes, and that this distinction is therefore of great pragmatic value.

These findings appear to support the notion that “executive” and “motor” planning are two reasonably distinct mechanisms. Thus, monkeys show the end-state comfort effect despite a lack of executive planning skills (Weiss, Wark, & Rosenbaum 2007). The executive planning deficits associated with autism may only become evident when tasks become more complex or contain competing attentional demands (i.e. tap more executive processes). Likewise, the motor planning problems of children with DCD may only be evident on tasks that isolate subtle differences in grip selection. It follows that grip selection experiments are best considered as tests of motor planning: studies of the biases that affect the selection of one action over other possibilities.

Conceptually separating motor from executive planning leads us to speculate about the underlying mechanism of the former, given what we understand about motor development. Any simple learning model predicts the selection of one action rather than another if (1) one particular action is reinforced by a positive outcome, and (2) action selection is competitive. Most motor theorists agree that such learning mechanisms underpin the acquisition of motor skills. In short, the acquisition of motor skills occurs through an evolutionary process, where a neonate’s spontaneous movements are reinforced when useful (“fit”) but become extinct if a more useful (“fitter”) movement pattern enters the ecological action niche. The waiter who grasps the upside-down wine glass with their hand uncomfortably positioned before rotating the glass into a comfortable position (in Rosenbaum’s classic example) gives the appearance of someone who has explicitly weighed up the costs and benefits of their future actions. This apparent explicit predictive behavior might actually reflect the fact that such grasping actions have been successful in the past and are therefore selected again (though executive planning might have been the original driver that caused the initial behavior). We suggest that motor planning works as a blind watchmaker, with actions reflecting a previous history of motor evolution where useful actions have survived and less useful ones have perished. This then accords nicely with the current data. Children with DCD seem to be taking their movement difficulties “into account” by selecting the simpler movement, but by our account are actually reproducing movements that past experience has shown to be successful. In the same way, younger typically developing children use less efficient movements because those are the most reliable movements they have yet produced, and hence the ones favored during learning. Older children have experienced and reinforced the more efficient action (driven to transition by the costs that arise from using an inefficient action) while adults have great experience with an efficient reach using their preferred hand, but less experience in their nonpreferred hand. No one “failed to plan”—instead, they reached in accordance with their experience and ability (their developmental motor status). We note in conclusion that in this account “executive” planning allows us to escape the shackles of reliance on previous experience, and action planning is the subtle interplay between learned behavior and postulated abstract outcomes.

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