Online corrections in children with and without DCD

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Abstract

Human arm movements need ‘online’ corrections due to noise in perception and action. A Step-Perturbation paradigm explored online corrections in control children and children with DCD aged between 7 and 13 years. Control children found the task straightforward: a distracter had no effect and they managed to stop relatively quickly. Children with DCD found the task difficult and the apparatus was modified accordingly (decreased postural and force production demands). The distracter affected some children with DCD and some found it difficult to stop. All of the DCD population showed poorer performance in both the perturbation and non-perturbation condition. Nevertheless, there was no interaction between group and condition. Thus, this study found no evidence for specific deficits in online correction mechanisms in DCD. We suggest that: (i) fundamental problems in generating basic movements can account for the documented difficulties in correcting on-going movements, and (ii) such fundamental difficulties make it very difficult to pinpoint specific mechanism deficits.

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1. Introduction

Simple aiming movements, where a participant must move from a start location to a pre-specified target, are well studied and understood and are thus a useful tool for studying children with developmental coordination disorder (DCD). DCD is defined as a specific problem with coordinative tasks despite normal IQ and no evidence of neurological, biochemical, or physical abnormalities (American Psychiatric Association., 1994). In common with most childhood disorders, estimates of prevalence vary but it is reasonable to consider approximately 5% of the childhood population as having DCD (Henderson & Sugden, 1992). The consequences of DCD are severe and a plethora of studies have found that poor movement skills in early childhood are associated with poor educational outcome (e.g., Losse et al., 1991).

There are two phases to a simple aiming movement. The initial acceleration phase is widely held to be open-loop in nature and variations reflect variability in feedforward control (e.g., increases in peak speed (PS) with distance). The second deceleration phase is under feedback control (primarily visual) and variations reflect changes in task demands such as increased accuracy requirements (e.g., lengthened duration with decreasing target size). Thus, variations in this task provide the potential to tease apart contributions of feedforward and feedback elements to movement production. The kinematic characteristics of such movements are lawful and regular – movement time (MT) lengthens with smaller targets and with increased distance, while PS increases with distance and decreases with task size. These well-behaved characteristics make variations on this task very useful, because changes in MT and PS can tell us about how various task constraints are affecting the organization of the movement.

Wilmut, Wann, and Brown (2006) used a double-step targeting task and demonstrated that children with DCD were relatively unimpaired at producing simple aiming movements but were slower when producing a second movement to the next target in a sequence. The authors suggested that children with DCD rely heavily on online visual feedback information for the generation and control of actions and take longer to utilize visual information. In a similar vein, Mon-Williams et al. (2005) suggested that one potential locus of the motor problems in DCD is in producing online corrections to movements in response to noise or external perturbation. Nevertheless, there are (in principle) two possible reasons why children with DCD may have problems with making corrections while moving. The first is that the children have a core difficulty with detecting errors and implementing corrections online (i.e., a deficit in the specific processes known to support online corrections). Such specific deficits have been reported in neuropsychological conditions affecting the parieto-occipital cortex such as optic ataxia (Rossetti, Pisella, & Vighetto, 2004). The second reason is a fundamental difficulty with the execution of movement to begin with, and problems with movement modification reflect the poor movement execution rather than arising through a specific deficit in any online correction mechanism.

The current experiment was therefore designed to try and tease apart these two possibilities, by measuring movement execution under conditions where a correction was only sometimes required.

The paradigm was a ‘Step-Perturbation’ task, where the participant is required to make a simple aiming movement to a target that was subsequently perturbed on some trials. This has been used in the past to study both limb (Megaw, 1974) and eye movements (Lisberger, Fuchs, King, & Evinger, 1974), and it is known that adults are capable of smooth
continuous corrections (Turrell, Bard, Fleury, Teasdale, & Martin, 1998). The other compensatory change that can occur is that planned strategic changes can be made to the feed-forward component of a movement in situations where it is likely that corrections will have to be made. One such strategy is to slow the whole movement down, allowing more time for any necessary corrections to be made.

There were six conditions (three types of Baseline trial and three types of perturbation trial). If children with DCD have a specific identifiable deficit with online feedback control, this will show itself by these children showing an additional cost in the perturbation conditions, relative to the cost shown by the controls (i.e., an interaction of group and condition). The same magnitude cost (i.e., a main effect of condition) would suggest no specific feedback control deficit, and instead a more general difficulty in executing movements.

2. Methods

2.1. Participants

Twenty-two children aged 7–13 years with DCD were recruited via Occupational Therapy at The Royal Aberdeen Children’s Hospital, and thirteen produced complete data sets and were included in the analyses here. The mean age of the thirteen children with DCD who completed the task was 9 years and 10 months and there were 11 boys and 2 girls. All but three were right handed. Thirteen age-matched children were recruited from Aberdeen primary schools to act as controls. The children with DCD had all scored below the 1st percentile on the Movement Assessment Battery for Children (Movement ABC: Henderson & Sugden, 1992). Parental permission was provided for each child to participate and parents were invited to observe during data collection. After testing, the participants were debriefed via an information sheet and were free to ask questions regarding the experiment. The experiments received ethical approval from the local Ethics Committee and were conducted in accordance with the declaration of Helsinki.

We assessed the verbal IQ of the children with DCD using the British Picture Vocabulary Scale (BPVS). They were also assessed for attention deficit hyperactivity disorder (ADHD) using the SNAP-IV-C rating scale, which includes the DSM-IV diagnostic criteria for ADHD, and the strengths and difficulties questionnaire. See Table 1 for results.

2.2. Procedure

The participant was required to stand with a stylus in their preferred hand. The stylus had an Optotrak infra-red emitting diode (IRED) on it. An Optotrak 3020 system (Northern Digital, Waterloo, Ontario) tracked the position of the IRED at 100 Hz. Participants began each trial by pressing down on a button on a box; when released, the button signalled the computer to advance the stimulus. The button was located 40 cm away from the target location which was displayed on a laptop computer monitor placed flat on a horizontal table surface 74 cm from the ground.

The target stimulus was a 2 cm circle placed initially at the center of the computer screen. The dot started as red and turned green (which served as the ‘go’ signal). The participant was instructed to move the stylus from the starting location (the button) to the green target dot as quickly but as accurately as possible.
There were eight Baseline trials at the beginning (‘Baseline Before’) in which the participant knew the target would not move. After this block, there was the experimental block (32 trials) in which one of four things could happen:

(i) The target stayed green and did not move from its initial location (8 × ‘Baseline Embedded’ trials).

(ii) The target stayed green and jumped 7 cm to the left, 10 ms after movement initiation (8 × ‘Step-Perturbation’ trials).

(iii) The target stayed green and did not move from its initial location, but a blue dot appeared 7 cm to the left of the target, i.e., in the same place as the final location in the ‘Step’ trials (8 × ‘Distracter’ trials).

(iv) The target changed color back to red, signalling the requirement to stop moving as quickly as possible, even in mid-air (8 × ‘Stop’ trials).

Following this block, there were 8 more Baseline trials, and again the participant knew the target would not move (‘Baseline After’).

The participant was allowed five practice baseline trials and given a break after the first eight Baseline trials. They received verbal instructions about the four conditions, repeated twice and then asked if they understood what was going to happen. A second break was given at the end of the experimental block and the participant was again told that the stimulus would remain constant and would not move.

2.3. DCD procedure

We were forced to make slight modifications to the procedure for the children with DCD. The design remained the same; however, the children all had great difficulty in:

1. Standing by the table. All the children leaned on the table and used it to maintain postural stability. This lead to marker occlusion and occasionally to the display being occluded. We therefore sat the children in chairs and modified the height of the display accordingly.

<table>
<thead>
<tr>
<th>Code</th>
<th>Age</th>
<th>BPVS</th>
<th>SNAP ADHD-C</th>
<th>S&amp;D hyperactivity scale</th>
<th>S&amp;D (total)</th>
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<td>19*</td>
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<tr>
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<td>10*</td>
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<td>89</td>
<td>1.5</td>
<td>9*</td>
<td>22*</td>
</tr>
</tbody>
</table>

Numbers marked with an * are outside the normal range.
2. Holding the stylus. The stylus was a thin piece of doweling about the size of a regular pencil, and the children with DCD all had difficulty holding this in a power grip with the marker at the thumb end and pointing down, as per the task instructions. We therefore gave them a much thicker stylus, which was easier to hold onto.

3. Pressing down on the button with the appropriate force. The start location for each trial was with the stylus holding down the trigger button – releasing this button triggered the onset of any perturbations for that trial and the recording of reaction time (RT). The children with DCD had great difficulty in keeping the stylus on the trigger – they often slipped off, or briefly failed to maintain pressure and then regained it (clicking the button). This lead to several lost trials due to the stimuli being advanced when the child was not ready. The larger stylus and the chair helped matters here by simplifying the grasp and postural demands of the task.

None of the control children, even the youngest, showed any of these difficulties. For the children with DCD, the incidental postural and grasp demands of the task were far from trivial. These modifications did make the task objectively easier, although given the initial difficulties the modifications were designed to try and equate the task difficulty across the groups. Even under these conditions, only 13 of the 22 children with DCD produced a complete data set, and these were the data analyzed below.

The position data recorded by Optotrak were analyzed using Labview 8 software routines. The data were filtered using a dual-pass Butterworth second order filter with a cut-off frequency of 16 Hz (equivalent to a fourth order zero phase lag filter of 10 Hz). Movement onset and offset times were identified as when the velocity crossed a threshold of 5 cm/s, and movement time (MT) was computed as the difference in these times. Peak speed (PS) and time to peak speed (TPS) were also computed. MT and PS are useful measures of task difficulty – as difficulty increases MT tends to increase and PS decreases. Finally deceleration time (DT) was computed as the difference between MT and TPS. This time window, after peak speed is reached, is when visual control of an aiming movement occurs. Any increases in the magnitude of this time window therefore suggests the participant is taking additional time to make online feedback correction.

3. Results

3.1. Movement time (MT)

We compared the children with DCD to the age-matched control group looking at (i) all 6 conditions together (Baseline Before, Baseline After, Baseline Embedded, Distracter, Stop, Step-Perturbation) and (ii) the three Baseline conditions. In the six Condition levels ANOVA, there was a main effect of Group, $F(1,24) = 7.6, p < .05$, partial $\eta^2 = .89$, with the children with DCD taking longer then the control group, and a main effect of Condition, $F(2.867, 68.8) = 5.7, p < .01$, partial $\eta^2 = .192$ – df corrected for violation of sphericity with a Greenhouse-Geisser correction). There was no significant interaction ($p = .69$). The two blocked Baseline conditions were fastest overall, and the Step-Perturbation condition took the longest. The Baseline Embedded, Stop and Distracter trials did not differ from each other, suggesting a common strategy was used in these trials (see the analysis of TPS and DT below). This is therefore evidence that online feedback control is not the primary deficit in DCD (see Fig. 1).
Fig. 1. Panel A: Movement times for the three difference Baseline trial conditions as a function of age group. Baseline Before and Baseline After trials were performed in two blocks before and after the experimental trials. Baseline Embedded trials were randomly embedded with the experimental trials. Panel B: Movement times for the three experimental trial types. Distracter trials entailed a to-be-ignored dot appearing to the right of the target. Stop trials entailed the dot changing color (to red) requiring the participant to stop moving as quickly as possible. Step-Perturbation trials entailed the target moving to the right 10 ms after the participant began moving. The final location on the Step trials was the same as the location of the distracter.
We next analyzed the three Baseline conditions separately, to test whether embedding these trials affected movement time and whether there was any effect of practice. In the 3 Condition levels ANOVA (on the Baseline conditions) there was a main effect of Group, $F(1,24) = 6.6, p < .05$, partial $\eta^2 = .215$, with the DCD population taking longer than the control group. There was no significant main effect of Condition ($p = .181$), nor any significant interaction ($p = .861$). Overall the children with DCD took longer to complete the movement, even the simple aiming task in the non-embedded Baseline conditions. The Baseline Embedded trials took longer than both the other conditions (which did not differ from each other). There was no interaction, suggesting all groups showed this pattern of slowing down the embedded Baseline trials in case they were a perturbation trial.

3.2. Peak speed (PS) and time to peak speed (TPS)

If the feedforward component of the reach has been influenced by the task constraints, we would expect these differences to show themselves in the PS and TPS measures. We therefore analyzed these variables in the same way as the MT data to see if we could account for the MT effects here. We performed a repeated measures ANOVA on PS and TPS with Group as a between-subjects factor and Condition (all 6 levels) as a within-subjects factor. There were no significant main effects or interactions.

3.3. Deceleration time (DT)

The remaining amount of MT after peak speed is reached, the deceleration time, is widely considered to be the phase of an aiming movement where visual feedback is used to make final corrections. We ran a repeated measures ANOVA on DT with Group as a between-subjects factor (2 levels) and Condition as a within subjects factor (6 levels). There was a main effect of Group, $F(1,24) = 6.9, p < .05$, partial $\eta^2 = .223$, and a main effect of Condition, $F(2.973,71.347) = 3.1, p < .05$, partial $\eta^2 = .114$ – df corrected for violation of sphericity with a Greenhouse-Geisser correction). There was no significant interaction ($p = .056$, partial $\eta^2 = .1$). Here we replicated the pattern of MT results, clearly showing that the differences in MT were being driven by differences in DT. The 7–8-year olds had longer deceleration times than would be predicted on the basis of their age, supporting the interpretation of their longer MTs.

4. Discussion

The current study investigated the effect of several perturbations to a simple aiming task on the movements of children with and without DCD. The results show that children with DCD have a general deficit in movement production. Nonetheless, the interaction between condition (perturbation vs. non-perturbation) and group was not statistically reliable with only a small effect size. It is always difficult to interpret a negative finding but these results suggest strongly that the poor DCD performance on the perturbation trials is parsimoniously explained by the known generic movement difficulties rather than a specific deficit in online correction mechanisms. In short, we failed to find evidence of an online specific deficit of the type reported in conditions such as optic ataxia (Rossetti et al., 2004). All the groups showed longer MTs in the perturbation conditions relative to baseline, and the DT analysis showed that this change was entirely attributable to an increased need for
feedback corrections in these conditions. This cost was constant for both groups, producing no interaction between Condition and Group. Simple aiming movements took longer when embedded in amongst perturbation trials (Baseline Embedded) in all groups, showing that both groups implemented a strategic slowing down to allow for the possibility of perturbation.

One possible outcome of this study was that we would have identified a specific problem with online corrections in children with DCD. However, given that this is not what we found, it has become clear that identifying a specific mechanism deficit will be very difficult. Refer to Fig. 2, which is a generic model of the basic processes involved in learning the production of a movement and its organization. We explored the possibility that the feedforward commands being generated by the ‘inverse model’ component are fundamentally intact and task-appropriate in DCD, but that a specific deficit affects the children’s ability to make online corrections. We were unable to find evidence to support this conjecture, which has the consequence that the potential problem could now be at any of at least five locations in this system:

1. There could be a deficit in using the error signal for the purpose of learning.
2. The inverse model could be disrupted, producing an unstable command.
3. The inverse model could be intact but there could be a problem in transmission of the command.
4. The feedback controller could be poor at implementing the error signal.
5. The effector may be corrupted by noise.

Having ruled out a specific online correction deficit, we are left with the fact that behaviorally, these remaining possibilities are indistinguishable from each other – they all predict impaired movement trajectories, which is all we can measure.

Additionally, this account also clearly supports the idea of DCD as a developmental disorder. An initial deficit at any of these components or processes would not only have the primary effect of disrupting movement stability, but would have the secondary consequence of affecting the development of all the other stages. For instance, if the initial problem is that the feedback error is poor, then fine tuning the inverse model will be much harder and the feedforward commands will be unstable. This schematic model is a percep-

![Fig. 2. Generic model of motor learning. The numbers refer to the points in the organization where a general deficit in movement production could be caused (see Wolpert, Ghahramani, & Flanagan, 2001; Wolpert, Miall, & Kawato, 1998).](image-url)
tion-action loop that not only shows what happens over the time course of a particular reach, but also how reaching is improved over the course of development. A problem at any stage will reverberate around the loop.

One interesting point of comparison in the current results and Wilmut et al. (2006) is that they failed to find any difference between their children with DCD and their controls in the simple aiming task. Here, we found that the DCD group was slower in all the Baseline conditions. However Wilmut et al. recruited their children from a school sample who had been assessed using the Movement ABC, with those scoring in the bottom 10th percentile being included. Here, the children were drawn from those already referred to occupational therapists and who had scored below the 5th percentile. These two distinctions are clearly important to note.

We noted in Section 2 that we had to modify the procedure for the children with DCD because of their problems maintaining a stable posture, holding the stylus and pressing the button down. These children therefore had difficulty in creating a stable platform from which they could perform the task, and their performance consequently suffered. Several of the children scored outside the normal range on the SNAP-IV assessment scale, suggesting they also exhibited symptoms consistent with ADHD. It seems likely that these attentional difficulties may be ‘knock-on’ consequences from their primary movement coordination difficulties. If they are only able to maintain a stable posture with great effort, they will then also likely be fidgety and have difficulty staying on task. If this is true it supports common clinical practice in which the child is trained to improve their basic posture, on the assumption that this improved platform will then allow more stable movements to emerge.

The results of the current study suggest that children with DCD do not have a specific impairment in making online feedback corrections per se. Their unwillingness to prepare an incompletely specified movement (as in Mon-Williams et al., 2005; Wilmut et al., 2006) may actually reflect their overall difficulty in producing a movement – after all, an online correction is simply a movement produced ‘on the fly’ (see also Katschmarsky, Cairney, Maruff, Wilson, & Currie, 2001, who showed that children with DCD have difficulties in generating secondary saccades under feedforward (i.e., incompletely specified) control). Behaviorally, this restricts our ability to locate the specific underlying initial deficit – not only are there multiple potential loci, these all interact and shape each other, and even if that were not the case, they all predict the same behavioral outcome. Structural brain imaging may be able to narrow down the possibilities, but behaviorally there is a clear need to move to new tasks. Nevertheless the current data shed light on the fundamental difficulties faced by children with DCD and also suggest that these measures have the potential to identify children requiring further intervention.

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References


