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The preparation of reach-to-grasp movements in adults, children, and children with movement problems

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This study explored the use of advance information in the control of reach-to-grasp movements. The paradigm required participants to reach and grasp illuminated blocks with their right hand. Four target blocks were positioned on a table surface, two each side of the midsaggital plane. In the complete precue condition, advance information precisely specified target location. In the partial precue condition, advance information indicated target location relative to the midsaggital plane (left or right). In the null condition, the advance information was entirely ambiguous. Participants produced fastest responses in the complete precue condition, intermediate response times in the partial condition, and the slowest responses in the null condition. This result was observed in adults and four groups of children including a group aged 4–6 years. In contrast, children with Developmental Coordination Disorder (DCD, $n = 11$, aged 7–13 years) showed no advantage of partial precueing. Movement duration was determined by target location but was unaffected by precue condition. Movement duration was a clear function of age apart from children in the DCD group who showed equivalent movement times to those of the youngest children. These findings provide important insights into the control of reach-to-grasp movements and highlight that partial cues are exploited by children as young as 4 years but are not used in situations of abnormal development.

It has been established that the human nervous system uses advance information (when available) in order to prepare goal-directed movements (Goodman & Kelso, 1980; Rosenbaum, 1980). The provision of information in advance of an imperative signal to act is known as "precuing". The use of precue information in the preparation of "simple" movements (e.g., pressing a button or moving the tip of a finger from one location to

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another) has been studied in some detail. In contrast, the use of precue information in more complex movements has attracted less research activity (presumably because of the greater complications involved in quantifying more complex actions). This paper is concerned with the issue of preparation in reach-to-grasp movements (prehension). A number of everyday situations require the rapid deployment of a reach-to-grasp action. It is reasonable to expect that success in such tasks might be maximized by preparing the movement in advance of an imperative signal to move. In order to test this notion, we manipulated the amount of advance information available in a prehension task (Mon-Williams et al., 2001). In a "complete precue" condition, participants were provided with information specifying the location of the target. In a "partial precue" condition, participants were given advance information indicating the location of the object relative to the midsaggital plane (left or right). In a "null" condition, there was no information concerning the position of the target. This paradigm allowed us to establish that adults show a reduction in reaction time (but not movement time) in partial precueing conditions. We found a further reduction in reaction time (but not movement time) in complete precueing conditions. These findings correspond well with existing studies involving precueing with simpler movement patterns (Goodman & Kelso, 1980; LeClair, Pollack, & Elliott, 1993; Rosenbaum, 1980).

The discovery that adult humans use advance information in the preparation of their movement raises the issue of when in the lifespan this ability emerges. A number of studies have investigated this issue. Olivier, Audiffren, and Ripoll (1998) found that children beyond the age of 6 years are able to use precue information in order to prepare a simple aiming movement (moving from one point location to another) and that this ability does not differ as children increase in age. Olivier and Bard (2000) showed that reaction times decreased in children when either the amplitude or the direction of the movement was specified by precueing, but the fastest response times occurred when both amplitude and direction information were provided in advance. Olivier and Rival (2002) further demonstrated that the optimal time frame for motor preparation decreases as age increases, but this is not dependent upon whether or not advance information is present. Our own research (Mon-Williams et al., 2001) has investigated the use of precue information in a reach-to-grasp task in a group of children aged around 6 years. In an extension of the studies highlighted above involving simpler movements, we found that precue information can be utilized by children as young as 6 years in complex actions (in our study this produced faster response times for reach-to-grasp movements).

In addition to studies with nonimpaired adults and children, we have studied the extent to which individuals with neurological deficits can use advance information in order to prepare a prehensile movement. We explored precue information and prehension in a population of adults with Down syndrome (DS; Mon-Williams et al., 2001). In contrast to an adult and an IQ-matched population, adults with DS showed a reduction in reaction time only when the precue information specified precisely the intended target location—the reaction times for the partial precue condition were the same as those for the null condition. These findings are of interest with regard to DS but they also raise important theoretical questions regarding how precue information is used by the human nervous system.

We explained the findings in DS by proposing that partial advance information allows for the programming of a movement to a location between possible target positions. Following the imperative signal, the nervous system could modify the movement trajectory either prior to the start of the hand movement or during the actual movement itself. We suggested that the adults with DS might find such rapid corrections difficult to implement, and thus the advantages of preprogramming are lost in the partial precue situation. In support of this general idea, it was noted that adults with DS do take advantage of partial precue information when programming less complex (aiming) movements (LeClair et al., 1993).

The results from the experiments involving adults with DS are fascinating but leave a number of issues unresolved. For instance, it is possible that the pattern of results might result from the lower IQ of adults with Down syndrome rather than reflecting the motor performance per se. In particular, the difficulties of implementing movement corrections might reflect deficits in information processing rather than movement execution. In order to address this issue it is of obvious interest to explore whether the same pattern of results might be found in disorders affecting movement but not IQ per se. Thus, we were interested particularly in exploring whether children with Developmental Coordination Disorder (DCD) would utilize advance information in the preparation of reach-to-grasp movements. DCD occurs in a significant proportion of children who present with impaired body/eye coordination and show poor acquisition of motor skills. DCD can be 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).

Our knowledge of the underlying problems in DCD is sparse. Children with DCD generally show gross deficits in a wide range of basic movement skills (Henderson & Sugden, 1992). Nonetheless, it appears that the children do not differ from their peers in their ability to plan a complex movement sequence (M. M. Smyth & Mason, 1997). Thus, the problems experienced by children with DCD appear to be related to deficits in programming relatively fundamental actions, such as prehension. It is known that children with DCD show longer than normal reaction times and movement times, together with greater movement variability, in simple aiming tasks (Henderson, Rose, & Henderson, 1992). T. R. Smyth (1991) noted that children with DCD show disproportionate increases in reaction time, relative to control children, as task complexity increases. One study has investigated prehension movements in children with DCD (M.M. Smyth, Anderson, & Churchill, 2001). M. M. Smyth et al. (2001) found a somewhat complex pattern of results in their study. The average movement times taken by eight children with DCD did not differ from a control population when reaching to a large object in a visually rich environment. In contrast to control children, however, children with DCD did not slow down their movements when the grasping surface was reduced in size or when the quality of the visual information was decreased. Smyth et al. reasonably interpreted their findings as indicating a decrement in adaptation to task requirements.

In the light of the findings outlined above we were interested in exploring further the preparation and execution of prehension in children with DCD. One particular question of interest was whether the increased movement latencies observed in DCD populations might be reduced by the provision of advance information. It is possible that children with DCD have general "cognitive" deficits that impair their ability to utilize advance information (Wilson, Maruff, & McKenzie, 1997). For example, Wilson et al. (1997) suggested that children with DCD show deficits in the "voluntary control of orienting visuospatial attention". This conclusion was based on the observation that although a group of children with DCD and a control group showed similar reaction times when the time interval between a precue and target appearance was small, the children with DCD failed to show a decrease in reaction time when the time interval was lengthened. Furthermore, children with DCD showed disproportionate increases in reaction time when a precue was incongruent with target position. The findings of Wilson et al. suggest that children with DCD might be unable to use advance visual information to prepare a motoric response. Indeed, a number of studies have shown that children with DCD have increased reaction times in tasks that require pressing a button in either a "simple reaction time" task (T. R. Smyth & Glencross, 1986) or a "choice reaction time" task (Schellekens, Scholten, & Kalverboer, 1983; T. R. Smyth & Glencross, 1986; Van Dellen & Geuze, 1988). In support of the general idea that cognitive impairment in DCD might prevent the use of advance information, Van Dellen and Geuze reported that children with DCD are unable to use an auditory precue to prepare a motor response. Mandich, Buckolz, and Polatajko (2003) have also suggested that children with DCD have attentional deficits relating to the use of advance information. Mandich et al. (2003) found that children with DCD find it harder to stop the execution of a primed movement and find it harder to modify a planned movement. Nevertheless, it remains an empirical question as to whether children with DCD are able to use advance visual information in order to prepare for a movement task. Wilson et al. (1997, p. 742) state with reference to children with DCD, "it would be of particular interest to examine their ability to use visual precues in a movement task".

Thus, we were interested in exploring whether participants with DCD are able to take advantage of advance information when preparing a prehensile movement and whether differences would be present in the time taken to execute the movement. Another issue we wished to investigate is whether children with DCD show a lag in normal developmental patterns of movement preparation or whether they follow a different developmental trajectory to the normally developing population. We were interested additionally in exploring whether a young group of children would be able to utilize advance information in order to prepare a prehensile movement. Previous research has shown that children around the age of 6 years show an advantage of precueing (Mon-Williams et al., 2001; Olivier et al., 1998). We decided, therefore, to investigate whether an advantage of partial precueing would be observed in a younger group of children (aged between 4 and 6 years of age).

In order to achieve these objectives, we employed a variation of the precue technique (Goodman & Kelso, 1980; Rosenbaum, 1980). In the present study, the participants used their right hand to reach and grasp illuminated Perspex blocks. The reach-to-grasp movements were made in three cue conditions. In the complete precue condition, the participants were provided with information specifying unambiguously the location of the target object. In the partial precue condition, participants were given incomplete advance information, indicating the location of the object relative to the midsaggital plane (left or right). In the null condition, advance information concerning the position of the target object was entirely ambiguous.

EXPERIMENT

Method

Participants

The participants in this study were drawn from three separate groups: (a) adults with no neurological problems, (b) children with no neurological problems, and (c) children with movement difficulties. The first group consisted of undergraduate students aged between 18 and 21 years (6 males and 6 females) who received course participation credits for taking part in the experiments. The second group was composed of four subgroups. The subgroups comprised children in the age ranges 4–6 years ($n = 14$), 7–8 years ($n = 13$), 9–10 years ($n = 13$), and 11–12 years ($n = 6$). The third group comprised 11 children with DCD (age range 7–13 years, median age 8.9 years). The children with DCD were referred to the laboratory from the Australian state education system and from a vacation programme run for children with movement problems. The children with DCD were all screened on the Movement ABC (Henderson & Sugden, 1992) by a qualified physical education teacher (working as a research associate) and fell below the 5th percentile. Children included within the study because of movement problems were diagnosed formally with DCD by a qualified physiotherapist according to DSM-IV criteria (American Psychiatric Association, 1994). Measures of motor competency (Movement ABC), receptive language (Peabody Picture Vocabulary Test), and chronological age are reported in Table 1. The children with DCD were selected from an original group of 14 children but we did not involve 3 of these children as they showed a clear preference for using their left hand.

The control children were also assessed using the Movement ABC and Peabody Picture Vocabulary Test (all of the children showed normal performance on these tests). The adults were not formally tested for IQ or motor proficiency but were asked to report any movement difficulties or history of ophthalmological or neurological problems (no participant reported any such difficulty).

All of the participants (from all of the groups) were assessed as being right-handed on the basis of their responses to the writing and throwing components of the Movement ABC (Henderson & Sugden, 1992) or, in the case of adults, by self-report. All participants had normal or corrected-to-normal vision.

TABLE 1
Details of the children with DCD

Child	*Age*	*PPVT*	*Manual*	*Ball*	*Balance*	*Total MABC*
AC	9.2	10.7	15	9	5	29
CDJ	8.1	10.9	8	4	3.5	15.5
HG	9	9.5	8.5	6	0	14.5
JW	8.9	7.9	11	5	6	22
KH	10	9.1	15	9	10.5	34.5
KLH	9	8.11	15	2	15	32
MC	13	14.1	6.5	6	13	25.5
MN	7	6.3	10.5	8	0.5	19
TL	7.7	11.7	5.5	7	2.5	14.4
MW	7.1	9.8	3.5	7	7.5	18
KW	7.9	7.7	2.5	7.5	6	16

Note: The initials identify the child. Age refers to chronological age (in years) at the time of testing. The total Movement ABC (MABC) score is given together with scores on three different sections (manual dexterity, ball skill, and balance). PPVT refers to scores from Peabody Picture Vocabulary Test.

Apparatus

The participants were seated at a table. A microswitch (diameter 40 mm) was located on the edge of the table closest to the participant, on a virtual line between the centre of the table and the participant's midline. Four Perspex target blocks (height 140 mm), of square cross section (30 mm × 30 mm), were positioned on a table surface, 260 mm from the edge of the table closest to the participant, two to each side (120 mm and 240 mm eccentric) of the midsaggital plane. Perspex is a transparent polycarbonate plastic renowned for its durability. An additional "fixation" block was located in line with the participants' midline, 390 mm from the edge of the table. A red light-emitting diode (LED) was embedded in each Perspex block. In conditions of low ambient light, illumination of the LED caused the block to glow red. The Perspex blocks were mounted on vertical shafts that passed through the surface of the table via linear bearings. Proximity switches were mounted on the lower surface of the table, on brackets positioned adjacent to each shaft. These switches were activated when the Perspex block was lifted 20 mm above the surface of the table. The LEDs and the microswitches were interfaced to a controlling microcomputer.

Procedure

Test sessions comprised three blocks of 24 (adults) or 20 (children) trials (i.e., 72 or 60 trials in total). A single block of trials was conducted for each precue condition (complete, partial, null). The order of block presentation was randomized across participants. Each target position was presented on six (adults) or five (children) occasions within a block. The order of target presentation was randomized within each block.

Protocol

All reaches were performed using the right hand. In order for a trial to commence, the participants were required to depress the microswitch with the palmar surface of their right hand. In the event that the microswitch was released prior to the presentation of the target stimulus, the trial was repeated. The start of each trial was indicated by the illumination of the central fixation block, for a period of 2 seconds, and a microcomputer generated a "warning" tone (1-s duration, 500-Hz square wave), initiated at the experimenter's command. Following this tone, the potential target blocks were illuminated for a period of 2 seconds (Figure 1).

In the complete precue condition, a single block defining precisely the location of the forthcoming target (i.e., the target block) was illuminated. In the partial precue condition, either the two blocks to the left of the midline or the two blocks to the right of the midline were illuminated, depending on the location (left or right) of the forthcoming target. In the null precue condition, all four target blocks were illuminated.

Following the 2-s precue period, the target blocks were extinguished, and the central fixation block was illuminated. The participant was required to fixate upon this position until the fixation block was extinguished after a variable interval (of between 500 and 3,000 ms). Simultaneously, a single target block was illuminated, and a second auditory tone was presented. This constituted the signal to the participant that they should reach and grasp the target block. A trial was terminated when the participant completed the reach-to-grasp movement by lifting the target block from the surface of the table. The interval between successive trials and between blocks was determined primarily by the participant. The test session typically lasted 45 minutes.

Reaction time was assessed as being the time from the illumination of the target until movement initiation (release of the microswitch). Movement time was defined as the interval between movement initiation and the time at which the target block was lifted from the table surface (Figure 1 shows the time course of the experiment).

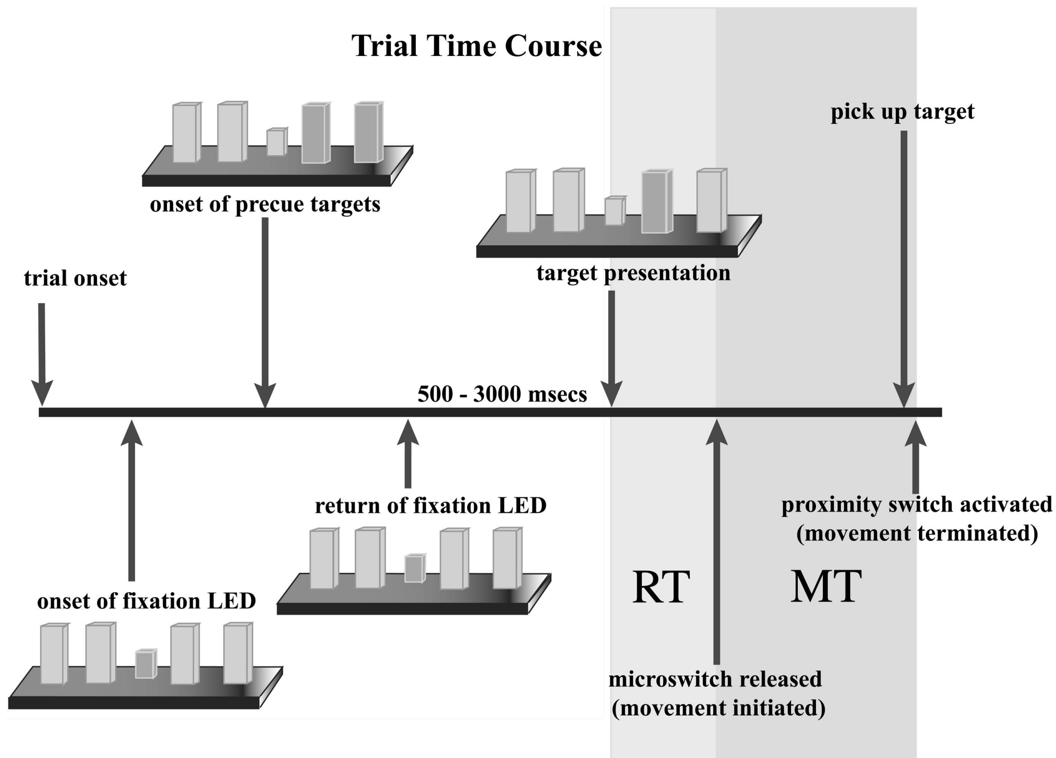

Figure 1. The temporal sequence of the experimental paradigm.

Instructions to participants

The participants were advised to take advantage of any advance information that was made available. It was also strongly emphasized to the participants that they should look at the central block until a target block was illuminated. An experimenter monitored gaze direction to ensure that the participants were following this instruction. The participants were instructed to react as quickly as possible when the target was presented, and to reach and lift the illuminated block as quickly as possible. All of the participants were able to comprehend the instructions and carry out the task without difficulty.

Results

Data reduction and inferential analyses

Median values for each dependent measure were derived from the experimental trials performed in each condition by each individual participant. Instances in which the participant had obviously anticipated the presentation of the target (reaction time < 150 ms) were excluded (less than 5% of trials for any individual within the experiment and less than 2% of trials for any participant group). We found that children reached and grasped the correct target on every trial. Planned comparisons (one-tailed) were performed separately for each experimental group using a repeated measures analysis of variance (ANOVA) design. In order to assist in the interpretation of the tests of significance, measures of effect size were calculated following Cohen (1988). The effect size index for ANOVA (f) is a dimensionless index, which describes the degree of departure from no effect—in other words, the degree to which the phenomenon is manifested. A small effect size is considered by convention to be indicated by an f of .1, a medium effect size by an f of .25, and a large effect size by an f of .4 (Cohen, 1988).

Comparisons between children with and without DCD

One aim of the experiment was to compare the behaviour of the children with DCD with a control population. One difficulty inherent in such a procedure is deciding the appropriate comparison group. On the one hand, it is interesting to compare performance with children of a comparable age. On the other hand, such comparisons lack interest when it has already been established that (by definition) the groups have different levels of movement ability. In the present experiment we decided to compare our group of children with DCD to the group of control children aged 7–8 years. In fact, the median age of our DCD population was 8.9 years with a number of the children being considerably older. The fact that on average the children with DCD are older (and no individual was younger) than the control children allows us to be confident that any differences between the groups reflect genuine disparities between behaviour. We were also interested in comparing our DCD population with the control group aged 4–6 years. This comparison is important because our DCD population showed comparable motor abilities to these younger children (as indexed by the Movement ABC). It follows that any differences between the DCD population and the youngest age group reflect underlying differences rather than representing a developmental "delay". Finally, we decided that it was important to look at all of the children on an individual basis in order to determine whether the pattern of observed results showed any individual variation.

Reaction times

The adults exhibited reaction times that were lower in both the complete, $F(1, 22) = 11.51$, $p < .01$, $f = .35$, and partial precue, $F(1, 22) = 3.52$, $p = .07$, $f = .19$, conditions, than in the null condition (Figure 2, Panel A).

The children in the 4–6 age group, $F(1, 26) = 18.69$, $p < .01$, $f = .41$, the 7–8 age group, $F(1, 24) = 38.16$, $p < .01$, $f = .60$, the 9–10 age group, $F(1, 24) = 41.55$, $p < .01$, $f = .63$, and the 11–12 age group, $F(1, 10) = 16.35$, $p < .01$, $f = .59$, exhibited reaction times that were lower in the complete precue condition than in the null condition. In addition, the children in the 4–6 age group, $F(1, 26) = 5.79$, $p < .05$, $f = .23$, the 7–8 age group, $F(1, 24) = 16.20$, $p < .01$, $f = .40$, the 9–10 age group, $F(1, 24) = 16.02$, $p < .01$, $f = .40$, and the 11–12 age group, $F(1, 10) = 8.10$, $p < .05$, $f = .41$, exhibited reaction times that were lower in the partial precue condition than in the null condition (Figure 2, Panel A).

The reaction times exhibited by children with DCD in the complete precue condition were lower than those observed in the null precue condition, $F(1, 20) = 6.20$, $p < .05$, $f = .27$, indicating that they had utilized advance information to prepare their movements. When advance information specifying only the location of the target object relative to the midline was provided, reaction times were equivalent to those obtained when ambiguous information was given, $F(1, 20) < 1$, $p > .20$, $f = .02$.

There were few indications that the location of the target impacted upon the response latencies. A statistically reliable effect was noted only for the youngest (4–6) age group, $F(3, 39) = 4.46$, $p < .01$. In this instance, movements directed to Target Position 3, the concentric target in contralateral (left) space, were initiated more quickly than movements directed to Targets 1, 2, or 4 (Figure 2, Panel B).

Movement times

In relation to the interpretation of the impact of precue condition upon reaction time, of particular significance was the observation that movement times did not vary in a consistent fashion as a function of precue condition. In the 11–12 age group, the movement times exhibited in both the complete, $F(1, 10) = 43.58$, $p < .01$, $f = .96$, and partial, $F(1, 10) = 19.02$, $p < .01$, $f = .63$, conditions were shorter than those observed in the null condition. In so much as the pattern of movement times and reaction times were equivalent, these results indicate that the 11–12 age group participants did not engage in a trade-off between response latency and movement duration. The precue condition did not impact in a reliable fashion upon the movement times exhibited by the other participant groups (Figure 3, Panel A).

The position of the target block had a predictable impact upon the duration of the movement: for the adults, $F(3, 33) = 27.00$, $p < .01$, the children in the 4–6 age group, $F(3, 39) = 28.77$, $p < .01$, the 7–8 age group, $F(3, 36) = 17.62$, $p < .01$, the 9–10 age group, $F(3, 36) = 19.58$, $p < .01$, and the 11–12 age group, $F(3, 15) = 23.43$, $p < .01$, and the children with DCD, $F(3, 30) = 110.12$, $p < .01$ (Figure 3, Panel B).

Discussion

The results from the study confirm the previously identified advantage of advance information regarding target location in a reach-to-grasp task. The advantage was observed in an

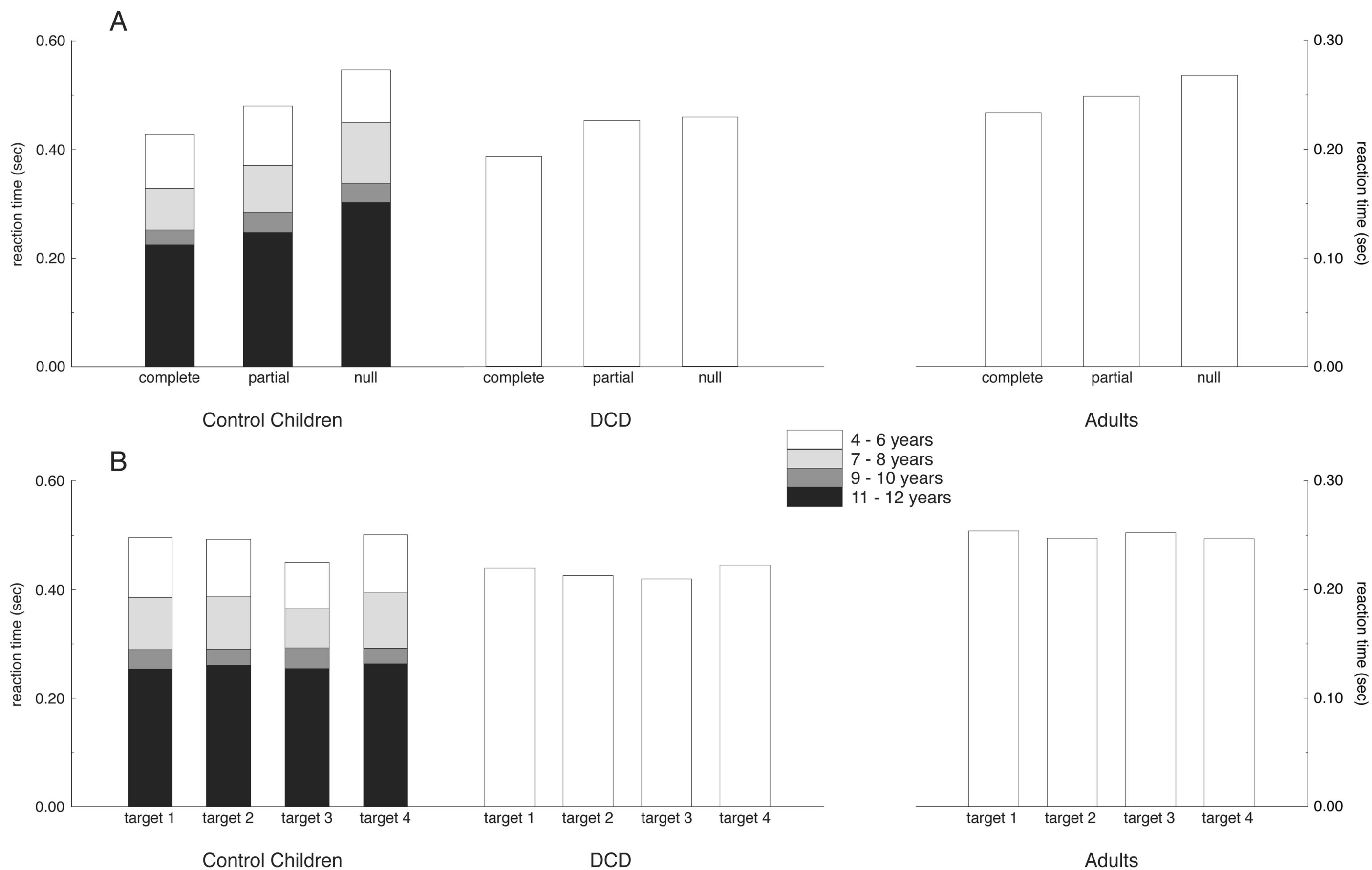

Figure 2. **A.** The median reaction times (s; collapsed over targets) for the three precue conditions are shown for the three participant groups. The data from the different groups of children are shown by the different column shading, as indicated in the legend. **B.** The median reaction times (s; collapsed over precue conditions) for the four target locations are shown for the three participant groups. The data from the different groups of children are shown by the different column shading, as indicated in the legend.

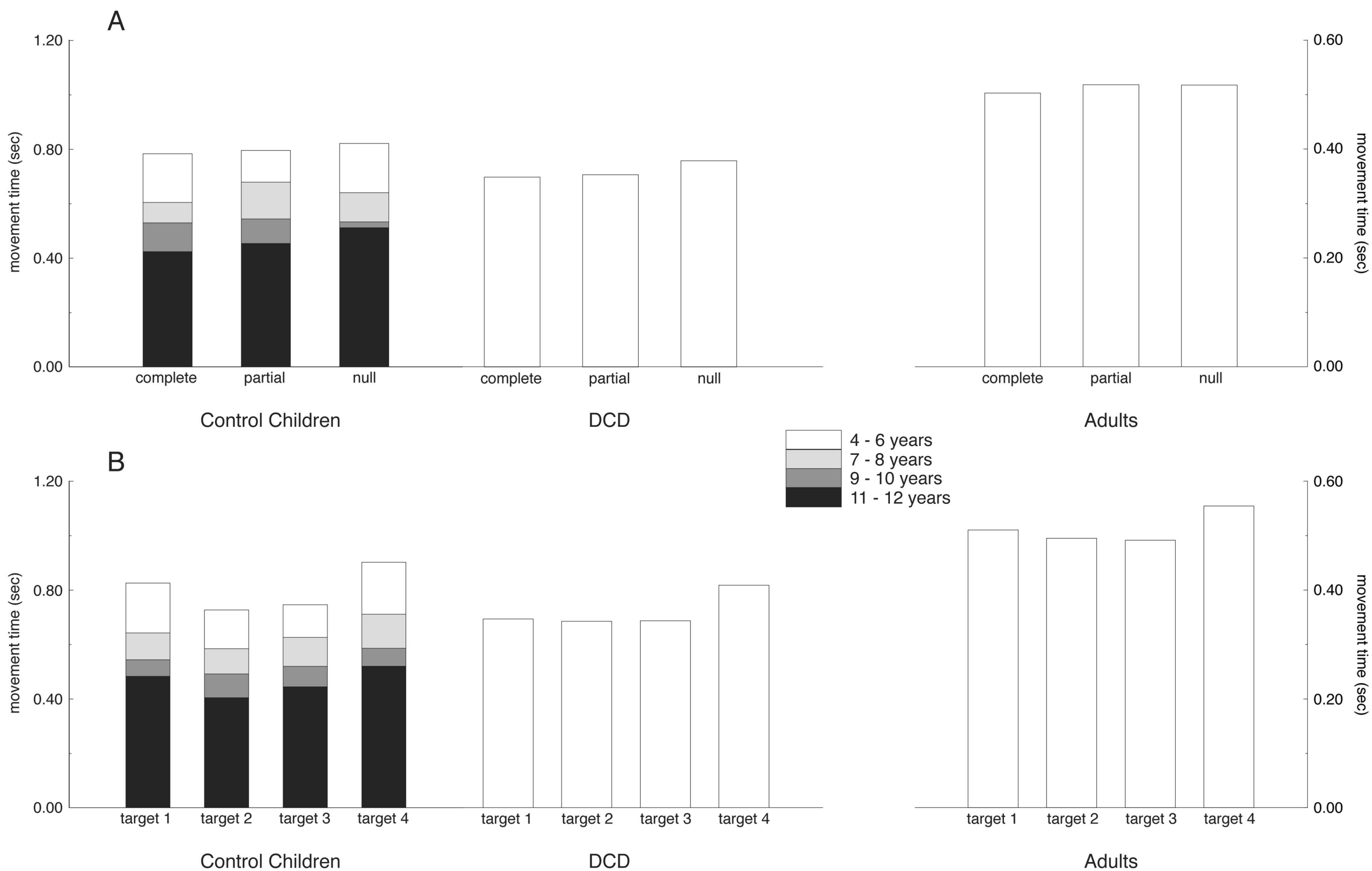

Figure 3. **A.** The median movement times (s; collapsed over targets) for the three precue conditions are shown for the three participant groups. The data from the different groups of children are shown by the different column shading, as indicated in the legend. **B.** The median movement times (s; collapsed over precue conditions) for the four target locations are shown for the three participant groups. The data from the different groups of children are shown by the different column shading, as indicated in the legend.

adult population and in four age groups of children. Notably, the advantage was present in even the youngest age group (4–6 years), suggesting that the human nervous system exploits precue information at a very early stage in the lifespan. A larger precue advantage was found in the full precue condition but all adults and all control children also showed an advantage (over the null condition) when partial precue information was provided. Interestingly, our data indicated that the children with DCD were able to utilize advance information in the preparation of their movement (i.e., the reaction times were lower in the complete precue condition than in the null condition). In contrast to the "normal" groups, the children with DCD showed no reduction in reaction time when the partial precue condition was compared with the null condition. Inspection of the data showed that neither the youngest nor the oldest child with DCD showed an advantage of partial precueing. It is interesting to note that even the youngest group of control children showed an advantage of partial precueing, suggesting a genuine underlying difference in the DCD and control populations. The youngest age band showed a similar level of motor performance (as indexed on tests like the Movement ABC) to that of the older children with DCD. Thus, our data strongly suggest that the children with DCD are not showing signs of developmental delay but rather are performing in a qualitatively different manner to children of a similar motoric ability.

The results from the present experiment also showed that movement time was not influenced in a systematic fashion by the precue condition for these groups. This finding suggests that none of the groups traded response time against movement duration. This result is in line with previous findings (LeClair et al., 1993; Mon-Williams et al., 2001). Our results also showed that the more eccentric targets (i.e., the targets furthest from the starting point) produced the greatest movement times, with the left-most target causing the largest movement duration for all the groups. This pattern of results is predicted from the relative difficulty of reaching to the different target positions (as dictated by distance and whether the target is contralateral or ipsilateral to the hand).

The results from the present study are remarkably similar to the findings from our previous study, involving adults with Down syndrome (DS). The effect size for the comparison of reaction times in the complete precue and the null conditions was .55 for the adults with DS and .27 for the children with DCD. In both groups, the provision of partial advance information had no effect ($f = .02$ for both groups) upon reaction time. In the youngest control group the advantage attributable to partial advance information was associated with a moderate effect size ($f = .23$). The findings from the adults with DS and the children with DCD raise the question of why neither group used the potentially useful information that was available in the partial precue condition. One possibility is that the children with DCD (and the adults with DS) were unable to process the information in a sufficient time period for the cue to be of use. Such a possibility seems unlikely when one considers the fact that the children with DCD (and the adults with DS) were able to process the information when it was unambiguous. Furthermore, the pattern of results does not appear to be caused by a general depression in cognitive ability. In the study involving adults with DS, those in the DS group were matched with control children on the basis of cognitive ability. In the current study, the children with DCD showed cognitive abilities commensurate with their chronological age and certainly in excess of the youngest age group of control children. In support of the idea that the pattern of results is not caused by an input processing problem, we note that adults with DS are able to take advantage of partial information when making relatively simple (aiming) movements (LeClair et al., 1993). It appears, however, that adults with DS "choose" not to use this information when preparing to make more complex movements.

If the pattern of results cannot be readily explained by a simple deficit in processing stimulus information, what can explain these findings? We have suggested previously that the partial precue information allows participants to prepare a movement to a point between possible target positions. The imperative stimulus would then trigger a response to an incorrect location but the system could correct the spatial error during the subsequent implementation of the movement. In fact, it is well established that participants can respond rapidly to target perturbations—even when those perturbations follow movement onset (e.g., Paulignan, Jeannerod, MacKenzie, & Marteniuk, 1991). It is clear, however, that such a strategy is only worth implementing if it is possible to make the requisite corrections during movement execution. In situations where the system is less able to make rapid corrections to an initial movement trajectory, it is likely that the cost associated with a "midway" strategy (end-point error) is greater than the potential benefit (a slightly faster initiation time). It seems reasonable to suggest that the cost of implementing a strategy based on partial information is too high for either the children with DCD or the adults with DS in a prehension task. Taken together, these findings suggest that people with movement problems are willing to adopt a strategy used by the normal population for simple movements but are unwilling to implement the same strategy when the movements become more complex. We should point out that our use of the term "strategy" does not imply a conscious decision (or a cognitively penetrable process). Nevertheless, we do intend to imply that the process is at a "higher" level of motor programming rather than a "lower" level of movement execution. In support of this suggestion, Weiss, Stelmach, Chaiken, and Adler (1999) have found that patients with Parkinson's disease are able to use advance information but do suffer from a slowing of the motor preparation process (a slowing that becomes more pronounced in complex tasks like prehension).

It will be noted that our explanation of the results places emphasis on the preparation and control of the movement itself rather than some putative "cognitive" functions. In contrast, a number of researchers prefer to interpret such observed deficits in DCD in more general terms. Thus, Mandich et al. (2003) describe their results in terms of the system's ability to "disengage ongoing attentional focus" whilst Wilson et al. (1997) discussed "voluntary control of orienting visuospatial attention". Mandich et al. found that a population of children with DCD are much slower at modifying a movement after the children have been primed to an incorrect location. Moreover, Mandich et al. reported that children with DCD find it harder to stop the execution of a primed movement (i.e., they are precued to move to a location but the target that appears is red rather than green, and, contrary to previous instructions, the movement is executed). Wilson et al. found disproportionate increases in reaction time when precue information was incongruent and sometimes a failure to use precue information in children with DCD. These findings seem to provide support for the suggestions we have made within this manuscript. Nevertheless, we prefer to consider the problems experienced by the children with DCD in terms of the stages that must occur in the preparation and execution of a movement rather than some hypothesized attentional control mechanisms whose relationship to movement control is poorly understood and even more poorly delineated.

In common with a number of other studies (e.g., Schellekens et al., 1983; T. R. Smyth & Glencross, 1986; Van Dellen & Geuze, 1988), we found that reaction times and movement times were greater for children with DCD than for a control group of equivalent or younger age. In fact, the reaction times and movement times found in the children with DCD were equivalent to those observed in the youngest group of children (4 to 6 years of age). These findings are at odds with the results reported by M. M. Smyth et al. (2001), who found that their DCD population executed movements at the same speed or more quickly than did control children. It is always difficult to compare such experimental results because prehension measures are influenced dramatically by relatively small changes in the constraints inherent within the task (Loftus, Goodale, Servos, & Mon-Williams, 2004). One plausible explanation of the differences between these results is the difference in the cost of colliding with the target objects in the two experiments. In the present experiments, the targets were mounted on rigid supports and thus could not be knocked over. This is likely to have encouraged all participants to move as fast as possible. In contrast, M. M. Smyth et al. (2001) had their participants reach to grasp relatively small spheres mounted on top of a piece of wood dowelling. In this situation, there are clear advantages to slowing down the movement—a strategy that the control children appeared to follow. In contrast, the children with DCD appeared to lack this strategic awareness (a conclusion reached by Smyth et al. with additional lines of evidence). It is also possible that the differences between studies simply reflect differences in DCD populations but at the present time such a conclusion lacks parsimony. Thus, a reasonable summary of research into prehension in DCD is that reach-to-grasp movements are intrinsically slower than those observed in control children in unconstrained tasks but children with DCD do not show the normal strategic slowing down when task constraints become more demanding (which can result in children with DCD moving faster than their age-matched peers).

In summary, our findings indicate that adults, children as young as 4–6 years, and children with DCD are able to use advance information that specifies precisely the location of a target object in order to prepare a reach-to-grasp movement. Partial information that specifies only one dimension of the movement goal (i.e., the position of the object relative to the body midline) is also used by adults and children as young as 4–6 years but is apparently not utilized by children with DCD when preparing a complex movement (prehension). A similar finding has been reported for adults with Down syndrome (Mon-Williams et al., 2001). The lack of advantage provided by the partial information does not appear to be related to a general depression of cognitive ability but rather is associated with deficits of movement control per se. We have provided one hypothesis that can account for why individuals with movement problems "choose" not to use advance information. Our explanation rests upon the difficulties inherent in modifying a preplanned movement. One test of this hypothesis is to explore the ability of people with Down syndrome and DCD to make online corrections to movements. We anticipate that the paradigm outlined in this paper and the reported results will provide fresh impetus to investigations regarding the preparation and execution of reach-to-grasp movements within experimental psychology.

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