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The aim of this study is to describe the reaching action of children with developmental coordination disorder (DCD) and to investigate whether their use of visual feedback during the time course of this action differs from that of normally developing children. Fifty-two children subdivided into 2 age bands (7–8 and 9–10 years) within 2 groups (with and without DCD) participated in this experiment. They were asked to reach for a target positioned either ipsilaterally or contralaterally to the reaching hand in 2 visual conditions: a condition where vision was unrestrained (normal vision) and a condition where they wore glasses with prismatic lenses (perturbed vision). An analysis of the experimental data indicates that the trajectories followed by the DCD group were longer and more curved than those of the control group. Further, the deceleration times were longer for the DCD group than for the normally developing children. The introduction of the prismatic lenses supports the idea that the use of visual feedback by children with DCD may be different from that in children without DCD.

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During development, up to 6% of primary schoolchildren ages 5 to 11 years have been found to exhibit developmental coordination disorder (DCD; Cermak & Larkin, 2001). The essential feature of DCD is the marked impairment of activities that require motor coordination when compared to normal age-matched children. This deficit is not due to a general medical condition and does not meet the criteria for an intellectual deficit or pervasive developmental disorder. See *Diagnostic and Statistical Manual of Mental Disorders* (4th ed. [*DSM–IV*]; American Psychiatric Association, 1994).

Despite progress in the clinical evaluation of DCD by means of tests such as the Movement Assessment Battery for Children (MABC; S. E. Henderson & Sugden, 1992), children with DCD are still misdiagnosed, and on some occasions simply described as naughty or lazy. Recently, however, various attempts have been made to make a more precise motor evaluation of this disorder by using kinematical analysis. In particular, the reaching action has been used as an experimental window to understand the cognitive organization of reaching movements.

Reaching movements provide an ideal means of investigating whether motor-planning strategies might be compromised in children with DCD. This is because a large body of information concerned with the characteristics of this action in normally developing children has already been acquired (Kuhtz-Buschbeck et al., 1998). For instance, it has been demonstrated that in contrast to adults, children perform straighter trajectories only after the age of 7 years, whereas the youngest have more curved trajectories (Schneiberg, Sveistrup, McFadyen, McKinley, & Levin, 2002). In addition, between ages 7 and 8 years, they seem to be markedly limited in their ability to flexibly adopt alternative perceptual strategies for movement control, and they seem to be more dependent on visual feedback (Bard, Hay, & Fleury, 1990; Brown, Sepehr, Ettlinger, & Skreczek, 1986; Rösblad, 1996). Further, that this period around the age of 8 years is crucial for the development of visual feedback control has also been confirmed by Hay (1978, 1979). Results from Hay's studies suggested that the reaching action is characterized by a ballistic control until the age of 7 years; whereas, between 7 and 8 years, movement can be controlled by either a ballistic or a feedback mode. Moreover, it appears from the age of 8 years that a feed-forward type of control is replaced by a more visual feedback type of control.

Few studies have addressed the question of whether the pattern of reaching movements reported in the preceding paragraph for normally developing children varies in children with DCD. Van der Meulen, Denier van der Gon, Gielen, Gooskens, & Willemse, (1991a, 1991b) analyzed velocity and acceleration of reaching movements performed by DCD children. They demonstrated that children with DCD used visual information similarly to normally developing children, but the *anticipatory control* of children with DCD seemed to be less developed. In their terms the notion of anticipatory control was the ability to scale movements appropriately during the first accelerative part of the reaching action. Hence, it appears that their DCD group may have had a deficit in open-loop control mechanisms, rather than in the ability to integrate visual information from the hand and target position with motor processes.

The ability of children with DCD to use visual information during reaching movements was also investigated by Smyth, Anderson, and Churchill (2001). In particular, they conducted kinematical analysis of the reach-to-grasp movements in children with DCD ages 9 and 10 years. Their results suggested that the reaching action of children with DCD was only affected when visual feedback was reduced. This was particularly evident when examining the time from peak deceleration to target contact (defined as the *low-velocity phase*). Although normal children showed a modulation in this phase, depending on whether visual feedback was available or not, children with DCD did not show any such modulation. This may indicate that they were less able to use visual feedback (when available), or they were less reliant on visual feedback than the normal children. However, as an alternative to the visual feedback hypothesis, Smyth et al. proposed that, as compared to controls, children with DCD might be both less careful when visually acquiring a target and less able to process the physical characteristics of the target object relevant to any set task.

All in all, although researchers agree that children with DCD show some disruption of the perceptual or motor control mechanisms or both, results have been mixed. Thus whether and how visual feedback mechanisms are affected in children with DCD has yet to be clearly determined. Consequently this study aims to investigate whether the level of reliance on visual feedback differs in children with DCD as compared to normally developing children. For this purpose, a prismatic condition was introduced, consisting of a visual perturbation involving a lateral displacement of the optic array to the right along the horizontal plane. It is well known that this type of psychophysical manipulation can be used to alter straight-ahead demonstrations in normal healthy subjects. Exposure to an optical alteration of the visual field is known to produce an initial disorganization of visuomotor behavior that can be corrected through visuomotor adaptation (Redding & Wallace, 1996). Our prediction is that if children with DCD are less reliant on visual feedback than normal children, they should be less affected by the presence of this visual perturbation.

MATERIALS AND METHODS

Participants

A sample of 286 right-handed children (168 boys and 118 girls, ages 7–10 years) from four primary schools within both urban and rural areas of a northeastern region of Italy were screened (after informed written consent had been obtained from their parents), using the MABC Scale (S. E. Henderson & Sugden, 1992). On the basis of these results, a group of 26 children with DCD were selected for this investigation (see Table 1). Indeed, after testing, the school teachers of these particular children described them as demonstrating motor problems in everyday performance. Of these 26 children, 19 were found to score at or below the 5th percentile, with the remaining 7 children scoring between the 5th and the 8th percentile. They also scored above the 70th percentile in the Raven Matrices test for nonverbal ability (Raven, 1954). This DCD group was compared with a control group of 26 normally developing children who were matched for age and sex (see Table 1). All of the children in the control group scored above the 36th percentile on the MABC test.

All of the children taking part in this experiment underwent a complete neurological examination, but none showed any alteration in tone or reflex, or any problematic cerebellar signs (e.g., intention tremors, delays in starting and stopping movements). In addition, no evidence of cranial nerve abnormalities was found. The children also had an ophthalmic examination and the outcome was negative. Only four children wore corrective glasses for myopia, with the remainder showing no deficit in visual acuity, convergence control, accommodation, or dynamic visual tracking. Neither did they suffer from strabismus.

The two groups with and without DCD were also subdivided into two age bands, 7 to 8 and 9 to 10 years, as described in Table 1.

Apparatus

Two red LEDs were embedded in the table surface (depth 65 cm × breadth 124 cm; see Figure 1). A thumbtack fixed to the desk (located 15 cm away from the front edge of the table and at the midpoint between the two target positions) defined the starting position (see Figure 1). This tactile mark was chosen to minimize the variability of the starting position across trials. Participants were seated on a height-adjustable chair such that the thorax pressed gently against the front edge of the table and the feet were supported. A reflective marker (1 cm in diameter) was attached to the radial side of the right-hand index finger's nail. Movements were recorded, at a sampling rate of 200 Hz, by a 3D infrared motion analysis system (ProReflex MCU 240 Version 6.42 constructed by Qualysis Medical Company—Gothenburg, Sweden), which consisted of two infrared cameras positioned in front of the working surface.

This technique permitted the reaching movements to be replayed in slow motion and quantitative kinematical analyses to be made of components of the whole movement that can be described in terms of velocity and time—for example, acceleration, deceleration, movement duration, and so on.

The calibrated working space considered by the system was a parallelepiped (depth 60 cm × breadth 61 cm × height 40 cm) from which the spatial error measured using both stationary and moving stimuli was calculated to be 0.1 mm.

TABLE 1
Details of the DCD and Control Groups

Child With DCD	*Sex*	*Age 7–8*	*Raven Score*	*Matrices (%)*	*MABC Score*	*Test (%)*	*Control*	*Sex*	*Age 7–8*	*Raven Score*	*Matrices (%)*	*MABC Score*	*Test (%)*
1	M	7 year	19	75	22	1	1	M	7 year	26	95	0.5	93
2	M	7 year 2	27	95	12	8	2	M	7 year 1	19	75	2	79
3	M	7 year 5	26	95	29	1	3	M	7 year 5	26	95	1.5	84
4	M	7 year 6	28	95	15	3	4	M	7 year 6	25	95	0	96
5	M	7 year 7	25	95	29	1	5	M	7 year 7	21	75–90	5.5	40
6	M	7 year 8	30	95	16.5	2	6	M	7 year 8	33	95	0	96
7	F	7 year 9	22	75–90	22.5	1	7	F	7 year 9	22	75–90	4	54
8	M	8 year	24	90	34	1	8	M	8 year	32	95	5	45
9	M	8 year 1	30	95	23.5	1	9	M	8 year 1	24	90	3.5	60
10	F	8 year 2	29	95	17.5	1	10	F	8 year 1	25	90–95	3.5	60
11	M	8 year 4	27	90	12	8	11	M	8 year 5	23	75	6	36
12	M	8 year 5	35	95	15	3	12	M	8 year 5	35	95	2	79
13	M	8 year 7	29	95	28.5	1	13	M	8 year 6	28	90–95	6	36
14	F	8 year 7	24	75–90	12	8	14	F	8 year 8	29	95	0.5	93
15	M	8 year 11	25	75	16.5	2	15	M	8 year 11	31	95	3	65
M		7 year 9	26.67		20.33				7 year 9	26.60		2.87	
SD		0.6	3.8		7.2				0.6	4.7		2.1	

(continued)

TABLE 1 *(Continued)*

Child With DCD	*Sex*	*Age 9–10*	*Raven Score*	*Matrices (%)*	*MABC Score*	*Test (%)*	*Control*	*Sex*	*Age 9–10*	*Raven Score*	*Matrices (%)*	*MABC Score*	*Test (%)*
16	M	9 year	24	50–75	14.5	4	16	M	9 year	33	95	6	36
17	M	9 year 1	28	90	28.5	1	17	F	9 year 1	28	90	1.5	84
18	M	9 year 2	33	95	15.5	3	18	M	9 year 2	35	95	2.5	70
19	M	9 year 6	36	95	13.5	5	19	M	9 year 6	35	95	6	36
20	M	9 year 8	30	75	13	6	20	M	9 year 7	29	75–90	6	36
21	M	10 year	29	75–90	17.5	1	21	M	10 year	33	95	4	54
22	F	10 year	35	95	15.5	3	22	F	10 year	36	95	9.5	16
23	F	10 year 1	30	90–95	22	1	23	F	10 year 1	30	75–90	0.5	93
24	M	10 year 6	33	95	12.5	7	24	M	10 year 6	32	90–95	6	36
25	M	10 year 8	34	95	12	8	25	M	10 year 8	33	95	3	65
26	M	10 year 8	29	75	38.5	1	26	M	10 year 8	35	95	4	54
M		9 year 8	31		18.5				9 year 8	32.64		4.45	
SD		0.6	3.5		8.2				0.6	2.7		2.6	

Note. DCD = developmental coordination disorder; MABC = Movement Assessment Battery for Children; M = male; F = female.

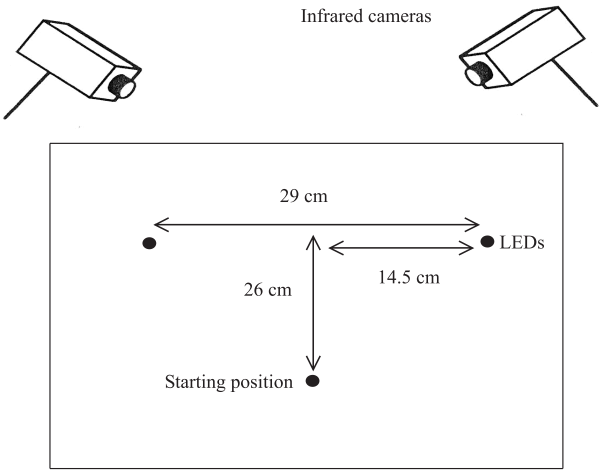

FIGURE 1 A schematic representation of the experimental set up (note not to scale).

Procedure

Participants took part in two experimental sessions. In the first session the MABC and Raven Matrices test were administered. The MABC test was specifically chosen to measure motor coordination skills after studying previously reported results obtained from comparing Italian-sourced data with norms gathered in North America. This comparison demonstrated that the MABC test may be considered suitable for Italian children (Zoia et al., 2002), as studies of other European populations (e.g., Netherlands, Sweden) have shown (Rösblad & Gard, 1998; Smits-Engelsman, Henderson, & Michels, 1998).

In the second session (2 months later) three experimental conditions were administered in the following order: (a) a baseline condition in which participants were required to reach with the index finger to one of the two LEDs in full vision; (b) a baseline with prism condition where participants were required to wear glasses with prismatic lenses of 15 diopters equivalent to 8.57° of visual angle and reach with the index finger to one of the two LEDs. The glasses with the prismatic lenses produced a visual perturbation that determined a lateral displacement of the optic array to the right along the horizontal plane so that the virtual target position was 5.61 cm from the real position; (c) a baseline postprism condition where participants were required to reach to one of the two LEDs in full vision, as in the baseline condition. Participants performed a total number of 42 trials. For each condition, 7 trials required a reaching action toward the left LED (contralateral target) and 7 trials required a reaching action toward the right LED (ipsilateral target). With the contralateral and ipsilateral positions defined with respect to the starting position, participants were instructed to start each trial with the right index finger positioned on the starting position and to touch one of the two LEDs as soon as it became illuminated. A practice session was conducted in normal vision to check that the participants fully understood the task. In this work, unlike what is customary in adult studies, the prismatic effect in terms of prism adaptation was condsidered, whereas the aftereffect (which appears after the removal of the prismatic lenses, as an overcorrection of the arm movement toward the opposite side of the perturbation) was not. This is because prism adaptation and aftereffect usually depend on the velocity of the movements (Kitazawa, Kimura, & Uka, 1997), and in our study velocity was not stressed or manipulated. Further, the aftereffect in children might be harder to resolve given their on-going cognitive and neural maturation.

Data Processing and Analysis

The Qualysis software package (Elekton, 2000) was used to assess the data and gave a three-dimensional reconstruction of the marker position as a function of time. The data were then smoothed using a moving average filter, with the Hanning window set at 16 Hz.

The dependent variables that were thought to be specifically relevant to the scientific hypotheses under test were specified and justified in advance, and the statistical analysis was confined to these variables. The variables of interest were movement time (duration), the time from peak velocity to the end of the movement (deceleration time), the length of the spatial trajectory, and the maximum deviation of the spatial trajectory. This latter parameter was calculated from considering the maximum distance between the child's spatial trajectory and the ideal path (which was defined by the minimum distance, i.e., a straight line between the start position and the target). These variables were chosen because consistent results within the reaching literature have shown that movement time and the characteristics of the velocity profile described previously are dependent on the position and visual availability of the target (Hay, 1979; Hay, Bard, Fleury, & Teasdale, 1991; Rösblad, 1996). The spatial trajectory analysis was conducted because specific features of trajectories may reveal how the central nervous system plans reaching actions. For example, when the initial and the final position of a movement are given in advance, subsequent trajectories tend to be straight and smooth (Abend, Bizzi, & Morasso, 1982).

Movement time was defined as the interval between the time the participant lifted his or her finger from the starting position and the time the participant touched the target. Temporal values were also calculated in relative terms, that is, as a percentage of movement time. This was done to normalize the occurrence of relevant kinematic parameters in the event that significant differences in movement time were found.

For each dependent variable an analysis of variance was conducted, with group (DCD and control) and age (7–8 and 9–10 years) as between-subject factors, and condition (baseline, baseline with prism, baseline with postprism) and target (contralateral, ipsilateral) as within-subjects factors. Post hoc comparisons on the means of interest were carried out using *t* tests.

RESULTS

Effects of Group and Age

Please note that this section considers the effect of group and age independently from the experimental conditions. That is, the results obtained for the baseline, baseline with prism, and baseline with postprism conditions are combined.

Two parameters, the length and the maximum deviation of the spatial trajectory, were found to be particularly sensitive to the distinction between the movement pattern of normally developing children and those with DCD. The length of the trajectory path for the group with DCD was longer than that for the control group: 374 vs. 343 mm respectively; $F(1, 48) = 13.805$, $p < .001$. The children with DCD also showed a greater deviation compared to that of the control group: 155 vs. 143 mm respectively; $F(1, 48) = 80.270$, $p < .001$. These two parameters were also sensitive with respect to age. For both the control and the DCD groups, the trajectory path was longer: 370 vs. 347 mm; $F(1, 48) = 7.008$, $p < .01$, and the maximum deviation was greater: 156 vs. 142 mm; $F(1, 48) = 105.842$, $p < .001$, at the age of 7 or 8 years compared with the age of 9 or 10 years, respectively.

The interaction between group and age was significant for the trajectory length, $F(1, 47) = 10.801$, $p < .002$ (see Figure 2) and for the maximum trajectory deviation, $F(1, 47) = 81.831$, $p < .001$ (see Figure 3). Scheffé's test confirmed these interactions and revealed that the trajectory path for the group with DCD ages 7 to 8 years was longer ($p < .001$) and showed a greater deviation ($p < .001$) compared to the age-matched controls. Further, the trajectory path for the 7-to-8-year-old DCD group was longer and showed a greater deviation than that for the children with DCD ages 9 to 10 years (trajectory path, $p < .002$; maximum deviation from the ideal path, $p < .001$). For the age-matched controls no differences in these parameters with respect to age were found. Furthermore, the interaction between group and age was also significant for movement time, $F(1, 47) = 5.815$, $p < .02$, and deceleration time, $F(1, 47) = 10.801$, $p < .002$. Scheffé's test revealed that movement time was longer for children with DCD ages 7 to 8 years compared to their control peers ($p <. 01$). For the deceleration time parameter, Scheffé's test revealed that the velocity profile for the control children was characterized by a longer deceleration phase at the age of 7 to 8 years than at the age of 9 to 10 years ($p < .03$). For the DCD group this age-related pattern was not evident.

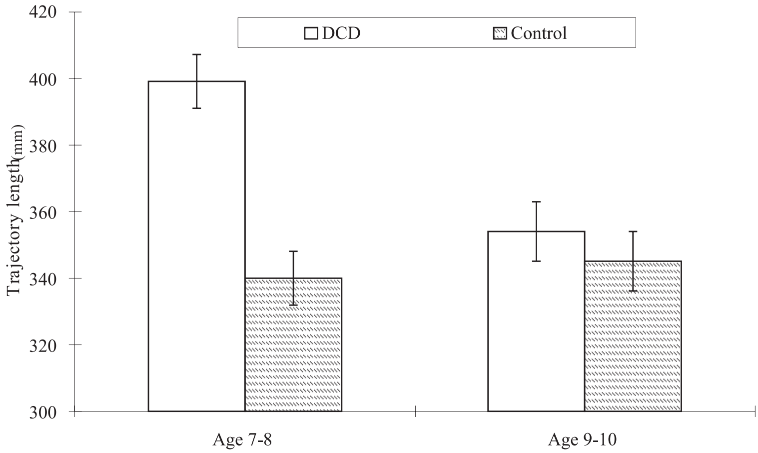

FIGURE 2 A graphical representation of the interaction Group (DCD and Control) x Age (7–8 and 9–10 years) for the trajectory length. Standard Errors are given by the error bars.

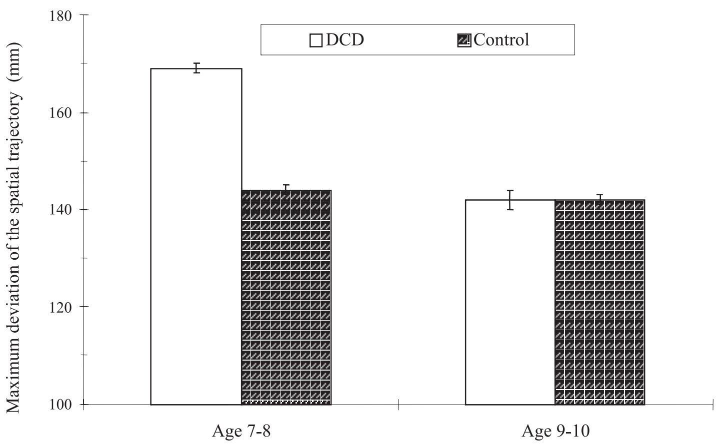

FIGURE 3 A graphical representation of the interaction Group (DCD and Control) x Age (7–8 and 9–10 years) for the maximum deviation of the spatial trajectory (panel B). Standard Errors are given by the error bars.

Effect of the Prism

When comparing reaching movements among the three conditions (baseline, baseline with prism, and baseline with postprism), it was evident that the introduction of the prism brought a general increase in movement time, maximum deviation, and deceleration time (see Table 2).

This trend was similar across both ages and for both groups. In other words, for all parameters, except movement time, the performance of the control children and those with DCD was very similar. However, as revealed by the interaction Condition × Group for the parameter movement time, $F(2, 46) = 4.424$, $p < .017$ (see Figure 4), this measure for the children with DCD was longer compared to that of their control peers in both the baseline, $t(50) = 2.79$, $p < .007$, and the baseline with prism condition, $t(50) = 2.27$, $p < .03$. The children with DCD reduced their movement time in the baseline with postprism condition, which returned (approximately) to baseline values. In addition, their movement time was significantly reduced only in the baseline with postprism condition compared to the baseline with prism condition, $t(25) = 3.035$, $p < .006$. These effects were not found for the children in the control group. For these, movement time in the baseline with postprism condition was longer both in the baseline condition, $t(25) = 2.519$, $p < .02$, and in the baseline with prism condition, $t(25) = 3.621$, $p < .001$, suggesting that their movement time was still affected by the prismatic condition.

Effect of Target Position

Statistical analyses revealed that deceleration time was shorter when reaching toward the contralateral target compared to the ipsilateral target: 63% vs. 67%, respectively; $F(1, 48) = 61.686$, $p < .001$. The trajectory path was longer for movements toward the contralateral target compared to the ipsilateral target (367 vs. 350 mm, respectively; $F[1, 48] = 18.008$, $p < .001$). The interaction between condition and target position was significant for both the maximum deviation of the trajectory path, $F(2, 47) = 98.059$, $p < .001$, and deceleration time, $F(2, 47) = 5.415$, $p < .008$. Post hoc t tests revealed that for the baseline with prism condition the maximum deviation of the trajectory path was greater for the ipsilateral than for the contralateral condition ($p < .001$). The opposite pattern was found for the baseline with postprism condition where the maximum deviation of the trajectory path was greater for the contralateral than for the ipsilateral condition ($p < .001$). Post hoc t tests revealed that deceleration time was longer for ipsilateral than for contralateral movements in each of the three conditions (always for $p < .001$).

DISCUSSION

This study was aimed at investigating whether there are differences in the reaching kinematics of DCD children compared to normally developing children in different visual feedback conditions.

It was found that children with DCD implement different strategies for the planning and execution of reaching movements compared to normally developing children. Indeed, compared to the control group, the children with DCD showed lon-

TABLE 2
Means and Standard Deviations for the Three Experimental Conditions (Baseline, Baseline With Prism, and Baseline With Post Prism) of Movement Time, Trajectory Length, Maximum Deviation and Deceleration time, Distinct for Both the DCD and Control Groups and the Two Age Bands (7–8 and 9–10 Years)

	Controls Baseline		*DCD*		*Controls Baseline*		*DCD With Prism*		*Controls Baseline*		*DCD Post Prism*	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Age 7–8												
Movement time (milliseconds)	768	179	985	216	838	200	1,021	183	813	183	921	135
Trajectory length (millimeters)	333	16.86	394.58	65.80	347.47	20.01	401.98	45.82	339.60	14.75	401.98	44.79
Maximum deviation (millimeters)	141.07	4.1	180.46	7.05	147.06	6.54	169.75	5.10	143.07	5	155.69	8.46
Deceleration time (%)	61	4.47	66	4.88	63	4.48	70	5.81	60	4.48	64	7.18
Age 9–10												
Movement time (milliseconds)	844	122	871	207	932	177	925	185	961	257	799	177
Trajectory length (millimeters)	345.40	22.37	354.79	28.94	347.12	14.50	356.42	34.57	343.86	15	350.30	35.53
Maximum deviation (millimeters)	140.04	4.41	139.91	4.55	146.26	145.34	5	139.93	5	141.05	5.4	
Deceleration time (%)	64	4.98	65	7.22	67	4.45	68	6.56	65	7.13	62	6.51

Note. DCD = developmental coordination disorder.

ger trajectories and made greater maximum deviations from the ideal path. Morasso (1981; see also Abend et al., 1982) demonstrated that the trajectory can reflect the quality of motor planning and showed that the hand tends to (a) displace from the starting position to the target (position) along a relatively straight line, and (b) it maintains a fairly constant movement duration, irrespective of its plane or extent. Morasso interpreted these findings as indicating that movements are programmed in terms of the kinematics of the endpoint of the limb in space. These results may be relevant to understanding possible motor differences in motor planning in children with DCD compared to age-matched controls. In particular, it could be said that the longer and more curved trajectories observed for the DCD children in this study reveal that they do not develop the ability to fully calibrate and fine-tune their reaching motor programs.

In this respect, age seems to be an important factor for children with DCD. At the age of 7 to 8 years they perform longer trajectories and greater trajectory deviations, compared to normal children. These group differences are not evident by the age of 9 to 10 years. This would infer that children with DCD might need a longer period to develop efficient motor planning. That is, at the age of 7 to 8 years children with DCD seem unable to estimate appropriately the distance between the target position and the hand. This is in accordance with the findings of other studies where it has been demonstrated that DCD children have greater movement variability (for a review, see Williams, 2001). Consequently, prolonging the trajectory length provides them with the extra time required for online movement calibration.

This strategy based on prolonging movement phases is also evident when looking at the distribution of the decelerative phases of the movement. Independent of age, the children with DCD spent more time in the deceleration phase compared to the controls, whereas for the normally developing children, deceleration time was shorter at the age of 7 to 8 years than at the age of 9 to 10 years; that is, typically developing children modify strategies concerned with the decelerative part of the action across the ages of 7 to 10 years, whereas those with DCD do not. In normal development, Hay (1978, 1979) suggested that movement is characterized by a ballistic control until the age of 7 years, whereas between 7 and 8 years movement can be controlled by either a ballistic or a feedback mode. Further, Hay suggested that, from the age of 8 years the ballistic control is replaced by the feedback control. The percentage increase of the decelerative part of the movement observed for the control group ages 9 to 10 years, with respect to the children belonging to the same group ages 7 to 8 years, appears to confirm Hay's hypothesized change in motor control strategy. However, this is not the case for the children with DCD examined in this study who at the age of 7 to 8 years were found to spend a percentage of time in the deceleration phase similar to that of the control children ages 9 to 10 years. This percentage, however, does not increase at 9 to 10 years of age, as it does for the equivalent control group. Thus it appears that, in terms of Hay's theory, by the age of 7 to 8 years DCD children develop a strategy possibly dictated by

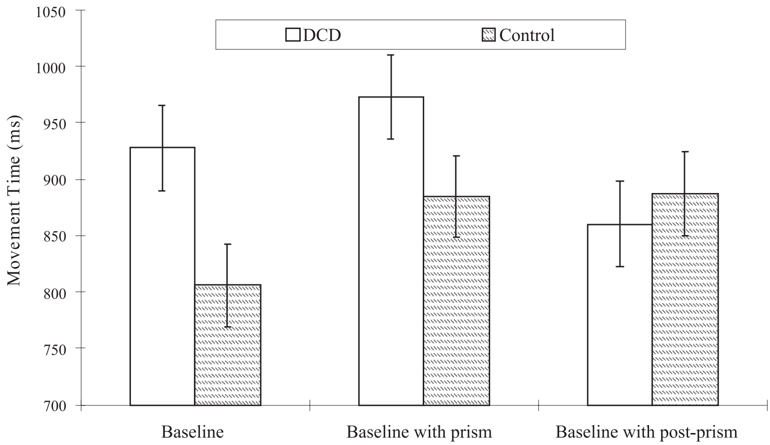

FIGURE 4 A graphical representation of the interaction Group (DCD and Control) x Condition (baseline, baseline with prism and baseline with postprism) for movement time. Standard Errors are shown by the error bars.

an awareness of their dysfunctional motor control, which results in a need for more time to calibrate and refine the action during the decelerative phase.

A "time" effect is also evident in DCD children when the prismatic lenses are introduced. Of particular interest is the effect in the baseline with postprism condition; movement time for the control children was similar to that measured during the baseline with prism condition, whereas for the children with DCD, movement time returned to the values shown in the baseline condition. This may suggest that normally developing children maintain a trace of the action performed under the prismatic condition longer than DCD children, that is, feedback information retained from a previous action might influence subsequent motor planning, preventing immediate readaptation to the condition of normal vision. Alternatively, it could be suggested that there was no effect in the use of prisms per se, but rather an effect due to a recovery from prism adaptation or use. In contrast, DCD children might be less responsive to the experimental manipulation of visual feedback information (Smyth et al., 2001) and thus be less affected by the prismatic perturbation. With a certain degree of caution, it could thus be advanced that the adaptive effect of the prismatic perturbation may have faded away more quickly. But further research is needed to understand why and how perceptual adaptation mechanisms to the prismatic distortion of these children differ from those of normally developing children.

It could be argued that movement time is not an ideal measure to quantify any changes due to prismatic perturbation, which in theory should be more evident along spatial trajectories, but movement time is a parameter that has been considered to both measure the speed of movement execution and indicate the efficiency of motor system function (Forsstrom & von Hofsten, 1982; L. Henderson, Rose, &

Henderson, 1992; Schellekens, Scholten, & Kalverboer, 1983). Further, this measure has been found to be sensitive to the visual perturbation of object size and location (Goodale, Pellisson, & Prablanc, 1986; Paulignan, Jeannerod, MacKenzie, & Marteniuk, 1991a, 1991b). For example, movement time increases when an object is suddenly displaced from one location to another or changes from one size to another. If we assume that the visual distortion produced by our prismatic condition is similar to other types of visual perturbation (as described previously), then it may not be surprising that movement time is a sensitive measure for the visual distortion produced during the prismatic condition.

A final point is concerned with target position. Both groups showed that reaching toward the contralateral target position required a longer trajectory compared to reaching toward the ipsilateral target. This is in line with previous accounts of reaching movements where moving toward a contralateral target produced both longer trajectories and movement durations (Fisk & Goodale, 1985). No differences between the groups with respect to target position for the prism condition were found. In particular, the effect of the prism was stronger for the target positioned ipsilaterally than for the target positioned contralaterally, but given that visual perturbation produces an effect to the right, this is not surprising. Given that literature suggests that DCD children have more difficulty with tasks that cross over the body's midline, it was expected that they would find the contralateral target more difficult to reach. A possible explanation is that the prismatic perturbation produced a ceiling effect that masked differences between the two target positions.

In conclusion, our findings support the view that children with DCD unfold the reaching action differently than control children. This is particularly evident looking at the distribution of the decelerative phase of the reaching action. Further, we have identified kinematic measures, namely, the maximum deviation from the ideal trajectory path and the trajectory length that, with a certain degree of caution, might be used to characterize the developmental time course of DCD with possible implications for the assessment and management of this disorder. However, a longitudinal assessment of these measures would help in relating the interventions to the specific characteristics of their motor development. It should also be taken into account that the children with DCD involved in this study had severe DCD; therefore our results might not apply equally across the entire DCD population, particularly given the evidence of extensive heterogeneity in their motor control, and no single set of characteristics has hitherto been clearly associated with DCD children.

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