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Perceptual skills of children with developmental coordination disorder

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Abstract

The aim of this study was to investigate whether children with a Developmental Coordination Disorder (DCD) experience problems in the processing of visual, proprioceptive or tactile information. Different aspects of visual perception were tested with the Developmental Test of Visual Perception (DTVP-2), tactile perception was assessed with the Tactual Performance Test (TPT), and a manual pointing task was employed to measure the ability to use visual and proprioceptive information in goal-directed movements. Nineteen children with DCD and nineteen age and sex-matched controls participated in this study. Differences between groups were most pronounced in the subtests measuring visual–motor integration of the DTVP-2, and in two subtests measuring visual perception (visual closure and position in space). On average the children with DCD performed slightly below the norm for tactile perception, with only three children failing the norm. On the manual pointing task, children with DCD made inconsistent responses towards the targets in all three conditions (visual, visual–proprioceptive and proprioceptive condition). No significant differences between groups were found for absolute error. Inspection of the individual data revealed that only two

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children failed on the majority of perceptual tasks in the three modalities. Across tasks, no consistent pattern of deficits appeared, illustrating the heterogeneity of the problems of children with DCD.

PsycINFO classification: 2330; 2820; 3250

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1. Introduction

The smooth and accurate performance of goal-directed actions is dependent upon the ability of the Central Nervous System (CNS) to process afferent information rapidly and efficiently (Jeannerod, 1997). The CNS needs for instance afferent information related to the respective positions of limb segments prior to and during movements, also called position sense (Jeannerod, 1988). Signals arising from static and dynamic proprioceptors provide position sense for the relative joint angles (Jeannerod, 1996). Proprioceptors thus inform us about the relative positions of the body and its parts. In this way a body-centred system of co-ordinates is created, which is essential for the planning and execution of complex movements (Purves, Augustine, Fitzpatrick, Katz, & McNamara, 1997; Latash, 1998). However, as proprioception is body-centred, information from proprioceptors needs to be matched with visual information about the position of the limb relative to the object of movements (Jeannerod, 1988, 1996). Therefore, visual cues are required to identify and locate an object in a body-centred system of co-ordinates. The localisation of an object depends on complex visual skills, including the ability to discriminate a target from its background (figure-ground perception), the perception of distance, and the perception of form constancy.

Although both proprioceptive and visual information about the location of an object are sufficient to transport the arm to the object, which is carried out mostly by the proximal joints of the hands, additional visual information is needed if the intention of a movement is to grasp or manipulate an object (Jeannerod, 1996). It concerns information about the intrinsic properties of an object, such as its size, shape, texture and colour (Paillard, 1990). With this information, distal movements can be planned, such as preshaping and rotation of the hand in order to enclose an object (Jeannerod, 1997). Once an object is contacted, tactile information becomes available. Mechanoreceptors of the human skin, which are sensitive to pressure, are involved in tactile discrimination (Latash, 1998). Tactile perceptions occur only if areas of the skin are in close contact with an object. The spatial–perceptual abilities of the hand can be enhanced by active, exploratory movements to provide additional kinaesthetic information (Hatwell, 1990). Tactile information provides information about the spatial properties of objects, such as its size and shape (Hatwell, 1990) and is used to plan posturing of the manual grasp of an object during manipulation, in association with visual information about the object (Paillard, 1990).

Considering the role of perceptual information in the planning and execution of co-ordinated movements, we may assume that these movements will be impaired in case of deficiencies in proprioceptive, visual or tactual perception. Visual perceptual deficits will for instance hamper the accurate perception of the location of an object, which will have consequences for planning of a goal-directed movement. In general, movements become less accurate as a result of deprivation of visual information (Jeannerod, 1988). If proprioception is impaired, goal directed movements are still possible, as has been demonstrated in several deafferentiation studies. However, deafferentiated animals or patients with a peripheral sensory neuropathy were not able to maintain a constant motor output, which was reflected in an increased variability of their errors, particularly in conditions when visual feedback was not available (Jeannerod, 1988). In clinical practice, both tactile perception and proprioception are assumed to be important for the development of a body scheme, which is the basis for the development of praxis (Royeen & Lane, 1991).

As children with a Developmental Coordination Disorder (DCD) experience difficulties in the performance of all kinds of motor skills, deficits in perceptual processes have often been assumed to underlie these difficulties. Over the past 20 years, perceptual skills of children with DCD have been investigated in studies concerning the visual and kinaesthetic perception of distance and spatial relationships (Hulme, Biggerstaff, Moran, & McKinlay, 1982; Hulme, Smart, Moran, & McKinlay, 1984; Lord & Hulme, 1987), studies directed at kinaesthetic sensitivity (Laszlo & Bairstow, 1985; Piek & Coleman-Carman, 1995), and studies on the use of visual and proprioceptive information in manual pointing (Rösblad & Von Hofsten, 1992; Smyth & Mason, 1997; Mon-Williams, Wann, & Pascal, 1999). Characteristic of these studies is that their main focus was on deficits in vision, and to a lesser extent kinaesthesis (Livesey & Coleman, 1998). To our knowledge, none of the studies addressed deficits in tactile perception.

According to a meta-analysis by Wilson and McKenzie (1998), nowadays, strong evidence exists for deficits in visual spatial processing in children with DCD, while they are also impaired in visual–proprioceptive and kinaesthetic perception. However, although perceptual deficits do occur in children with DCD, no evidence exists for a causal relation between DCD and these deficits. In addition, the relative contribution of each mode of perception to the movement problems of children with DCD has not been studied yet (Wilson & McKenzie, 1998). Therefore, the present study aims to investigate different modes of perceptual processing in the same sample of children with DCD, referred for their motor problems to a rehabilitation clinic. Neuropsychological tests will be employed measuring different aspects of visual perception and visual–motor integration as well as haptic perception (or the ability to recognise the shape of objects by tactual manipulation). Both visual and proprioceptive perception will be measured in a manual pointing task, originally developed by Von Hofsten and Rösblad (1988).

With few exceptions, nearly all studies concerning perceptual processing deficits in children with DCD were based on group comparisons, thereby neglecting the performance of individual children within a group (Geuze, Jongmans, Schoemaker, & Smits-Engelsman, 2001). Group comparisons do not tell us how many children with DCD deviate from the norm nor do they provide information about individual profiles of performance across tasks. Therefore, in the present study, both group and individual data will be presented.

2. Method

2.1. Subjects

The subjects were 19 children referred to a rehabilitation clinic for their motor problems by their general practitioner. The inclusion criteria for the referred group stipulated that the subjects were 6–12 years of age, did not have any indication of a neurological or physical impairment as examined by a rehabilitation doctor, and had an IQ-score above 70 on an intelligence test. The WISC-R was administered to check for IQ. All children scored above 70 on the IQ test (range 79–126, mean 97.6). Only children with a total impairment score on the M-ABC test (Henderson & Sugden, 1992) below the 15th centile or a score on one of the three clusters (manual dexterity, ball skills, and balance) below the 5th centile were included in the group with DCD. In the group with DCD, 14 children obtained total impairment scores

Table 1
Characteristics of the DCD and control groups

	DCD	Control
Age		
Mean (years months)	8.4	8.6
Range	6.2–11.10	6.7–11.11
Sex		
Boys (N)	11	11
Girls (N)	8	8
Handedness (R/L)	14/5	16/3
M-ABC test score		
Mean	16.6	3.2
S.D.	6.3	2.4

below the 5th centile, and five children were considered 'at risk': 1 child had a score between the 5th and 15th centile, and four children were included because of cluster scores below the 5th centile, one for manual dexterity, one for ball skills and two for balance problems. In addition, a control group matched for age and sex was randomly selected from children attending a mainstream primary school. The selected children had total scores on the Movement ABC Test (M-ABC test) above the 25th centile, and IQ scores above 70 on the Raven's Progressive Matrices (Raven, 1960) (range 79–129, mean 105.8). Descriptive statistics on age, sex, and M-ABC test scores for each group can be found in Table 1.

2.2. Materials and procedure

Children with DCD and control children were individually assessed in a quiet room at a rehabilitation clinic or at their school, respectively. As part of an assessment protocol before the start of intervention, a physical therapist administered the M-ABC test and a psychological assistant administered the WISC-R in case of a child with DCD. For control children, a research assistant administered both the M-ABC test and the Raven's Progressive Matrices. In addition, the research assistant administered the DTVP-2, the TPT and the manual pointing task to the children in both groups.

2.2.1. The Developmental Test of Visual Perception (DTVP-2) (Hamill, Pearson, & Voress, 1993)

The DTVP-2 aims to document the presence and degree of visual perceptual or visual–motor difficulties in children aged 4–10 years. The test is a revision of Frostig's milestone test battery (Frostig & Horne, 1964). The test comprises eight subtests that measure different but interrelated visual perceptual and visual–motor abilities. Four subtests measure motor reduced visual perception as they require little or no motor ability: These are: (1) Position in space: Measures the ability to match two figures according to their common features. It involves discrimination of reversals and rotations of figures. (2) Figure-ground: Measures the ability to see specified figures even when they are hidden in complex, confusing backgrounds. (3) Visual closure: Measures the ability to recognize a stimulus figure when it has been incompletely drawn. (4) Form constancy: Measures the ability to match two figures that vary on one or more discriminating features (i.e., size, position, or shade). The other four subtests measure visual–motor integration: (1) Eye–hand coordination: Measures the ability to draw precise straight or curved lines in accordance with visual boundaries. (2) Copying: Measures the ability to recognize the features of a design and to draw it from model. (3) Spatial Relations: Measures the ability to connect dots to reproduce visually presented patterns. (4) Visual–motor speed: Measures the number of correct marks which a child can make within large circles (ϕ 10 mm) or small squares (6×6 mm) on a sheet with additional small circles and large squares within a fixed time. The raw scores for each subtest, for the composite scores for the clusters 'motor-reduced visual perception (MRP)' and 'visual–motor integration (VMI)', and for the total test score (general visual perception (GVP)) can be converted into centiles and standard scores (mean of 10, standard deviation of 3). The inter-rater reliability of the DTVP-2 is good as correlations range from 0.92 to 0.99. After factor analysis, two factors emerged, providing evidence of the validity of the subtests as measures of visual perception under either motor-reduced or motor enhanced testing conditions in six of eight subtests (Colarusso & Hammill, 1972). Two subtests, Figure Ground and Spatial Relations contributed about equally to both factors. Criterion-related validity of the DTVP-2 is good, as the test correlates 0.78 with the motor-free visual perception test (MVPT) (Colarusso & Hammill, 1972) and 0.87 with the developmental test of visual–motor integration (VMI) (Beery, 1989).

2.2.2. Tactual Performance Test (TPT) (Reitan & Davison, 1974)

The TPT is a measure of haptic perception, which is the ability to recognize the shape of an object through active manipulation. The test is a modification for children aged 5–14 of the test developed by Halstead in 1947 (Reitan & Davison, 1974) and consists of a formboard and six blocks of different geometrical shapes. During the test, the child is blindfolded and not permitted to see the formboard or blocks. The formboard is placed vertically at an angle of 70° on a table in front of the child. Next, the child is asked to fit the six blocks into the proper spaces in three conditions: (1) with the dominant hand (without feeling with the other hand), (2) with the non-dominant hand, and (3) using both hands. The time needed to place the blocks on the board in the three conditions is recorded. In the memory condition, the board and blocks are removed, and the child is asked to draw a diagram of the board representing the blocks in the proper spaces. In this condition, the number of blocks correctly reproduced is recorded. Raw scores for each condition and each year-group are converted into *t*-scores (mean of 50). *T*-scores below 36 (equivalent to below the 15th centile) are considered to reflect poor performance.

2.2.3. Manual pointing task (Von Hofsten & Rösblad, 1988)

The task was originally designed by Von Hofsten and Rösblad (1988). During the task, children are seated at a table with a central inlay of 16×20 cm^2 which could be lifted up. On top of the inlay, four small markers (height 1 mm) were fixed in a rectangle of 8×10 cm^2. A3 paper was attached to the bottom of the table inlay. The center of the four markers is situated in the sagital plane of the child. During the task, a child is asked to place bulletin pins into the bottom of the table as accurately as possible in three conditions:

Visual condition: The experimenter pointed to a dot and the child's task was to place a bulletin pin into the bottom of the table matching the position of the dot as closely as possible.

Visual–proprioceptive condition: The experimenter pointed to a dot, the child placed the index finger of the free hand on the dot, looked at that location, and was asked to place the bulletin pin under the table in the matching position.

Proprioceptive condition: The experimenter pointed to a dot, the child placed the index finger of the free hand on the dot, closed the eyes, and was asked to place the bulletin pin under the table in the matching position.

Each condition consisted of four trials, one to each of the dots in a randomized order. Both the right and left arm were tested. The following variables were calculated afterwards: mean absolute error, which is the distance between the position of the pin and the correct position of the dot, summed over four trails and divided by four; variable error, which is the standard deviation of the distribution of pin positions over four trials; systematic error, which is the distance of the mean of the four pin positions from the center of dot positions; directional error, which was calculated for x and y directions as the mean of the distance between the four pin positions and the dot position in x and y directions separately.

2.3. Data analysis

DTVP-2 and TPT: One-way analyses of variance were carried out on the standard scores of the DTVP-2 and the *T*-scores of the TPT with group (DCD/control) as between factor.

Manual pointing task: An analysis of variance (repeated measurement) was carried out on the error measures with group (DCD/control) as between factor and hand (preferred/non-preferred) and modality (vision, visual–proprioceptive, and proprioception) as within factors.

Spearman's Rho was calculated both between scores on the different tests in order to investigate the relationship between performance on different tests of perception, and between the total impairment score of the M-ABC test and the different tests of perception. Bonferroni correction was used to adjust the level of significance of the correlations, i.e. for correlations between DTVP-2 and TPT or pointing task an $\alpha < 0.002$ was used and for the correlations between TPT and the manual pointing measures an $\alpha < 0.005$.

3. Results

3.1. The Developmental Test of Visual Perception (DTVP-2)

In Table 2 an overview is given of the means and standard deviations of children with DCD and the control group on the DTVP-2 and the TPT. Children with DCD performed significantly worse compared to children in the control group on all subtests measuring visual–motor integration: eye–hand coordination ($F(1,36) = 13.25, P < 0.001$), copying ($F(1,36) = 46.87$, $P < 0.001$), spatial relations ($F(1,36) = 7.00, P = 0.01$), and visual–motor speed ($F(1,36) = 17.97, P < 0.001$). Two out of four subtests of motor reduced perception did not reach significance: form constancy ($F(1,36) = 0.037$, $P = 0.42$) and figure-ground ($F(1,36) = 0.154, P = 0.35$). Children with DCD performed worse than the control group on the subtests position in space ($F(1,36) = 11.36, P = 0.001$) and visual closure ($F(1,36) = 6.24, P = 0.01$).

Table 2
Means and standard deviations (between brackets) for the different subtests and conditions of the DTVP-2 and TPT for each group

	Children with DCD	Control children	P^a
DTVP-2			
Eye–hand coordination (standard score)	9.5 (3.7)	13.2 (2.4)	<0.001**
Position in space (standard score)	8.5 (2.8)	11.4 (2.4)	0.001**
Copying (standard score)	9.9 (2.6)	14.5 (1.5)	<0.001**
Figure-ground (standard score)	9.5 (2.3)	9.8 (2.6)	0.35
Spatial relations (standard score)	12.0 (3.2)	14.2 (1.7)	0.01*
Visual closure (standard score)	7.3 (3.9)	10.6 (4.2)	0.01*
Visual–motor speed (standard score)	6.4 (2.2)	9.5 (2.3)	<0.001**
Form constancy (standard score)	10.5 (2.8)	10.7 (2.5)	0.42
Motor reduced perception	35.4 (8.9)	42.8 (7.6)	0.07
Visual–motor integration	38.1 (7.8)	51.0 (4.8)	0.004**
General visual perception	73.4 (14.9)	93.2 (10.1)	0.01*
TPT			
Preferred hand (s)	388 (226)	256 (140)	0.02*
Non-preferred hand (s)	233 (129)	173 (100)	0.06
Both hands (s)	128 (95)	89 (56)	0.07
Memory condition (amount of forms remembered)	3.8 (1.4)	4.5 (1.4)	0.10

[a] Significance of group difference, $^{*}P \leqslant 0.02$, $^{**}P \leqslant 0.002$.

When we look at the number of children who obtained scores in the clinical range (i.e. scores below the 15th centile), 42% of the children with DCD appear to have problems with visual–motor speed, and about one out of five children with eye–hand coordination. Although significant differences were obtained between children with DCD and control children for the subtests copying and spatial relations, only a few children obtained scores in the clinical range on these subtests. As far as the motor reduced subtests is concerned, 47% of the children with DCD performed badly on the subtest visual closure, which is twice as many as in the control group. For position in space, one out of five children with DCD obtained scores in the clinical range. Hardly any children obtained scores in the clinical range on the subtests figure-ground and form constancy. See Table 3 for an overview of the number of children with poor scores on the DTVP-2.

3.2. Tactual Performance Test (TPT)

Children with DCD needed significantly more time than children in the control group to place the shapes in the formboard with the preferred hand ($F(1,36) = 4.65, P = 0.02$). As it concerns their performance with their non-

Table 3
Number and percentage of children with DCD and control children with scores below the 15th centile on subtests of the DTVP-2

Subtest	Children with DCD	Control children
Eye–hand coordination	4 (21%)	0 (0%)
Copying	1 (5%)	0 (0%)
Spatial relations	1 (5%)	0 (0%)
Visual–motor speed	8 (42%)	1 (5%)
Position in space	4 (21%)	1 (5%)
Figure ground	1 (5%)	2 (11%)
Visual closure	9 (47%)	5 (26%)
Form constancy	0 (0%)	0 (0%)
Motor reduced perception	7 (37%)	2 (11%)
Visual motor integration	4 (21%)	0 (0%)

Table 4
Number and percentage of children with DCD and control children, with a *T*-score below 36 on the TPT (below the 15th centile)

Condition	Children with DCD	Control children
Preferred hand	2 (11%)	0 (0%)
Non-preferred hand	2 (11%)	1 (5%)
Both hands	2 (11%)	1 (5%)
Memory condition	3 (16%)	1 (5%)

preferred hand or both hands, no significant differences were found although the findings came close to significance (Table 2). In the memory condition, children with DCD were as able to complete the task as the children in the control group. Table 4 presents an overview of the number of children with scores in the clinical range on the subtests of the TPT. At the most, only three children obtained scores in the clinical range.

3.3. Manual pointing task

3.3.1. Effects of hand and perceptual condition

Main task effects were significant for hand (preferred/non-preferred) as it concerns both absolute error ($F(1,36) = 4.68, P = 0.015$) and systematic error ($F(1,36) = 5.16, P = 0.01$), but not variable error ($F(1,36) = 0.496, P = 0.24$). Larger absolute and systematic errors were made with the non-preferred hand (Tables 5 and 6). The average directional error was to the left and more distal from the target (see Fig. 1). Subjects pointed more to the left with their non-preferred hand ($F(1,37) = 17.63, P < 0.001$). No difference

Table 5
Mean absolute errors and standard deviation (between brackets) of the DCD and control groups on the manual pointing task (in cm)

Condition	Children with DCD	Control children	P^a
Preferred hand			
Visual	2.6 (1.9)	1.9 (0.6)	0.08
Visual–proprioceptive	2.2 (1.3)	1.8 (0.6)	0.09
Proprioceptive	2.2 (1.3)	2.0 (1.1)	0.29
Non-preferred hand			
Visual	2.4 (1.0)	2.4 (0.9)	0.46
Visual–proprioceptive	2.5 (0.9)	2.7 (1.4)	0.33
Proprioceptive	3.0 (1.1)	2.9 (1.2)	0.39

[a] Significance of group difference, $^*P \leqslant 0.05$.

Table 6
Mean systematic error and standard deviation (between brackets) of the DCD and control groups on the manual pointing task (in cm)

Condition	Children with DCD	Control children	P^a
Preferred hand			
Visual	2.4 (1.9)	1.8 (0.6)	0.12
Visual–proprioceptive	1.9 (0.4)	1.5 (0.7)	0.19
Proprioceptive	1.4 (1.2)	1.8 (1.1)	0.19
Non-preferred hand			
Visual	2.0 (1.0)	2.2 (1.0)	0.34
Visual–proprioceptive	2.2 (1.1)	2.4 (1.4)	0.34
Proprioceptive	2.6 (1.2)	2.6 (1.3)	0.49

[a] Significance of group difference, $^*P \leqslant 0.05$.

was found between left-handed subjects and right-handed subjects in this respect.

A main effect for condition (visual/visual–proprioceptive/proprioceptive) was significant in case of variable error ($F(2,72) = 6.01, P = 0.002$). In the visual condition the variable error was smaller than in the proprioceptive condition (1.4 cm vs 1.6 cm; $F(1,37) = 4.12, P = 0.05$), whereas the visual condition did not differ from the visual–proprioceptive condition ($F(1,37) = 1.78, P = 0.19$). The visual–proprioceptive condition had a smaller variable error than the proprioceptive condition (1.22 cm vs 1.6 cm; $F(1,37) = 9.05, P = 0.005$) (Table 7). There was also a main effect for condition in the error in the y-direction, not in the x-direction. This directional error shows the largest inaccuracy in the visual condition (1.04 cm), followed by the visual–proprioceptive condition (0.71 cm) and the smallest error in the proprioceptive condition (0.23 cm) ($F(2,72) = 9.53, P < 0.001$).

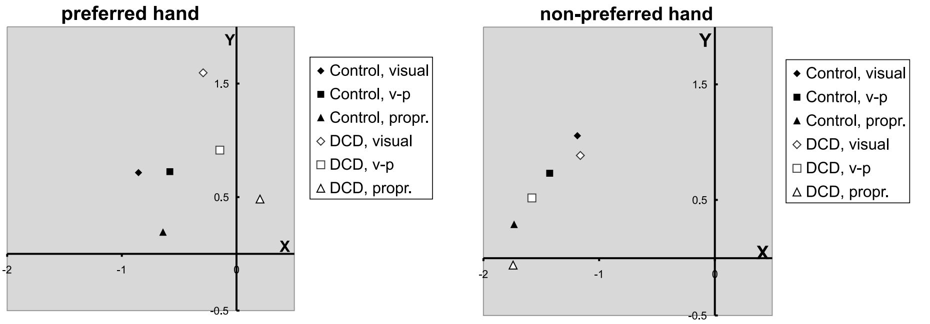

Fig. 1. Average directional error of control children and children with DCD for each of the perceptual conditions. Left for the preferred hand, and right for the non-preferred hand.

Table 7
Mean variable error and standard deviation (between brackets) of the DCD and control groups on the manual pointing task (in cm)

Condition	Children with DCD	Control children	P^a
Preferred hand			
Visual	1.4 (0.6)	1.0 (0.3)	0.02*
Visual–proprioceptive	1.2 (0.4)	0.9 (0.4)	0.015*
Proprioceptive	1.7 (1.1)	1.1 (0.5)	0.015*
Non-preferred hand			
Visual	1.4 (0.7)	1.1 (0.3)	0.07
Visual–proprioceptive	1.2 (0.4)	1.2 (0.4)	0.46
Proprioceptive	1.5 (0.7)	1.3 (0.5)	0.28

[a] Significance of group difference, $^*P \leqslant 0.05$.

The interaction between hand and condition was significant for both absolute error ($F(2,72) = 5.21, P = 0.004$), systematic error ($F(2,72) = 9.04$, $P < 0.001$) and directional error for the x-direction ($F(2,72) = 4.43, P = 0.015$). None of the other main effects or interaction effects reached significance.

3.3.2. Group differences

The overall effect of group was not significant in case of either absolute error ($F(1,36) = 0.99, P = 0.17$), or systematic error ($F(1,36) = 0.031$, $P = 0.43$), but significant in case of variable error ($F(1,36) = 6.75, P = 0.005$). The spread of error around the midpoint of responses was more variable for children with DCD. The directional error differed between the groups for the x-direction. Control children pointed on average 0.3 cm more to the left than

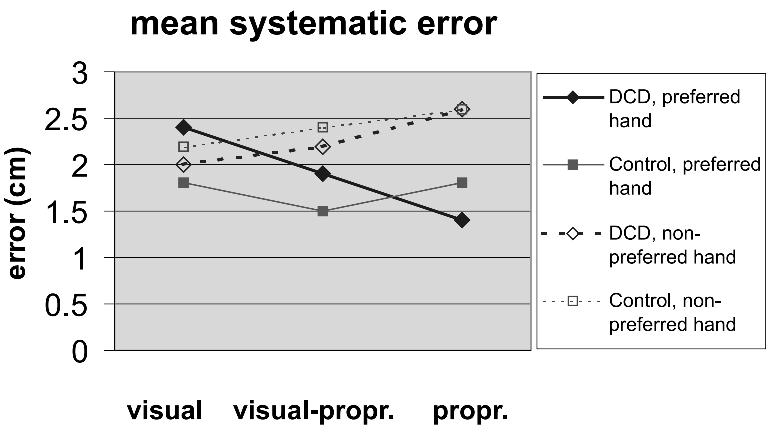

Fig. 2. The interaction between group, hand and perceptual condition for the mean systematic error in the pointing task.

children with DCD did (−1.1 cm vs −0.8 cm; $F(1,37) = 1.52, P = 0.041$). No group differences were found for the y-direction (Fig. 1).

The interaction between modality and group was not significant in case of either absolute error ($F(2,72) = 0.36, P = 0.35$), systematic error ($F(2,72) = 0.98, P = 0.19$), or variable error ($F(2,72) = 1.01, P = 0.19$). As it concerns the interaction between hand (preferred/non-preferred) and group, no significant interactions were found in case of both absolute error ($F(1,36) = 0.96, P = 0.17$), systematic error ($F(1,36) = 0.34, P = 0.29$) and variable error ($F(1,36) = 2.78, P = 0.055$). For systematic error, the interaction between hand, condition and group reached significance ($F(2,72) = 2.79, P = 0.04$). Fig. 2 shows that in both groups the non-preferred hand becomes less accurate across the visual, visual–proprioceptive and proprioceptive conditions, whereas the preferred hand of the DCD group increases in accuracy over these conditions, being most accurate in the proprioceptive condition. None of the other three-way interactions reached significance. Tables 5–7 present an overview of the performance of children with DCD and control children across conditions in the manual pointing task.

3.4. Relationship between performance across tests for perception

In Table 8, an overview is given of the results for each child across tests of perception. As can be seen from this Table, the performance of children with

DCD varied widely across tasks. Two out of 19 children obtained scores failing on 7 or 8 out of 17 measures across the subscales of the DTVP-2, the TPT and the measures of the manual pointing task (cases #2 and #16). Two children (cases #3 and #15) performed well on all tests. The remaining children performed well on the majority of the subtests but failed on one to five subtests. Among the control children four performed well on all measures, the others scored below 1 S.D. or the 15th centile on one to not more than three measures. Table 8 also shows that children with DCD fail mostly on the absolute error measures of the preferred hand, the visual motor speed score and the visual closure score.

In order to investigate the relation between performances across the different tasks, absolute error scores for the three conditions of the manual pointing task, and scores on the TPT and DTVP-2 subtests were correlated. Only one correlation just reached the required level of significance after Bonferroni correction. The DTVP-2 copying subscore in the DCD group correlated with the TPT score for both hands ($\rho = -0.71, P < 0.05$). This correlation was not significant in the control group ($\rho = -0.23$).

3.5. Relation between the M-ABC test and the tests of perception

For the control group, no significant correlations were obtained between the performance on the M-ABC test and performance on the perceptual measures. The same holds for the group with DCD. This may be illustrated by the cases #2, #4 and #16 having an M-ABC total score below the first centile failing three of the six AE measures as compared to the cases #1, #3 and #15 also having an M-ABC total score below the first centile, but with all six AE measures within the normal range.

4. Discussion

The aim of this study was to investigate whether children with DCD experience impairments in the processing of visual, proprioceptive or tactile information. In previous studies, generally isolated aspects of perceptual skills were investigated. By applying various measures of perception, we were able to differentiate between performance on a wide range of perceptual skills. As it concerns visual perceptual tasks in which no motor response is involved, children with DCD showed evidence of poor performance in previous studies (Wilson & McKenzie, 1998). In the present study, no impair-

Table 8
Individual level of classification of children with DCD on each of the task conditions[a,b]

Subject	AE V ph	AE V nh	AE VP ph	AE VP nh	AE P ph	AE P nh	TPT ph	TPT nh	TPT bh	CO	EH	SR	VM	FC	FG	PS	VC
1	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	O
2	O	+	+	+	O	O	O	+	O	+	O	+	OO	+	+	+	OO
3	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
4	+	OO	+	O	+	O	+	+	+	+	+	+	+	+	+	O	OO
5	OO	+	+	+	+	+	+	O	+	+	+	+	+	+	+	+	+
6	O	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
7	+	+	+	+	+	+	+	+	+	+	O	+	O	+	+	+	+
8	+	+	+	+	+	+	+	+	O	+	+	OO	O	+	+	+	O
9	+	+	O	+	+	+	+	+	+	+	+	+	+	+	+	+	+
10	+	+	+	+	+	+	+	+	+	+	+	+	+	+	OO	O	OO
11	+	+	O	+	+	+	+	+	+	+	+	+	+	+	+	+	OO
12	+	O	+	+	+	+	+	+	+	+	+	+	OO	+	+	+	+
13	O	+	+	+	+	OO	+	+	+	+	+	+	O	+	+	+	+
14	OO	+	OO	O	+	+	+	+	+	+	+	+	O	+	+	+	OO
15	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
16	OO	+	OO	+	OO	+	O	+	+	+	OO	+	OO	+	+	OO	+
17	+	+	O	+	O	O	+	+	+	+	+	+	+	+	+	+	O
18	+	+	+	+	O	+	+	+	+	+	OO	+	+	+	+	O	+
19	O	OO	+	+	+	+	+	O	+	+	+	+	OO	+	+	+	OO

[a] + – performance in the normal range. DVTP: O – performance below the 15th centile, OO – performance below the 5th centile. TPT: O – *T*-score below 36 (15th centile), OO – *T*-score below 25 (5th centile). Manual pointing task: O – absolute error score larger than 1 S.D. and OO – larger than 2 S.D. above the mean of the control group.
[b] Abbreviations: V – Visual condition, VP – Visual–proprioceptive condition, P – Proprioceptive condition, AE – Absolute error, ph – preferred hand, nh – non-preferred hand, bh – both hands, CO – copying, EH – eye–hand coordination, SR – spatial relations, VM – visual–motor speed, FC – form constancy, FG – figure ground perception, PS – position in space, VC – visual closure.

ments were found in tasks measuring figure ground perception or the perception of form constancy. Children with DCD were as able as control children to detect figures when they are hidden in a complex, confusing background, and to match figures that vary in size or position.

The findings regarding form constancy were in contrast with those by Lord and Hulme (1987, 1988), who reported significant differences between children in the control group and children with DCD on a comparable task in which children had to discriminate between pairs of triangles with the same or different sizes. Previously, Hulme, Smart, and Moran (1982) also reported visual spatial impairments for children with DCD in matching the length of simultaneously presented straight lines. The conflicting results are difficult to explain. When we compare selection criteria applied in both studies, there is no reason to believe that differences in selection criteria were responsible for the findings, as both in our and Lord and Hulme's study 19 children were included referred to a clinic because of significant motor problems. In both studies, the motor problems were objectified by an age-appropriate motor test. Only age of the children differed between studies as the mean age in the Lord and Hulme study was 9.8 compared to 8.4 in our study. However, it is hard to tell whether differences in age account for the conflicting findings.

Two tests measuring visual perception did differentiate between children with DCD and control children: visual closure and position in space. Children with DCD performed particularly poor when they had to recognise a figure that had been incompletely drawn (visual closure). The individual data confirmed this finding as almost 50% of the children with DCD obtained scores below the 15th centile on this task, as compared to 26% of the control group. With respect to the subtest position in space, four children with DCD appeared to experience problems in discriminating figures when they were rotated, compared to one in the control group.

Overall, the problems of children with DCD became most pronounced on the visuomotor subtests of the DTVP-2. They were less proficient to draw between lines (eye–hand coordination), to copy a design, to connect dots to reproduce visually presented patterns (spatial relations), and to make marks in certain designs as fast as possible (visual–motor speed). However, although children with DCD performed significantly more poorly on these subtests compared to children in the control group, the results did not appear to be of general clinical significance according to the individual data. For copying and spatial relations nearly all subjects scored in the normal range. Four children with DCD experienced problems with eye–hand coordination compared to none of the control children. This implies that for most of the children with

DCD the severity of their impairments in these visual–motor skills did not warrant further clinical attention. Previous studies mainly reported on significant group differences, without providing detailed information on the severity of the individual perceptual deficits. The present data illustrate that group differences may be statistically significant without having general clinical implications.

This does not hold for visual–motor speed, as 42% of the children with DCD obtained scores in the clinical range. Remarkably, this is the only task that is performed under time pressure. These children appeared not to be able to comply to the speed instructions, and made fewer marks in the same amount of time compared to control children. Slowness of movements seems to be a common feature in children with DCD as comparable results were obtained in several experimental studies (Forsstrøm & Von Hofsten, 1982; Van Dellen & Geuze, 1990; Van der Meulen, Denier van der Gon, Gielen, Gooskens, & Willemse, 1991; Schoemaker, Schellekens, Kalverboer, & Kooistra, 1994).

An interesting question is whether some common factor underlies the pattern of failure of the four main discrimination subtests, i.e. visual closure, visual motor speed, position in space and eye–hand coordination. For example, it has been put forward that visual processing can be divided into two main categories, one concerned with the processing of object properties, and one concerned with the location of objects or targets in space. They are generally referred to as the 'what' system and the 'where' system, and are related to a dorsal and a ventral stream of information processing, each stream processing information in a different way. Both streams process information about orientation and shape, and probably about spatial relations and depth. The ventral stream, however, is mainly concerned with the enduring characteristics of the object, while the dorsal stream is concerned with the instantaneous characteristics, including spatial location (Milner & Goodale, 1993). One might argue that the two factors in the DTVP-2, motor reduced perception and visual–motor integration could be linked to these distinct types of visual information processing. However, the items of the DTVP-2 have not been designed to make such a clear distinction. As the visual–motor integration factor seems to be the more sensitive factor for differences between the groups, it seems worthwhile to pursue the visual information processing deficit in children with DCD in terms of the neural substrate in the future.

Although problems in the perception of tactile information have not been investigated previously in experimental studies on children with DCD, in clinical practice, these problems have often been mentioned. Especially in sensory integration therapy, a treatment programme developed by J. Ayres for children with learning problems including children with DCD, problems with tactile perception are often mentioned. It is assumed that poor tactile perception is related to difficulties in manipulative hand skills (Royeen & Lane, 1991). In addition, tactile perception and propriocepsis are believed to make important contributions to the development of a body scheme, which is thought to be essential for the development of praxis (Royeen & Lane, 1991). What evidence do we have to objectify the supposed problems in tactile perception? According to the data of the present study, children with DCD performed slightly more poorly compared to the control group on the TPT when using their preferred hand, their non-preferred hand or when using both hands. Thus, children with DCD appeared to be less proficient to recognise the shape of an object through active manipulation and to place this object in the appropriate location of a form board. On average, however, the children with DCD performed only slightly below the norms of the TPT (their mean T-score varied from 46 to 49 across conditions). Converging evidence is provided by the individual data, which show that only a few children in the group with DCD experienced problems.

Although tactile perception is an important component of the TPT, it cannot be denied that there is some motor involvement as well, as the child has to reach for a shape and transport the shape to the form board. Thus, slowness of movements, which we mentioned above as an important characteristic of the behaviour of the child with DCD, might account for the extra amount of time these children needed to complete the tasks. The data cannot be explained by differences in the ability to remember the position of the shapes, as no differences between groups were found for the memory condition of the TPT.

On the manual pointing task, the difference in performance between children with DCD and their controls was most pronounced in variable error. Pointing to a location with their preferred hand was more inconsistent for children with DCD, regardless whether they could use visual, visual–proprioceptive or proprioceptive information. These results are in agreement with Smyth and Mason (1997), who used the same task in a sample of 96 children with DCD recruited from primary schools. Inconsistent patterns of performance have been reported before in experimental studies where children with DCD had to make goal-directed movements (Geuze & Kalverboer, 1987; Van der Meulen et al., 1991).

When we consider absolute error, no significant group differences were found, although the difference between groups in both the visual and visual–proprioceptive conditions approached significance as it concerned performance with the preferred hand. This finding is supported by the individual data of the absolute error of pointing with the preferred hand in the visual condition which show that seven children with DCD performed below the 15th centile, 3 of which were below the 5th centile. It may be noted that also in the TPT it was the preferred hand of the children with DCD which performed significantly unfavourable compared to the control children.

Sigmundsson, Ingvaldsen, and Whiting (1997) report absolute error scores on a similar task, but with four additional targets rotated 45° from the original targets. They compared a group of eleven children with hand eye coordination problems (HECP group, selection based on a sum-score of the five subtests of the M-ABC manual dexterity cluster and the ball skills cluster ranging from 8 to 17; the balance cluster was not assessed) with 11 proficient control children (M-ABC five subtest score ranging from zero to one). The HECP group was found to be clearly less accurate in the visual, the visual–proprioceptive and the proprioceptive condition.

The study of Sigmundsson et al. (1997) took a closer look at the lateralization of the pointing responses. The HECP children performed significantly worse with their non-preferred hand in the visual–proprioceptive and the proprioceptive condition. There were no differences between the hands in the control group. In our study both DCD and control children performed worse with their non-preferred hand only in the proprioceptive condition. The main reason for the contrasting results are found in the accuracy of the control group in the study by Sigmundsson et al. With the non-preferred hand our control group performed at the level of the DCD group. With the preferred hand the differences between the groups are in close agreement. The most likely explanation is the difference in group selection. The target group of children in the study of Sigmundsson was selected specifically for hand eye coordination problems, without further assessment of balance, and compared to a group of children being very proficient in this area. In our study balance problems contributed to the selection of the groups, and the control group was less separated on the motor score. So it seems that lateralization effects contribute to the group and modality differences. Both studies find a superior performance when the target is located visually.

Sigmundsson et al. (1997) also provide evidence for hand differences in favour of the preferred hand when pointing to the contralateral side of the body in the visual–proprioceptive and proprioceptive condition, and under the proprioceptive condition when pointing to the ipsilateral side. An additional study with HECP children matching targets located proprioceptively with a finger with pointing with a toe indicated right hemisphere insufficiency with or without a dysfunctional corpus callosum (Sigmundsson, Whiting, & Ingvaldsen, 1999). In our study the directional errors showed a general tendency to point up to 2 cm to the left and away from the target, both for left-handed and right-handed children. This systematic bias was larger for the non-preferred hand and in conditions with visual and visual–proprioceptive perception. This general tendency to point too far away and to the left indicates an inaccuracy of matching the visual information of target location with the proprioceptive information of the pointing hand, irrespective of the handedness of the children. These data cannot be interpreted as an effect of position of the subject relative to the target positions, i.e. the shoulder joints being located to the left and right of the center of the targets. In that case one would predict a tendency to point too far to the left for right-handed children, and too far to the right for the left-handed children, or vice versa. Further research is needed to resolve these contrasting results.

It has been suggested that children with DCD rely more heavily on visual feedback as a strategy to deal with the inaccuracy of their movements (Van der Meulen et al., 1991). If this would be correct, larger errors would have been expected for the group with DCD in the proprioceptive condition, where vision was precluded. Although children in both groups made larger errors in the proprioceptive condition, the absolute errors of children with DCD did not increase more than those of the children in the control group. This was unexpected as children with DCD in the Smyth and Mason (1997) study performed worst in the proprioceptive condition. Also Rösblad and Von Hofsten (1992) reported a significant decrease of performance in the proprioceptive condition in a sample of 10 children with DCD within the age range of 5.9 and 13.6 years. However, it must be noted that the diagnosis DCD was based upon clinical observation alone in this study, so it is not clear whether comparable groups of children are being compared. Recently, Mon-Williams et al. (1999) employed the same task in a small ($n = 8$) group of children with DCD. Only children with total scores below the 5th centile on the M-ABC test were selected, who also achieved poor scores (below 1 S.D.) on all four sections of the Checklist of the M-ABC. The authors used the mean square root error as an overall measure of how successful a child was in achieving a target. They found that children with DCD differed from controls only in the visual–proprioceptive condition, and not in the visual or proprioceptive condition (Mon-Williams et al., 1999).

As has been stressed by both Rösblad and Von Hofsten (1992) and Mon-Williams et al. (1999), there is much variety in performance of children with DCD. The data in our manual pointing study once again underline this statement. Although group differences have been found, the majority of the children with DCD made errors within the normal range of the control group. Five out of 19 children had three or more absolute errors that fell below one standard deviation of the control group compared to one child in the control group. When we take performance on the DTVP-2 and the TPT also in account, it becomes clear that no consistent pattern of problems can be found. Only two children appeared to experience problems across all perceptual tasks, but most children only failed on one to four isolated subtests or conditions of the perceptual measures. Two children even showed no signs of perceptual problems at all. So we may conclude that no hard evidence can be found in our study for a common problem in one of the perceptual modalities investigated.

Several authors have postulated a causal relation between DCD and deficits in visual perception (Hulme et al., 1982) or between DCD and deficits in proprioception or kinaesthesis (Laszlo & Bairstow, 1985). However, no relation was found between the severity of DCD as measured by the M-ABC test and any of the perceptual abilities. Previously, Sugden and Wann (1987) too failed to find a relation between measures of kinaesthesis and measures of motor coordination. Therefore, the findings of this study and other work lead us to suggest that some children with DCD do experience deficits in visual, proprioceptive or tactile perception, but that no causal relation exists between motor and perceptual impairments. The problems of children with DCD in the present study were most pronounced in tasks where children had to make fast movements or accurate goal-directed movements. In these tasks, children with DCD moved slower and pointed with less consistency than children in the control group. Thus, we may conclude that the motor component present in some perceptual tasks seemed to contribute more to poor performance in the DCD group than the perceptual component.

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