

# Vertical and horizontal smooth pursuit eye movements in children with developmental coordination disorder

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## ABBREVIATIONS

DCD	Developmental coordination disorder
HPG	Horizontal pursuit gain
SPG	Smooth pursuit gain
VPG	Vertical pursuit gain

**AIM** Our aim was to study horizontal and vertical smooth pursuit eye movements in children with developmental coordination disorder (DCD).

**METHOD** Horizontal and vertical smooth pursuit eye movements of 91 children were studied using electro-oculography: 27 children with DCD (23 males, four females), according to the DSM-IV-TR criteria, and 64 comparison children (26 males, 38 females). All children were 7 to 12 years old (mean 9y, SD 1.5y). Among the group of children with DCD, eight had received intervention. Intervention exercised static and dynamic fixation, saccades, visual strategies, visuospatial abilities, and eye–hand coordination. A smooth pursuit gain index was calculated and statistical comparisons were made between the two groups of children.

**RESULTS** Horizontal pursuit gain was similar in both populations, but vertical pursuit gain was significantly impaired ( $p < 0.001$ , after adjusting for age as covariate), i.e. more saccadic in children with DCD (18–99%;  $n = 27$ , mean 51.6%, median 48.5%, SD 23.2%) than in comparison participants (35–97%;  $n = 63$ , mean 66.4%, median 65.0%, SD 15.4%). Among the DCD group, the vertical pursuit index was also significantly higher ( $p = 0.009$ ) in the intervention subgroup (29–99%;  $n = 8$ , mean 69.4%, median 75.5%, SD 28.7%) than in the non-intervention subgroup (18–74%;  $n = 19$ , mean 44.1%, median 42.5%, SD 15.9%).

**INTERPRETATION** These results suggest a delay in the maturation of the pursuit system in children with DCD.

Developmental coordination disorder (DCD) and developmental dyspraxia are often regarded as synonymous. These entities have long remained confusing to clinicians, owing to divergent concepts and lack of precise descriptions. The term DCD was coined in 1987 in the DSM-III-R,<sup>1</sup> and is described as impairment of motor coordination that significantly interferes with activities of daily living and/or academic achievement. The International Statistical Classification of Diseases and Related Health Problems (ICD-10) later stated: ‘It’s usual for the motor clumsiness to be associated with some degree of impaired performance on visuospatial cognitive tasks’.<sup>2</sup> Since 1994, following the recommendations of an international consensus conference, the term DCD has been consistently used in research and practice to identify children with mild motor coordination deficits of developmental origin.<sup>3</sup>

Developmental coordination disorder should not be confused with acquired apraxia, seen mainly in adult neurology, although the concept of developmental dyspraxia first emerged with reference to adult apraxia. DCD and

acquired apraxia share common features, hence the similarities in some subtype classifications that do not imply similar cerebral involvement.<sup>3</sup> DCD should be distinguished from impairment of the execution of voluntary movement, and should also not be confused with visual or visuoperceptual disorders, which need to be carefully excluded from the diagnosis.<sup>3</sup> Recent systematic studies now allow us to define DCD and identify subtypes of DCD that meet specific clinical criteria.<sup>4,5</sup> In DCD, motor planning and programming are primarily affected in the absence of any obvious neurological structural abnormality or intellectual and perceptual disability.<sup>3</sup> Three clinical subtypes of DCD can be distinguished: pure ideomotor DCD, pure visuospatial or visuomotor DCD, and mixed DCD including features of ideomotor and visuospatial/constructional DCD with additional comorbidities.<sup>5,6</sup> This recent refinement of the clinical descriptions supports new integrative pathophysiological models and suggests a dysfunction in the cerebellum–cerebral network<sup>7</sup> or basal ganglia–thalamocortical

circuits.<sup>6</sup> Nevertheless, the neural correlates of DCD remain largely unknown.<sup>8</sup>

Eye movement recordings are used increasingly in clinical neuroscience and are now a routine examination for several neurological conditions in adults. They allow for clinical and neuro-anatomical correlations and help better understanding of the pathophysiology of diseases. In the paediatric field, such recordings have been used less commonly, owing to technical difficulties; however, they have been proved to be feasible.<sup>9–11</sup>

Smooth pursuit eye movements are continuous eye movements that ‘keep the line of regard congruent with the line of interest’.<sup>12</sup> They mature throughout childhood and adolescence. Pursuit studies in children, therefore, require normative data in similar age groups, which have been obtained in a recent study.<sup>11</sup> As motor skills are impaired, impaired oculomotor performance would also be expected in children with DCD, especially with pursuit eye movements, which ‘have the character of habitual movements’.<sup>12</sup> While quantification of global motor skills is difficult, oculomotor performance can be quantitatively assessed, offering new insights on this condition.

A previous study on eight children with DCD showed a reduced velocity gain for horizontal pursuit relative to age-matched comparison participants.<sup>13</sup> To the best of our knowledge, these results on a small cohort have not been replicated, nor have they been extended to vertical pursuit characteristics.

The purpose of this study was to compare the characteristics of both horizontal and vertical smooth pursuits in children with DCD with age-matched comparison participants without DCD.

## METHOD

### Participants

Children with DCD were recruited through the Department of Child Psychiatry, Necker-Enfants Malades Hospital, and the Department of Paediatrics, Cochin-Port Royal Hospital, in Paris. All underwent, as part of their clinical evaluation, extensive neuropsychological and neuropsychomotor assessments, consisting of a test battery comprising 49 milestone assessments covering tone, praxis, perception, as well as visual, motor, perceptuomotor, and general performance.<sup>6</sup> Participants’ responses were treated as binary indicators of failure and success, based on the standard deviation or centile reference for each test (an attempt was classed as a failure if the response score was <1SD or less than the 15th centile). All fulfilled the criteria of the DSM-IV-TR for DCD: mild to moderate motor coordination difficulties interfering with the performance of daily activities (criterion A) and with academic achievement (criterion B).<sup>14</sup> Participants were assessed for these criteria using the clinical history and questionnaire from Geuze’s research,<sup>15</sup> in accordance with the European Academy for Childhood Disability recommendations from Blank et al.<sup>4</sup> All showed visuospatial or visuoconstructional motor impairment according to the ICD-10,<sup>2</sup> corresponding to

### What this paper adds

- First assessment of horizontal and vertical pursuit in children with DCD.
- Horizontal pursuit gains are typical in 7- to 12-year-old children with DCD.
- Vertical pursuit gains are significantly impaired in 7- to 12-year-old children with DCD.

two subtypes as previously defined: pure visuospatial/visuoconstructional DCD and mixed DCD.<sup>3</sup> Children with comorbid disorders, including attention-deficit-hyperactivity disorder, visual or auditory deficit, preterm birth (<37wks), neurological impairment (including traumatic brain injury), or any psychiatric abnormality, were excluded. Within the group of children with DCD, a few had received intervention. Intervention had been executed under different conditions in various centres external to the hospitals in this study, regardless of the DCD severity, and sometimes before the diagnosis had been formally established and intervention prescribed by the child’s general practitioner. As is usually the case in France, intervention programmes had been conducted by orthoptists; they had taken the form of weekly sessions for a mean duration of a year, were tailored for each child, and exercised static and dynamic fixation, saccades, visual strategies, visuospatial abilities, and eye–hand coordination.<sup>16</sup> Comparison participants without DCD were recruited through a Parisian primary school. Authorization was obtained from the Académie de Paris with the consent of parents.

Only children aged from 7 to 12 years were included. All children underwent a complete ophthalmological and orthoptic examination including refraction, visual acuity measurement, slit-lamp examination, fundus examination, near and distant cover test, version and vergence examination, fusional amplitudes, and the Wirt test. Children with any abnormality of visual function, nystagmus, heterotropia, or oculomotor palsy were excluded from the study. For all participating children, the nature of the study was orally explained to the children and their parents, and an informed consent form was signed by both parents or, in specific cases, by the one parent exercising parental authority. INSERM institutional review board approval was obtained for the study.

### Apparatus and visual stimuli

Electrooculography was carried out in a quiet room after careful instruction was given to the children. The Metrovision (Perenchies, France) apparatus was used for stimulation and recording. Nine ECO 10 skin electrodes (Metrovision) were used in each participant: four per eye plus a ground electrode. The skin was carefully cleansed at the site of each electrode; an abrasive paste was used to ensure skin impedance at about 3 k $\Omega$ . The electrodes themselves contained a conductive paste. Horizontal electrodes were located 1cm away from both the outer and inner canthi. For vertical eye movement testing, the infra-orbital electrode was placed 1cm below the inferior eyelid margin on the vertical line going through the pupil; the superior electrode was located above the superior orbital

edge, on the same line. The ground electrode was placed on the forehead. Ten minutes passed between installation of the electrodes and onset of recording. Signal processing included a pre-amplifier and an amplifier, connected serially to a computer through an analogue–digital device. A personal computer with dedicated software (Metrovision) was used. Bandpass of the amplifiers was 1–35 Hz; input impedance was 1000 G $\Omega$ . The same protocol was used for all children. During the procedure, the child was sitting comfortably, his or her head resting on a head restraint so that the forehead was situated at 30cm distance from the screen. The child was then given clear and detailed instructions about the tasks to be performed. Standard procedures were followed to encourage, reassure, and ensure attention and motivation from the participant.

### Design and procedure

Eye movements were recorded without and then with stimulation. Spontaneous movements were first recorded to explore ocular fixation. Then, a target appeared on the screen and moved as a sinusoid, horizontally (amplitude 40°; stimulus velocity 30°/s) and then vertically (amplitude 30°; stimulus velocity 30°/s). Each stimulus was presented twice. Each trial lasted for 20 seconds after a 5- to 10-second pause. An additional short break took place if the child lost concentration. If the child became inattentive during a trial, it was conducted again at the end of the experiment. The entire experiment lasted 10 to 15 minutes.

### Statistical analysis

Eye movements were calibrated by adjusting the measured amplitude to the amplitude of the target motion. Eye movement velocities were calculated as the first derivative of the eye movement position. A smooth pursuit gain index (SPG index) was automatically calculated using dedicated software, an index of 100% corresponding to perfect smooth pursuit (i.e. the movement of the eyes strictly followed the movement of the target); the lower the index, the more saccadic the pursuit (see Fig. S1, online supporting information). In order to compare horizontal pursuit gains (HPGs) with vertical pursuit gains (VPGs), a ratio between the two measurements was calculated. According to distributions evaluated by Kolmogorov–Smirnov and Shapiro–Wilk tests, the comparison group and the DCD group were assessed using an analysis of covariance or, in case of non-normality, using the Mann–Whitney *U* test. The comparison of the SPG index between the two groups was adjusted for age when possible. Correlations were analysed using Spearman's *r*<sub>ho</sub>. A statistical analysis was also performed within the DCD group, comparing the intervention and the non-intervention subgroups. As some data were missing, the number of participants considered for calculation is specified each time. All statistical analyses were carried out using IBM SPSS V19.0.0 software (IBM SPSS statistics, IBM, Corp., Armonk, NY, USA). A *p* value of <0.05 was considered statistically significant.

## RESULTS

### Group composition and smooth pursuit characteristics

Participants in this study were made up of 27 children with DCD (23 males, four females) and 64 comparison children (26 males, 38 females). All children were 7 to 12 years old (mean 9y, SD 1.5y). Results are shown in Table I. The Kolmogorov–Smirnov and Shapiro–Wilk tests were non-significant only for the VPG index. There was no statistically significant difference in the HPG index between the groups (*p*=0.98). Adjusting for age as a covariate, the VPG index was significantly higher in the comparison group than in the DCD group (*p*<0.001). In both groups, the VPG index was positively correlated with the HPG index (comparison group: *n*=63,  $\rho$ =0.39, *p*=0.002; DCD group: *n*=26,  $\rho$ =0.57, *p*=0.002; see Fig. 1). The HPG/VPG index ratio between the two groups was statistically significant (*p*=0.02).

### Effects of intervention

Within the group of children with DCD, eight children had received intervention and 19 had not. Results are shown in Table I. There was no statistically significant difference in HPG index between the two subgroups (intervention vs non-intervention; *p*=0.23). Adjusting for age as a covariate, the VPG index was significantly higher in the intervention subgroup than in the non-intervention subgroup (*p*=0.009). Figure 2 illustrates the projections of these two groups according to the HPG and VPG indices. The HPG/VPG index ratio between the two groups was not statistically significant (*p*=0.18). Differences between the children receiving intervention (*n*=8) and the comparison group (*n*=64) are non-significant (age: *p*=0.50; HPG index: *p*=0.32; VPG index: *p*=0.65; ratio: *p*=0.85).

## DISCUSSION

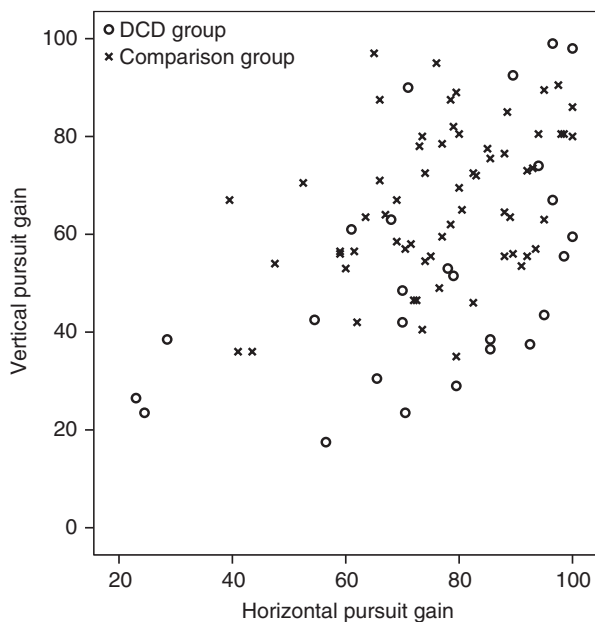
This study is the first to show that in children with DCD aged 7 to 12 years, vertical pursuit is significantly impaired relative to children without DCD. It failed, however, to demonstrate a statistically significant difference in horizontal pursuit, as was the case in a previous study in a smaller population.<sup>13</sup>

One of the reasons for this could be the younger age of the children (5–7y) in the study by Langaas et al.<sup>13</sup> In typical development, horizontal smooth pursuit is mature by the age of 7 years,<sup>11</sup> while vertical smooth pursuit is not mature until late adolescence.<sup>17</sup> If one hypothesizes that children with DCD exhibit a delayed maturation of both pursuit systems, this delay could be picked up at different ages according to the type of pursuit studied: before the age of 7 years for horizontal pursuit and between 7 year and 12 years for vertical pursuit. As the diagnosis of DCD is usually not formally confirmed before the age of 7 years, vertical pursuit studies might appear more relevant for practical purposes. Another reason for this difference could be that the children's phenotype may have been more severe in the study by Langaas et al.,<sup>13</sup> as suggested by their young age at diagnosis. The main limitation of the present study is its cross-sectional nature. A longitudinal

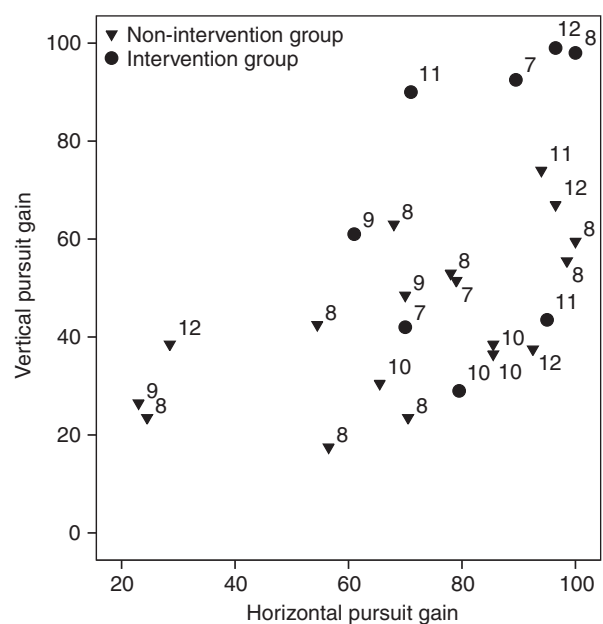
**Table 1:** Group composition and smooth pursuit characteristics of the comparison group, the developmental coordination disorder (DCD) group and the DCD subgroups

Measure	Group		<i>p</i> -value for groups	Developmental coordination disorder subgroups		<i>p</i> -value for developmental coordination disorder subgroups	<i>p</i> -value for comparison and intervention subgroups
	Comparison	Developmental coordination disorder		Intervention	Non-intervention		
Age (y:mo)							
<i>n</i>	64	27	0.66 <sup>a</sup>	8	19	0.83 <sup>a</sup>	0.50 <sup>a</sup>
Mean	9:0	9:1		9:4	9:0		
Median	9:0	8:7		9:5	8:3		
SD	1:4	1:6		1:8	1:6		
Range	7:0–11:0	7:1–11:9		7:3–11:5	7:1–11:9		
Horizontal pursuit gains index,%							
<i>n</i>	64	26	0.98 <sup>a</sup>	8	18	0.23 <sup>a</sup>	0.32 <sup>a</sup>
Mean	76.9	74.4		82.8	70.6		
Median	77.8	78.5		84.5	74.3		
SD	14.6	22.7		14.5	24.9		
Range	40–100	23–100		61–100	23–100		
Vertical pursuit gains index,%							
<i>n</i>	63	27	<0.001 <sup>b</sup>	8	19	0.009 <sup>b</sup>	0.65 <sup>c</sup>
Mean	66.4	51.6		69.4	44.1		
Median	65.0	48.5		75.5	42.5		
SD	15.4	23.2		28.7	15.9		
Range	35–97	18–99		29–99	18–74		
Ratio (HPG index/VPG index)							
<i>n</i>	63	26	0.02 <sup>a</sup>	8	18	0.18 <sup>a</sup>	0.85 <sup>a</sup>
Mean	1.2	1.6		1.4	1.7		
Median	1.2	1.5		1.0	1.5		
SD	0.3	0.7		0.7	0.7		
Range	0.6–2.3	0.7–3.2		0.8–2.7	0.7–3.2		

As some data were missing, the number of participants considered for calculation is specified each time. <sup>a</sup>Mann–Whitney *U* test. <sup>b</sup>Analysis of covariance adjusting for age as a covariate. <sup>c</sup>Student’s independent-samples *t*-test. HPG, horizontal pursuit gains; VPG, vertical pursuit gains.



**Figure 1:** Relationship between horizontal pursuit gain index and vertical pursuit gain index in comparison and developmental coordination disorder (DCD) groups. Correlations were significant in both groups (comparison group:  $\rho=0.39$ ,  $p=0.002$ ; DCD group:  $\rho=0.57$ ,  $p=0.002$ ).



**Figure 2:** Horizontal pursuit gain index and vertical pursuit gain index in the eight children in the developmental coordination disorder group who had received intervention and the 18 children who had not received intervention. The age of each participant is shown.

study would clarify whether this alteration of vertical pursuit in DCD is due to a delayed maturation or a definite abnormality of vertical pursuit.

Recent research allows for more refined hypotheses concerning the pathophysiology of DCD, which suggest a specific disruption of the predictive control of action.<sup>18</sup> Motor adaptation studies suggest cerebellar dysfunction in DCD.<sup>8,19,20</sup> Other anatomical structures potentially involved in DCD are the parietal lobe, the corpus callosum, and the basal ganglia.<sup>8</sup> Smooth pursuit is a complex, non-reflexive, conscious function under the control of numerous cerebral structures: the cerebellum, pontine nuclei, central thalamus, medial superior temporal cortex, caudal frontal eye field, and the supplementary eye field.<sup>18</sup> A few studies have specifically investigated the development of smooth pursuit tracking in children.<sup>10,21–25</sup> Smooth pursuit alteration can result from the dysfunction of many anatomical structures and is encountered in a large variety of neurological and psychiatric diseases.<sup>21</sup> Little is known, however, about delayed maturation of the pursuit system, which may result from distinct processes and can also be observed in children born preterm.<sup>13,26</sup> Clinically, poor pursuit gains often result from cerebellar or cerebello-cerebral network dysfunctions. Low pursuit indices as found in this study are part of the cerebellar syndrome and are definitely consistent with the hypothesis of a cerebellar involvement in DCD. Yet it has also been hypothesized that visual selective attention, which is probably mediated by the dorsolateral prefrontal cortex, is one of the driving factors in adaptive changes for smooth pursuit.<sup>27,28</sup> Poor pursuit may, therefore, also result from altered inputs, such as poor visual attention. Impaired ocular pursuit results from similar mechanisms such as impaired non-ocular coordinated movements. It also, in turn, has itself a negative impact on many visually guided coordinated movements; as such, it can be considered as part of a vicious motor impairment circle in DCD.

Intervention is often proposed for these children; however, its nature, pathophysiological bases, and effects are controversial. A few studies have evaluated intervention in DCD; the two main approaches are often referred to as process oriented (e.g. sensory integration and kinaesthetic training) and task oriented (or motor skill intervention). Based on a recent combined systematic review and meta-analysis, Smits-Engelsman et al.<sup>29</sup> concluded that there is evidence only to support task-oriented intervention. In the

present study, some children had previously received intervention, but its modalities had been heterogeneous. We chose not to exclude these children, as the usual population of children diagnosed with DCD now comprises many children who have already received intervention. It is, therefore, difficult to draw conclusions regarding the underlying mechanisms of the more accurate vertical pursuit demonstrated in the intervention subgroup, as well as regarding the efficiency of intervention on DCD itself, as oculomotor abnormalities are only one of the various clinical indicators of DCD. This improvement may either reflect the direct effect of intervention itself on oculomotor functions or result from a general improvement in DCD. In adults, simple, short visual training sessions induce significant, lasting improvements in smooth pursuit performance.<sup>30</sup> Adult patients with such improved smooth pursuit performance then better adapt to vestibular dysfunction, as improving one of the preserved inputs of a multisensory process, such as orientation in space, helps to compensate for the deficient input.<sup>27</sup> If oculomotor markers, such as the SPG index used in this study, are proved to be correlated with the severity of DCD, they could become, as for many neurological diseases in adulthood, a useful tool in the initial and longitudinal assessment of children with DCD. The effects of intervention on ocular pursuit, and hence in DCD, would also be better appreciated in an ongoing large, prospective, longitudinal study.

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## SUPPORTING INFORMATION

The following additional material may be found online:

**Figure S1:** An example of horizontal pursuit patterns in two 10-year-old children: a typical comparison participant (top pattern) and a participant with DCD (bottom pattern). The grey pattern is for the target, the red pattern is for the right eye, and the green pattern is for the left eye. The HPG index was 95% for the typical comparison child and 27% for the child with DCD. *x*-axis, time; *y*-axis, position of the target/eye.

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## Erratum

Best practice when using the Strengths and Difficulties Questionnaire with extremely preterm children: are two informants better than one?<sup>1</sup>

In the above commentary, the sentence, ‘However, other research suggests that mothers with a history of anxiety or depression may actually be more accurate at perceiving internalising symptoms in their children’, cited reference 3, but the citation should have been reference 4 (Chilcoat HD, Breslau N. *Am Acad Child Adolesc Psychiatry* 1997; **36**:971–9).

The authors apologize for the error.

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