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Impact of Gross Motor Coordination Exercises on Perceptual Processes and Praxis in Early School Children With Symptoms of Developmental Coordination Disorder: Preliminary Report of Randomized Controlled Study

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Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
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Background: Physical activity has a general impact on cognitive processes, but evidence on the effects of specific exercises on particular cognitive or executive functions remains limited. Previous studies suggest that movements crossing the body's midline stimulate excitability and plasticity in the dorsolateral prefrontal cortex and superior parietal cortex. This study aimed to investigate whether such exercises produce long-term functional changes in these areas.


Material/Methods: The study involved 22 children aged 6 to 8 years with symptoms of developmental coordination disorder (DCD), divided into 2 equal groups. Both groups completed approximately 9 weeks of coordination training based on Bilateral Integration by Sheila Dobie OBE (the total diagnostic and therapeutic cycle lasted approximately 16 weeks, including a break). The intervention group performed exercises involving midline crossing, while the control group performed exercises without this element. Assessments (sensory integration and praxis tests and the bilateral motor coordination test) were conducted 3 times: before intervention, after 9-week program, and at follow-up.

Results: Significant improvements were observed in both groups in sequencing praxis ($P=0.041$ in the control group; $P<0.001$ in the intervention group) and bilateral motor coordination ($P=0.013$; $P=0.020$), but at different rates. In the intervention group, improvements appeared after the intervention, while in the control group only at follow-up. Large effect sizes were found ($\eta^2 \in [0.293, 0.670]$), with high statistical power. No significant changes were observed in other functions.

Conclusions: The Bilateral Integration method improves sequencing praxis and interhemispheric integration in children with DCD symptoms. Midline-crossing exercises may yield relatively fast improvements in short-term programs.

Keywords: **Developmental Coordination Disorder • Motor Skills • Perception**

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Introduction

Functional movements crossing the body's midline influence the activation of cortical areas responsible for some cognitive and executive functions [1] and are associated with the excitation of electroencephalographic signals, which are treated as correlates of plasticity [2]. However, the long-term changes associated with such exercises have not been studied. Therefore, we investigated whether exercises using functional movements crossing the body's midline would improve cognitive and executive functioning.

This paper presents the preliminary results of a study on the effects of exercises according to the Bilateral Integration program, which uses movements involving crossing the body's midline, on improvements in selected cognitive and executive functions. Although the previously mentioned electroencephalographic studies referred to the Proprioceptive Neuromuscular Facilitation (PNF) method, the Bilateral Integration method was used in this study. This method also includes exercises with and without crossing the body's midline and, like the PNF method, incorporates multi-plane functional movements. The Bilateral Integration method was selected because it systematically incorporates midline-crossing movements, making it an ideal framework for testing the proposed neural activation theory.

This method was chosen primarily because of its target group: early school children with symptoms of developmental coordination disorder (DCD). Although the PNF method can be used for many disorders and with individuals of all ages, it is most often used in adult neurorehabilitation as a method for retraining movement patterns [3]. Bilateral Integration is developmentally broad in nature, and although it is intended for people of all ages, it was originally used primarily in exercises with children [4]. The detailed assumptions of this study are discussed in the study protocol [5], and only the most important points will be briefly mentioned in this Introduction.

Among the key elements of psychomotor development are somatognosia and praxis. Although somatognosia is primarily interpreted as awareness of one's own body schema, it is also associated with spatial orientation, and therefore depends not only on tactile or kinesthetic perception but also on visual perception. Somatognosia requires constant cooperation between many sensory systems and is shaped by the optimal reception and modulation of sensory information [6,7]. Praxis, in turn, is the ability to plan and execute a complex motor act, as well as to control its course. Depending on the category of the motor task or the goal of the movement, we can distinguish, among others, postural praxis, sequencing praxis, constructional praxis, or praxis on verbal command. Research clearly shows the relationship between different dimensions of praxis and executive functions [8,9].

Praxis integrates thought and movement, involving planning and executing new actions [10,11].

DCD, also referred to as developmental dyspraxia, is associated with a range of symptoms such as motor clumsiness, lack of fluidity of movement, muscle tension disorders, static and dynamic balance disorders, attention disorders, and sometimes even involuntary movements [12]. Since praxis involves 3 distinct stages (ideation, planning, and execution), its impairment can present in multiple ways. These can include the inability to plan a movement, inability to perform a movement despite having planned it, difficulty in switching from one action to another, lack of precision in movement, difficulty in performing sequences of actions, inappropriateness of movements, problems in imitating movements, difficulty in combining movements into a whole, problems in following instructions, or difficulties in rhythmization [13,14]. A core problem for children with DCD is the difficulty in developing a coherent action plan based on visual, tactile, and proprioceptive feedback, as well as in modifying the action plan in such a way that it is effective. As a result, they may struggle to perform specific motor tasks or only succeed in familiar environments, with limited ability to transfer learned skills to a new context. In diagnosis according to the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition, Text Revision criteria, DCD is therefore characterized by significant motor skill deficits (criterion A) that substantially interfere with daily activities (criterion B), emerge in early development (criterion C), and are not better explained by other medical, neurological, intellectual, or sensory conditions (criterion D) [15,16].

Because DCD symptoms can be similar to other neurodevelopmental or psychomotor developmental disorders, researchers highlight diagnostic difficulties. These difficulties are related not only to underdiagnosis but also to inconsistent and incorrect terminology [15-17]. Current recommendations for the diagnosis and interventions for DCD emphasize that a child may present DCD symptoms (eg, exhibiting significant motor skill deficits that are not better accounted for by any other medical, neurodevelopmental, psychological, social, or cultural background, thus meeting criterion B for diagnosis) but not have a formal DCD diagnosis. In such a situation, the recommendations suggest using diagnostic codes describing coordination disorders, gait and movement disorders, or other disorders of the nervous and musculoskeletal systems [18]. This group of children is often referred to in research as "children with probable DCD" [19] or "children with symptoms of DCD" [20]. In this paper, the latter term will be consistently used to refer to this group. The profile of DCD highlights clear disruptions in both praxis and perception, particularly in the field of visual and tactile perception, as well as kinesthetic perception. From a psychomotor perspective, these areas are fundamental and typically require targeted therapeutic intervention.

One therapeutic approach that shows potential in this area is the Bilateral Integration method developed by Sheila Dobie OBE. The main principles of exercises according to this method are the cooperation and coordination of both sides of the body (ie, left from right, upper from lower, front from back) during the execution of a sequence of movements and the dissociation of specific motor acts of one side of the body from the acts of the other side of the body. Exercises within the Bilateral Integration program involve the ability to coordinate both sides of the body and develop lateralization using simultaneous and opposite movements of both sides of the body. The aim of the exercises is to cause the maturation of the central nervous system and thus improve the coordination and regulation of sensory processes, which occurs because these exercises focus on simultaneous stimulation of the motor and cognitive spheres, building a body schema in the child's mind [21,22]. Considering the above recommendations for DCD [18], Bilateral Integration can be classified as a body-oriented intervention. Its main goal is therefore to train general motor coordination as a body function that can influence both the activity and participation of the child, in accordance with the standards of the International Classification of Functioning, Disability and Health.

Previous research on the Bilateral Integration method or programs based on its assumptions has shown that these exercises improve somatognosia, static and dynamic balance, postural control, multi-plane motor coordination, memory of muscle activity sequences, motor planning, movement automation, executive functions, and basic cognitive functions (perception, attention, memory), as well as broadly understood interhemispheric cooperation [22-24]. Recent research conducted using this method in a group of school students with moderate intellectual disabilities has shown that as a result of using exercises based on Bilateral Integration by Sheila Dobie OBE, visual-spatial processing, working memory, and verbal reasoning are improved [25]. However, it remains unclear whether the specific midline-crossing component is a critical active ingredient for the method's efficacy.

In this study, the functional indicators examined regarding cognitive and executive functioning will include mainly perceptual processes and praxis. The main research questions, which are already posed in the study protocol, are as follows: (1) Do exercises with crossing the body's midline improve perceptual processes more than exercises without crossing the body's midline? (2) Do exercises with crossing the body's midline improve praxis processes more than exercises without crossing the body's midline?

The conducted analyses are aimed to determine if exercises involving midline crossing lead to greater improvements in perceptual and praxis processes compared with those without this element, or if some of these functions are less responsive to such motor interventions.

Material and Methods

Ethics Statement

The study was approved by the Bioethics Committee of the Poznan University of Medical Sciences under resolution No. 847/22 of November 3, 2022, with later changes accepted by resolution No. 214/24 of March 7, 2024.

Sample Size Calculations

When planning the minimum sample size, we referred to a similar study that examined the impact of exercises using the Bilateral Integration program on cognitive function in 27 students with moderate intellectual disabilities [25]. Although the cited study did not concern children with DCD symptoms (currently there are no studies using the Bilateral Integration method in a population of children with DCD symptoms), it was considered a sufficient reference because the intervention itself – in the form of Bilateral Integration – was used in that study. Studies strictly on children with DCD, using different interventions and examining motor functions rather than cognitive or executive functions, also showed significant results even with a sample size of $n=26$ [26] or $n=27$ [27]. The minimum number of participants planned for recruitment was therefore 28, and assuming a dropout rate of 10% (due to the longitudinal nature of the study), 32 participants were estimated to be recruited.

Study Recruitment

The inclusion criteria were as follows: age 6 to 9 years and symptoms of dyspraxia without organic damage (in line with the previously discussed developmental nature of dyspraxia in DCD), even without formal diagnosis of DCD (but meeting some diagnostic criteria). The main exclusion criteria were the lack of informed consent of parents/guardians for the child's participation in the study, or the level of documented intellectual disability that would make it impossible to understand the instructions of the diagnostic testing or intervention exercises.

Thirty-two participants were recruited for the study, but not all completed the full research cycle. Detailed study recruitment, participant qualification, and dropout procedures are presented in the flowchart in **Figure 1**. Group assignment was made immediately before the first functional (balance and biomechanical) tests (at stage $n=26$), without reviewing the questionnaire results, using the basic randomization principle: participants with odd numbers constituted the control group, while participants with even numbers constituted the intervention group. The main principle for assigning numbers was the order in which the participant registered for the study; the assigned number was not changed after other participants withdrew.

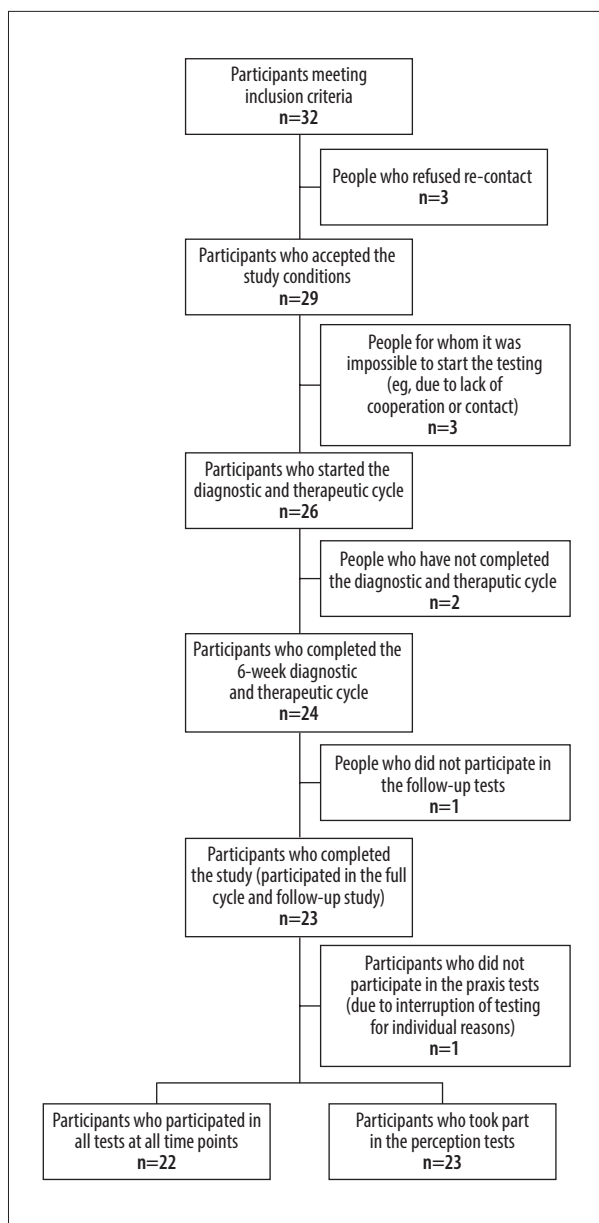


Figure 1. Flowchart.

This analysis included the results for the 22 participants who completed the full diagnostic and therapeutic cycle, participated in the follow-up study, and participated in all the main functional tests (n=11 for the control group and n=11 for the intervention group). The final dropout rate was therefore considerable, at 31.25% (or 28.125% for the praxis tests alone).

Structure of Research

Each participant was planned to participate in a 10-week study cycle, which consisted of a 6-week diagnostic and therapeutic cycle and a 4-week break before the follow-up assessment. The methodological assumption was that the intervention would

last 6 weeks, with exercises performed 5 times a week, and that the intensity of the exercises and the pace of learning new exercises would be individually tailored to the participants by the facilitator (principal investigator). The duration of the session was also adjusted to the child; if more time was needed to repeat the exercise, the child was given an adequate amount of time. In practice, however, in many cases, the assumed continuity of the intervention was disrupted by various factors (most often absences due to the child’s illness), and in such cases, it was extended accordingly. Details on this can be found in the Results section. The individual groups differed in the type of intervention used. Both groups used exercises from the Bilateral Integration program. However, in the control group, these exercises were performed without crossing the body’s midline (exercises: body lifts, basic angels, alternating exercise), while in the intervention group, these exercises primarily involved crossing the body’s midline (exercises: body lifts, cross overs, sun-wind-rainbow). A detailed description of the interventions used can be found in the study protocol [5].

Before the intervention, a questionnaire was administered using the Developmental Coordination Disorder Questionnaire (DCDQ) [28], the accuracy of which was also tested in a group of Polish children (DCDQ’07 PL) [29]. During this phase, the Sensorimotor Development Questionnaire by Przyrowski was also administered (the modified questionnaire has already been used, among others, in research on children with autism) [14]. We also used the Institute for Neuro-Physiological Psychology Screening Questionnaire (INPP) [30]. In addition to the questionnaires, functional (balance) and biomechanical tests were conducted: the Unterberger test [31], the Standing and Walking Balance test [32], knee joint valgus/varus angle, shin torsion angle [33], and examination of the foot arch using the podoscopic method [34].

The main functional tests were performed at 3 time points: before the intervention (t₀), after the 6-week intervention (t₁), and after a 4-week break following the intervention (t₂). These tests included kinaesthesia, localization of tactile stimuli, manual form perception, figure-ground perception, postural praxis, constructional praxis, praxis on verbal command, sequencing praxis, bilateral motor coordination, and gross motor coordination [22,30,35-38].

Due to the specificity of the study, we also considered 1 random variable, which was lifestyle changes, especially in terms of the level of physical activity. This level was tested before and after intervention, using a survey based on the criteria of the Moderate-to-Vigorous Physical Activity (MVPA) index and the recommendations of the World Health Organization (WHO) defining the recommended level of activity, such as the Nordic Physical Activity Questionnaire (NPAQ). With the use of these indicators, it was possible to determine the level of

physical activity based on the frequency of various types of activities and the duration of these activities. The MVPA and NPAQ scales also provide, according to WHO recommendations, appropriate conversion factors for people who combine different types of physical activity [39,40].

Statistical Analysis

The obtained data were then analyzed in accordance with the principles of research design and data analysis [41,42], using PQStat software (version 1.8.6.122), assuming statistical significance for a verified P value of <0.05 . All obtained data were first analyzed using the Shapiro-Wilk test to test for normality of distribution, and then other statistical tests were applied, depending on the parametricity of the distribution. For tests requiring homogeneity of variance, the Levene test was additionally used. For variables analyzed once (demographic and anthropometric variables, questionnaire results, and results of balance and biomechanical tests), the t test for independent samples or the Mann-Whitney U test were used for comparisons between groups. Physical activity results were compared between groups using the t test for independent samples or the Mann-Whitney U test, and either the t test for dependent samples or the Wilcoxon test (with an exact P value, not an asymptotic one) was used to test for significance of changes in physical activity levels within individual groups. Before using the t test for independent samples, the Fisher-Snedecor F test was also used. ANOVA for dependent samples and for independent samples was used for the intergroup and intragroup analysis of the results of the main functional tests, conducted at the 3 time points and for 2 groups. In the case of normal distribution, depending on the Levene test results, parametric ANOVA with or without Welch correction was used; and depending on the Mauchly test results, the Greenhouse-Geisser correction was or was not applied. In the case of nonparametric distribution, nonparametric ANOVA (Kruskal-Wallis one-way ANOVA by ranks or Friedman test for repeated measures) was used. The Tukey HSD post hoc test (or Dunn-Benjamini-Hochberg post hoc test in nonparametric ANOVA) was used to examine significant interactions between groups over time and to assess changes between the 3 time points in the intervention group and the control group. Effect sizes were calculated to quantify the magnitude of observed effects. For parametric ANOVA tests, η^2 (eta-squared) was obtained directly from the model outputs. For nonparametric tests, corresponding effect size measures were computed (eg, r for Wilcoxon/Mann-Whitney, η^2 or equivalent for Friedman/Kruskal-Wallis tests), ensuring comparability across analyses. To confirm the actual effect of the tests were statistical significance were observed, a post hoc power analysis was also conducted using G*Power 3.1.9.7 software and selecting the “ANOVA: repeated measures, within factors” option, which considers effect size f , α error probability, total sample size, number of groups,

number of measurements, correlation among repeated measures, and nonsphericity correction ϵ (here calculated according to Greenhouse-Geisser).

Results

Demographic and anthropometric variables were analyzed in detail to characterize both groups (Table 1). The demographic analysis was also extended to include a neurodevelopmental analysis (Table 2), since the level of neurological development could also be important from the point of view of interpreting the study results.

The analysis of demographic and basic anthropometric data shows that the groups were not only equal in size, but also did not differ significantly in terms of characteristics that could be important for the further course of the study. In the next analysis, we examined the actual duration of individual stages of the study (Table 3).

Although the duration of the intervention and the break before the follow-up examination – and thus the duration of the entire diagnostic and therapeutic cycle – differed from the assumptions in both groups, the actual time did not differ significantly in the intergroup comparison, which is also important in relation to the study assumptions.

Among the test variables, the results of the questionnaire studies were first analyzed, namely the results of the DCDQ divided into individual domains (Table 4) and the results of the Sensorimotor Development Questionnaire by Przyrowski, also divided into individual domains (Table 5). Due to the diversity of scales, the scores were standardized to percentages; the modified results for all domains are presented in the tables.

Another important element was the initial functional (balance) and biomechanical testing prior to the intervention, the results of which were also analyzed (Table 6). Owing to the complexity of the podoscopic examination and because this work is a preliminary report, the results regarding the foot arch are presented in a summed form (1 point for each indicator that was within the normal range: maximum of 6 points for 1 foot and maximum of 12 points for both feet).

The final analyzed contextual variable was physical activity level, which was measured both before and after the intervention. Intra- and intergroup comparisons are provided in Table 7.

There was no significant difference between the groups in physical activity levels before and after the intervention, both on the MVPA and NPAQ scales. A statistically significant increase in physical activity levels on the MVPA scale was observed in

Table 1. Demographic and anthropometric characteristics of participants.

		Control group	Intervention group
Sex		Male=6; Female=5	Male=6; Female=5
Preterm birth		0	0
Age [years]	Min-Max	6-7	6-7
	M	6.18	6.18
	Me	6	6
	SD	0.40	0.40
	CV	6.54%	6.54%
	Mann-Whitney U	<i>P</i> =0.960	
Age [months]	Min-Max	72-94	75-90
	M	78.27	79.18
	Me	76	78
	SD	7.91	4.75
	Mann-Whitney U	<i>P</i> =0.196	
Height [cm]	Min-Max	118-157	109-130
	M	128.64	120.5
	Me	125	120
	SD	10.90	6.73
	CV	8.48%	5.61%
	Mann-Whitney U	<i>P</i> =0.044	
Weight [kg]	Min-Max	20-40	17-29
	M	26.32	22.22
	Me	23	22
	SD	6.78	3.61
	CV	25.77%	16.26%
	Fisher-Snedecor F	<i>P</i> =0.059	
	t	<i>P</i> =0.092	
BMI	Min-Max	11.48-19.53	13.19-17.70
	M	15.76	15.34
	Me	15.28	15.38
	SD	2.63	1.40
	CV	16.67%	9.15%
	Fisher-Snedecor F	<i>P</i> =0.060	
	t	<i>P</i> =0.642	

Min-Max – score range; M – mean; Me – median; SD – standard deviation; CV – coefficient of variation. *P* values that were statistically significant are bolded.

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Table 2. Neurodevelopmental characteristics of participants.

		Control group	Intervention group
Confirmed accompanying developmental diagnoses	Neurodevelopmental	1	3
	Sensorimotor	4	1
	Other	0	0
INPP Questionnaire of Neurodevelopment	Min-Max	1-12	1-9
	M	5.09	3.64
	Me	4	3
	SD	3.75	2.25
	CV	73.74%	61.83%
	Fisher-Snedecor F		<i>P</i> =0.121
	t		<i>P</i> =0.283

Min-Max – score range; M – mean; Me – median; SD – standard deviation; CV – coefficient of variation. *P* values that were statistically significant are bolded.

Table 3. Actual duration of individual stages of the study.

		Control group	Intervention group
Intervention (between t_0 and t_1) [weeks]	Min-Max	6.00-13.00	7.00-12.86
	M	9.01	9.86
	Me	8.29	9.57
	SD	2.37	1.90
	CV	26.33%	19.23%
	Fisher-Snedecor F		<i>P</i> =0.490
	t		<i>P</i> =0.368
Break (between t_1 and t_2) [weeks]	Min-Max	3.14-8.57	3.57-9.00
	M	5.97	6.60
	Me	5.86	6.71
	SD	1.68	1.68
	CV	30.99%	25.45%
	Fisher-Snedecor F		<i>P</i> =0.762
	t		<i>P</i> =0.419
Whole diagnostic and therapeutic cycle (between t_0 and t_2) [weeks]	Min-Max	9.14-19.71	11.86-19.71
	M	14.99	16.45
	Me	16.71	16.14
	SD	3.20	2.69
	CV	21.33%	16.37
	Fisher-Snedecor F		<i>P</i> =0.595
	t		<i>P</i> =0.258

Min-Max – score range; M – mean; Me – median; SD – standard deviation; CV – coefficient of variation. *P* values that were statistically significant are bolded.

Table 4. Pre-intervention Developmental Coordination Disorder Questionnaire (DCDQ) scores expressed as percentages (the higher the score, the higher the level of functioning).

		Control group	Intervention group
Motor control	Min-Max	33.33-90.00	43.33-86.67
	M	67.27	67.58
	Me	70.00	76.67
	SD	18.85	16.27
	CV	28.01%	24.07%
	Fisher-Snedecor F	<i>P</i> =0.651	
	t	<i>P</i> =0.968	
Dexterity (fine motor skills)	Min-Max	25.00-90.00	35.00-95.00
	M	68.18	65.91
	Me	70.00	70.00
	SD	16.47	21.31
	CV	24.16%	32.33%
	Mann-Whitney U	<i>P</i> =0.947	
	General coordination	Min-Max	32.00-92.00
M		64.00	62.18
Me		64.00	68.00
SD		18.15	18.27
CV		28.37%	29.39%
Mann-Whitney U		<i>P</i> =0.895	
Total score of DCDQ		Min-Max	30.67-88.00
	M	66.42	65.33
	Me	66.67	70.67
	SD	16.44	17.56
	CV	24.74%	26.87%
	Mann-Whitney U	<i>P</i> =0.895	

Min-Max – score range; M – mean; Me – median; SD – standard deviation; CV – coefficient of variation. *P* values that were statistically significant are bolded.

the intervention group, but this was not confirmed by analyses of the NPAQ.

Main functional tests were performed for both groups at 3 time points. The results of these tests and inter- and intra-group comparisons are presented in **Table 8**.

In none of the functional tests did the results differ significantly between the groups at the beginning of the diagnostic and therapeutic cycle. Significant increases were observed in both

groups for the bilateral motor coordination and sequencing praxis tests. The trajectory of change was similar in both cases: the intervention group showed a significant increase in scores immediately after the intervention, followed by a result indicating sustained changes (and even a slight further increase) after the break (**Figures 2, 3**). In the control group, a statistically insignificant gradual increase between subsequent time points was observed, resulting in a statistically significant increase at the end of the cycle (t_2) compared with the first test (t_0) (**Figures 4, 5**).

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Table 5. Pre-intervention Sensory Development Questionnaire scores expressed as percentages (the higher the score, the greater the level of disorder).

		Control group	Intervention group
Postural disorders	Min-Max	9.38-78.13	31.25-65.63
	M	45.74	43.75
	Me	40.63	37.50
	SD	19.88	11.00
	CV	43.46%	25.15%
	Mann-Whitney U	<i>P</i> =0.920	
Developmental dyspraxia	Min-Max	0.00-50.00	9.38-62.50
	M	26.70	28.41
	Me	21.88	21.88
	SD	18.08	19.44
	CV	67.70%	68.42%
	Mann-Whitney U	<i>P</i> =0.895	
Tactile defensiveness	Min-Max	15.91-61.36	29.55-54.55
	M	38.02	38.22
	Me	40.91	36.36
	SD	12.94	8.31
	CV	34.04%	21.74%
	Fisher-Snedecor F	<i>P</i> =0.178	
	t	<i>P</i> =0.964	
Gravitational uncertainty	Min-Max	10.00-40.00	10.00-55.00
	M	24.55	26.82
	Me	30.00	25.00
	SD	9.61	15.85
	CV	39.14%	59.12%
	Fisher-Snedecor F	<i>P</i> =0.130	
	t	<i>P</i> =0.689	
Sensory defensiveness	Min-Max	12.24-55.10	22.45-46.94
	M	33.40	32.28
	Me	32.65	32.65
	SD	13.39	8.65
	CV	40.10%	26.79%
	Fisher-Snedecor F	<i>P</i> =0.184	
	t	<i>P</i> =0.819	

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Table 5 continued. Pre-intervention Sensory Development Questionnaire scores expressed as percentages (the higher the score, the greater the level of disorder).

		Control group	Intervention group
Body schema disorders	Min-Max	5.88-58.82	5.88-52.94
	M	28.82	22.99
	Me	17.65	17.65
	SD	19.65	15.66
	CV	69.35%	68.12%
	Fisher-Snedecor F	<i>P</i> =0.486	
	<i>t</i>	<i>P</i> =0.488	
Sensory-based movement disorders	Min-Max	4.76-61.90	23.81-65.08
	M	36.80	36.65
	Me	38.10	31.75
	SD	18.60	13.74
	CV	50.56%	37.48%
	Fisher-Snedecor F	<i>P</i> =0.353	
	<i>t</i>	<i>P</i> =0.984	
Sensory modulation disorders	Min-Max	15.04-52.21	23.89-44.25
	M	33.63	33.63
	Me	31.86	35.40
	SD	11.44	7.66
	CV	34.01%	22.79%
	Fisher-Snedecor F	<i>P</i> =0.223	
	<i>t</i>	<i>P</i> =1.000	

Min-Max – score range; M – mean; Me – median; SD – standard deviation; CV – coefficient of variation. *P* values that were statistically significant are bolded.

Table 6. Results of preliminary functional and biomechanical tests.

		Control group	Intervention group
Unterberger Test [Number of participants with abnormal results]		1	1
Standing and Walking Balance (SWB)	Min-Max	36-100	19-102
	M	76.55	59.18
	Me	86	68
	SD	23.67	27.48
	CV	30.92%	46.43%
	Mann-Whitney U	<i>P</i> =0.107	

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Table 6 continued. Results of preliminary functional and biomechanical tests.

		Control group	Intervention group
Knee joint valgus (+) or varus (-) angle (right lower limb)	Min-Max	+2 to +10	+5 to +10
	M	+7.09	+6.82
	Me	+6	+6
	SD	3.02	1.47
	CV	42.52%	21.57%
	Mann-Whitney U	<i>P</i> =0.810	
Knee joint valgus (+) or varus (-) angle (left lower limb)	Min-Max	+4 to +11	0 to +14
	M	+6.36	+7.36
	Me	+6	+10
	SD	2.69	4.65
	CV	42.33%	63.19%
	Mann-Whitney U	<i>P</i> =0.762	
Shin torsion angle-bone directed outward (-) or inward (+) (right lower limb)	Min-Max	+3 to +24	+10 to +40
	M	+12.09	+18.91
	Me	+10	+16
	SD	6.36	8.60
	CV	52.63%	45.46%
	Mann-Whitney U	<i>P</i>=0.037	
Shin torsion angle-bone directed outward (-) or inward (+) (left lower limb)	Min-Max	+4 to +28	+6 to +35
	M	+15.00	+20.18
	Me	+16	+20
	SD	7.99	8.95
	CV	53.25%	44.36%
	Fisher-Snedecor F	<i>P</i> =0.725	
	<i>t</i>	<i>P</i> =0.167	
Podoscopic examination [number of indicators within the norm for both feet]	Min-Max	4-9	4-10
	M	6.73	7.18
	Me	7	7
	SD	1.79	1.94
	CV	26.67%	27.01%
	Fisher-Snedecor F	<i>P</i> =0.809	
	<i>t</i>	<i>P</i> =0.575	

Min-Max – score range; M – mean; Me – median; SD – standard deviation; CV – coefficient of variation. *P* values that were statistically significant are bolded.

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In the remaining tests, no statistically significant intragroup change over time was observed. However, to confirm the actual effect of Bilateral Integration exercise on sequencing praxis and bilateral motor coordination parameters, a post hoc power analysis was also conducted. The most significant statistical parameters – specifically the calculated statistical power and the minimum sample size to achieve the required power of at least 90% – are presented in **Table 9**.

Discussion

The results of this study showed that the Bilateral Integration method can be an important element in supporting sequencing praxis and bilateral motor coordination in children with DCD symptoms.

Table 7. Level of physical activity in groups.

		Control group	Intervention group
MVPA scale before intervention	Min-Max	0-7	1-6
	M	4.45	2.82
	Me	5	3
	SD	2.62	1.54
	CV	58.85%	54.55%
	Fisher-Snedecor F	P=0.107	
	t	P=0.089	
MVPA scale after intervention	Min-Max	0-7	1-7
	M	4.45	4.00
	Me	5	4
	SD	2.91	2.14
	CV	65.34%	53.62%
	Mann-Whitney U	P=0.546	
NPAQ scale before intervention	Min-Max	1-3	2-3
	M	2.45	2.73
	Me	3	3
	SD	0.82	0.47
	CV	33.42%	17.13%
	Mann-Whitney U	P=0.522	
NPAQ scale after intervention	Min-Max	1-3	1-3
	M	2.64	2.45
	Me	3	3
	SD	0.67	0.69
	CV	25.57%	28.01%
	Mann-Whitney U	P=0.463	

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Table 7 continued. Level of physical activity in groups.

		Control group		Intervention group	
		Before	After	Before	After
MVPA scale intragroup	Min-Max	0-7	0-7	1-6	1-7
	M	4.45	4.45	2.82	4.00
	Me	5	5	3	4
	SD	2.62	2.91	1.54	2.14
	CV	58.85%	65.34%	54.55%	53.62%
	Wilcoxon/t test	P=1.000		P=0.034	
	NPAQ scale intragroup	Min-Max	1-3	1-3	2-3
M		2.45	2.64	2.73	2.45
Me		3	3	3	3
SD		0.82	0.67	0.47	0.69
CV		33.42%	25.57%	17.13%	28.01%
Wilcoxon		P=0.157		P=0.180	

Min-Max – score range; M – mean; Me – median; SD – standard deviation; CV – coefficient of variation; MVPA – Moderate-to-Vigorous Physical Activity; NPAQ – Nordic Physical Activity Questionnaire. P values that were statistically significant are bolded.

Table 8. Results of the main functional tests at 3 time points.

Measure	Group	Pre-test (t ₀)	Post-test (t ₁)	Follow-up testing (t ₂)	P value ANOVA within group (effect on time)	Significant differences within group (post hoc test)
KIN	Control	<u>41.91±19.29</u> 36.4 [30.55-45.6]	<u>43.15±21.05</u> 35.8 [31.7-42.35]	35.13±9.13 38 [28.75-40.85]	P=0.178	
	Intervention	40.01±14.28 37.3 [30.1-51.25]	38.69±9.08 38.1 [34.35-44.15]	<u>43.96±19.10</u> 38.7 [35-46.55]	P=0.529	
	P value ANOVA between groups	P=0.974	P=0.232	P=0.507		
LTS	Control	16.23±5.46 14.7 [12.3-19.3]	<u>13.88±3.63</u> 12.8 [10.7-16.9]	<u>11.90±3.00</u> 10.2 [9.6-15.1]	P=0.148	
	Intervention	13.25±4.09 14.9 [9.85-16.35]	12.89±4.28 12.2 [9.8-15.1]	14.29±5.93 14 [10-14.75]	P=0.722	
	P value ANOVA between groups	P=0.163	P=0.563	P=0.269		
MFP	Control	8.36±1.29 8 [8-9.5]	7.91±1.30 8 [7-9]	8.00±1.26 8 [7-9]	P=0.605	
	Intervention	7.91±1.22 8 [7-9]	8.09±1.38 8 [7-9]	8.18±2.18 9 [7-10]	P=0.815	
	P value ANOVA between groups	P=0.405	P=0.753	P=0.064		

Table 8 continued. Results of the main functional tests at 3 time points.

Measure	Group	Pre-test (t ₀)	Post-test (t ₁)	Follow-up testing (t ₂)	P value ANOVA within group (effect on time)	Significant differences within group (post hoc test)
FG	Control	16.27±2.24	16.73±2.49	16.18±3.22	<i>P=0.821</i>	
	Intervention	15.36±3.41	17.27±2.94	16.82±3.34	<i>P=0.219</i>	
	<i>P value ANOVA between groups</i>	<i>P=0.469</i>	<i>P=0.644</i>	<i>P=0.654</i>		
BMC	Control	8.60±5.56	11.00±7.09	13.73±6.02	P=0.013	t ₂ >t ₀ (P=0.009)
	Intervention	7.45±6.42	12.09±7.60	12.82±9.15	P=0.020**	t ₁ >t ₀ (P=0.027) t ₂ >t ₀ (P=0.010)
	<i>P value ANOVA between groups</i>	<i>P=0.669</i>	<i>P=0.731</i>	<i>P=0.786</i>		
GMC	Control	6.09±2.02	5.09±1.81	4.91±1.04	<i>P=0.108</i>	
	Intervention	4.45±1.69	4.27±1.10	5.27±2.00	<i>P=0.338</i>	
	<i>P value ANOVA between groups</i>	<i>P=0.053</i>	<i>P=0.216</i>	<i>P=0.601*</i>		
PPr	Control	15.73±4.15	15.82±5.31	16.64±5.03	<i>P=0.108</i>	
	Intervention	14.45±4.80	14.27±5.12	15.73±6.28	<i>P=0.338</i>	
	<i>P value ANOVA between groups</i>	<i>P=0.514</i>	<i>v=0.495</i>	<i>v=0.712</i>		
CPr	Control	13.18±2.32 13 [12-15]	13.36±2.34 13 [13-15]	14.82±1.08 15 [14-16]	<i>P=0.126</i>	
	Intervention	12.64±3.91 14 [13.5-14.5]	14.27±2.57 15 [14.5-15.5]	13.73±2.97 15 [13.5-15.5]	<i>P=0.159</i>	
	<i>P value ANOVA between groups</i>	<i>P=0.920</i>	<i>P=0.177</i>	<i>P=0.541</i>		
SPr	Control	47.82±18.95	51.09±19.83	55.64±22.20	P=0.031	t ₂ >t ₀ (P=0.025)
	Intervention	38.55±18.73	50.55±20.32	55.00±21.51	P<0.001	t ₁ >t ₀ (P<0.001) t ₂ >t ₀ (P<0.001)
	<i>P value ANOVA between groups</i>	<i>P=0.262</i>	<i>P=0.950</i>	<i>P=0.946</i>		
PrVC	Control	<u>18.73±4.36</u> 21 [17-22]	<u>19.55±4.80</u> 21 [19-22]	<u>20.18±3.37</u> 21 [19.5-22]	<i>P=0.376</i>	
	Intervention	18.55±4.03 20 [16-22]	19.09±5.20 22 [15-22.5]	19.36±5.73 23 [14.5-24]	<i>P=0.567</i>	
	<i>P value ANOVA between groups</i>	<i>P=0.894</i>	<i>P=0.617</i>	<i>P=0.595</i>		

KIN – kinaesthesia; LTS – localization of tactile stimuli; MFP – manual form perception; FG – figure-ground perception; PPr – postural praxis; SPr – sequencing praxis; CPr – constructional praxis; PrVC – praxis on verbal command; BMC – bilateral motor coordination; GMC – gross motor coordination. Results are presented as mean with standard deviation (M±SD). If at least 1 result of a given functional test did not meet the criteria for a normal distribution (the mean and standard deviation are underlined), the results are also presented as median with lower and upper quartiles (Me [Q1-Q3]). For parametric ANOVA, means should be compared, while for nonparametric ANOVA, medians should be compared. *P* values obtained from nonparametric ANOVA (Friedman ANOVA for dependent measures and Kruskal-Wallis ANOVA for independent measures) are in italics. *P* values that were statistically significant are bolded (bolding was not used for post hoc test results, as only those that were significant are indicated in the table). * Values calculated with the Welch correction due to unequal variances. ** Values calculated with the Greenhouse-Geisser correction due to failure to meet the sphericity condition.

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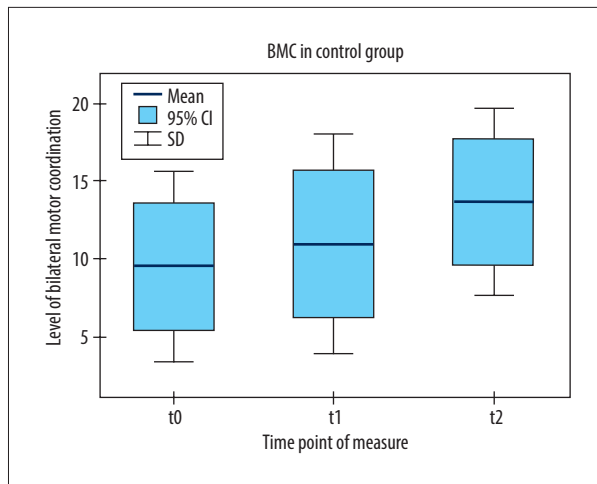


Figure 2. Results of bilateral motor coordination (BMC) in the control group in 3 time points.

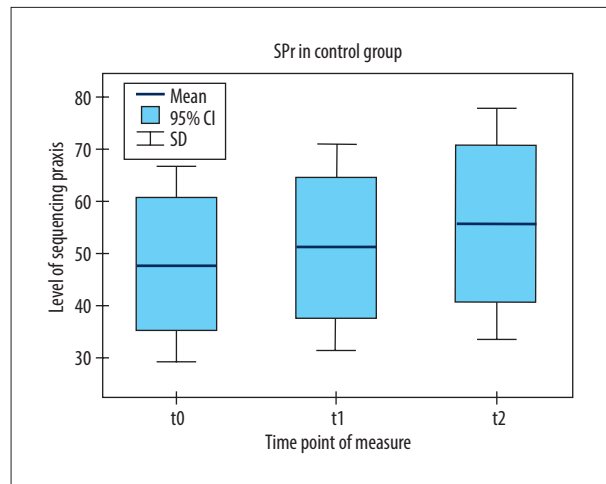


Figure 4. Results of sequencing praxis (SPr) in the control group in 3 time points.

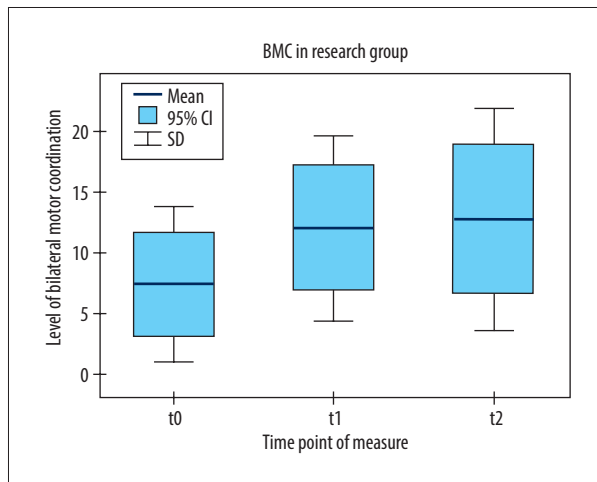


Figure 3. Results of bilateral motor coordination (BMC) in the intervention group in 3 time points.

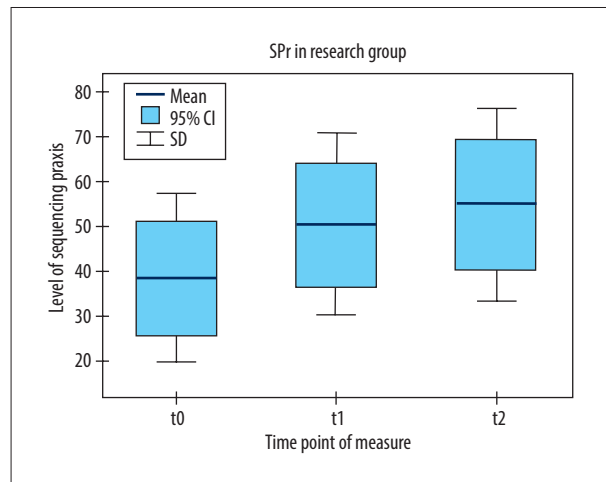


Figure 5. Results of sequencing praxis (SPr) in the intervention group in 3 time points.

Table 9. Post hoc power analysis for one-way repeated measures ANOVA of sequencing praxis (SPr) and bilateral motor coordination (BMC).

Function	Group	P value of ANOVA	Effect size	Sphericity (Mauchly Test)	Test power (1-β)	Minimal sample size to 90% of power
SPr	Control	$P=0.031$	$\eta^2=0.293$ (large effect)	$P=0.567$	100.00%	n=3
	Intervention	$P<0.001$	$\eta^2=0.670$ (large effect)	$P=0.805$	100.00%	n=3
BMC	Control	$P=0.013$	$\eta^2=0.350$ (large effect)	$P=0.141$	99.99%	n=4
	Intervention	$P=0.008$	$\eta^2=0.387$ (large effect)	$P=0.038$	99.99%	n=4

The presented study included several methodological changes from the plan presented in the study protocol [5]. For instance, femoral head antetorsion/retrotorsion angle was not analyzed because not all parents/guardians were receptive to palpation of the gluteal region. Similarly, physical activity levels were not analyzed during the follow-up phase because access to some parents/guardians was difficult after the study was completed. However, two significantly more important elements were added: an INPP Neurodevelopment Questionnaire and balance testing using the Standing and Walking Balance test. This allowed for even better characterization of the study groups and clarification of aspects that could also significantly impact the study. Detailed analysis revealed that the groups differed only in individual parameters (height was significantly higher in the control group, and right shin torsion was significantly more medially directed in the intervention group). However, in isolation, these parameters are of marginal significance. No studies were found to suggest any relationship between shin torsion and cognitive, executive, or praxis processes; therefore, this difference was not considered clinically significant. In the case of height, research indicates that there is no relationship between height and mental conditions [43]. Although the cited study concerns the intelligence index (intellectual domain), other studies clearly indicate the current lack of relationship between height and cognitive functioning [44]. The groups also differed in the distribution of developmental difficulties: the control group included 1 child with a diagnosis of neurodevelopmental disorders and 4 children with confirmed sensory processing disorders; the intervention group included 3 children with a diagnosis of neurodevelopmental disorders and 1 child with confirmed sensory processing disorders. Differences in co-diagnoses may have potential clinical significance, but details of co-diagnoses, such as type of autism or type of sensorimotor processing disorder, were not analyzed, because the analysis of the diagnostic structure in both groups showed that the number of people with an accompanying neurodevelopmental diagnosis and an accompanying sensorimotor diagnosis and without an accompanying diagnosis was statistically independent of group membership (the exact Fisher-Freeman-Halton test was performed, which showed a P value of 0.258; P value of Pearson's χ^2 test was 0.237). Therefore, the presence of diagnoses did not affect the comparability of groups in further analysis of the results. The distribution of diagnoses was therefore not a confounding factor for the results. Additionally, after administering the INPP Neurodevelopment Questionnaire, the level of neurodevelopment in both groups was not significantly different. The actual duration of interventions and breaks also did not differ significantly between the 2 groups. This suggests that the groups were nearly homogeneous in terms of the contextual factors examined.

Although physical activity level measured on the MVPA scale significantly improved in the intervention group, the levels

ultimately did not differ significantly between groups. It is possible, however, that the significant increase in activity levels in the intervention group is a positive side effect of the intervention. This would require a detailed analysis, which is beyond the scope of the preliminary report. However, this would be consistent with the assumptions of Self-Determination Theory and research confirming that exercises from the Bilateral Integration program family support well-being, self-confidence, concentration, and affective regulation in school-age youth [45], which may in turn translate into increased motivation, including motivation to engage in physical activity.

Among the main functional tests studied, statistically significant results were observed only in sequencing praxis and bilateral motor coordination. Neither group demonstrated statistically significant results in improving perceptual function. One reason may be the duration of the intervention, which in this study averaged approximately 9 weeks (the entire diagnostic and therapeutic cycle averaged approximately 16 weeks). While this is not a short duration, as the standard intervention time in physiotherapy and rehabilitation studies is approximately 6 weeks [46-49], and neuroplastic changes can be seen as early as 1 week [50], significant changes in basic cognitive functions following exercises from the Bilateral Integration program may be visible after approximately 26 weeks [25]. The lack of visible changes in cognitive function could potentially also be due to the sensitivity of the assessment tools, as recent studies on the SIPT test battery focus more on tests assessing praxis than perception [51,52]. The lack of significant changes should not be due to the characteristics of the population of children with DCD symptoms, as studies clearly indicate that although DCD primarily affects motor symptoms, it is often associated with perceptual disturbances [53,54]. The nature of the intervention also did not rule out changes in perception, as other studies have clearly shown that exercises from the Bilateral Integration program improve some cognitive functions [25]. However, it is possible that the key explanation lies in the group-intervention interaction, and it may turn out that this type of intervention does not significantly affect perceptual functions in the group of children with DCD. A 26-week study would likely be necessary, as many studies examining changes in cognitive functioning are conducted for 26 weeks [55-57]. This practice also appears in studies involving children [25]. A longer intervention could therefore produce broader results.

Improvement in sequencing praxis and bilateral motor coordination is notable due to the importance of rhythmization, counting, auditory-motor integration, somatognosia, movement control, inhibitory control, and sequence reproduction. At the neural level, many of these elements (or their components) are reflected in the parietal cortex. The right parietal cortex is associated with spatial processing, while the left is associated with

movement initiation [58]. Medial parietal areas also encode a bias regarding which hand will be used to execute a movement long before its initiation [59]. The parietal lobe, because it also encompasses the dorsal visual stream, is also responsible for mapping visually perceived objects to body coordinates [60]. Other studies, in turn, attribute functions to the parietal cortex such as movement observation, sensory-motor integration, and hand movement control (reaching, grasping, pointing) [61], as well as spatial awareness, orientation, and motor control [62]. Emphasizing the role of the parietal cortex in these functions, and thus indirectly in the abilities measured by the sequencing praxis and bilateral motor coordination tests, is important because research indicates that movements that cross the midline additionally stimulate the dorsolateral prefrontal cortex and the parietal cortex, especially the superior parietal cortex [1].

However, in the present study, improvements in the above functional tests were visible in both groups. It is therefore possible that movements without crossing the body's midline also cause changes that ultimately translate into similar functional improvement. A deeper analysis, also taking into account the sequencing praxis and bilateral motor coordination subtests, will likely reveal more differences in the mechanisms of improvement in both groups. In the present study, the main difference was the speed of functional changes in sequencing praxis and bilateral motor coordination. In the intervention group, statistically significant functional improvement appeared already in the second measurement (immediately after the intervention) and then were maintained until the third measurement, whereas in the control group, the improvement was small but relatively constant, leading to a significant difference between the first and the third measurements.

A longer study would allow for determining the further trajectory of change; however, the present results already indicate that the change was similar in both groups (there were no significant differences between groups), with improvement in the intervention group occurring already in the second measurement. This is consistent with other studies that have shown that midline-crossing exercises are associated with the elicitation of plasticity-related potentials [2], which could suggest that in the intervention group similar movements stimulated neuroplastic changes more quickly and intensely than the exercises in the control group. However, due to the lack of a detailed analysis of the "group × time" interaction effect from the repeated measures, it cannot be clearly stated that the improvement in the intervention group occurred statistically significantly faster than in the control group. Effects were observed in both groups, with the main difference being the occurrence of change in the second measurement, not the final level of the functions tested. Therefore, midline-crossing exercises are not clearly superior, but rather may accelerate the effects; however, this would require additional detailed analysis.

Finally, it should be emphasized that the group of 22 children was relatively small. For example, as indicated in the flowchart (**Figure 1**), the final number of participants was lower than initially planned (the dropout rate was higher than anticipated). Therefore, the results should be interpreted with caution. The dropout rate was a staggering 31.25%, and the reasons for dropout are indicated in the flowchart. However, these reasons were not analyzed in detail. Baseline characteristics of those participants who completed the study were also not compared with the characteristics of those who dropped out. Therefore, it cannot be ruled out that the results might have changed had these individuals remained in the sample, which potentially limits the reliability of the results. The analysis was conducted on available participant data, without a full intention-to-treat analysis, which should be considered an additional limitation.

Nevertheless, it should be noted that the main results demonstrated very high statistical power and even demonstrated that the results were so significant that a much smaller sample would have yielded similar results. Although the number of participants was small compared with that of some studies regarding interventions using Bilateral Integration or interventions used with children with DCD or with symptoms of DCD, the statistical power confirms that the collected sample size was sufficient.

Conclusions

The results verify the research hypotheses. Midline-crossing exercises according to the planned protocol did not contribute to improved perceptual functions more than exercises that did not include this element. However, they did contribute to the earlier appearance of changes in sequencing praxis and bilateral motor coordination than the exercises used by the control group. This suggests that in short-term programs (approximately 9 weeks duration) aimed at supporting movement sequencing and interhemispheric integration processes in early school-age children, midline-crossing exercises would be very effective, as they may lead to a fast rate of functional improvement. In long-term programs (approximately 16 weeks duration), however, there appears to be no difference, but a second follow-up study to demonstrate the changes over a longer period was lacking. Long-term equivalence requires verification through studies with extended follow-up (eg, 26 weeks or longer). Nevertheless, this study shows that exercises from the Bilateral Integration program support sequencing praxis and interhemispheric integration processes in children with DCD symptoms. The high power of statistical tests also indicates that the detected relationships are not accidental, and this allows us to accept Bilateral Integration as a method with proven effectiveness in supporting the psychomotor

development of early school-age children, at least in terms of sequencing praxis and interhemispheric integration processes.

The results indicate that a Bilateral Integration exercise protocol improves sequencing praxis and bilateral motor coordination in children with DCD symptoms. Within this protocol, the inclusion of a midline-crossing component may be associated with an accelerated rate of improvement during the study period, although the final level of function achieved was similar between groups.

Ethics Approval and Consent to Participate

The study was conducted in accordance with the Declaration of Helsinki. The study was approved by the Bioethics Committee of the Poznań University of Medical Sciences under resolution No. 847/22 of November 03, 2022, with later changes accepted by resolution No. 214/24 of March 7, 2024. Only children whose parents or legal guardians gave informed written consent to participate in the study participated in the study.

Availability of Data and Materials

This work is a preliminary report of research for a doctoral thesis. The full data cannot yet be publicly available until they are

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subjected to further detailed analysis as part of a doctoral thesis (which should be finalized by 2028). Use of these data in publications by other authors could pose a significant obstacle to the implementation of the doctoral thesis, which assumes innovative results. The corresponding author will later be able to share the data with interested researchers by email contacting.

Acknowledgements

This article is part of a series of publications constituting a doctoral dissertation “Assessment of the impact of motor exercises according to Bilateral Integration program (by Sheila Dobie OBE) on cognitive functions among early school children with symptoms of Developmental Coordination Disorder (DCD)”.

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Declaration of Figures’ Authenticity

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