Motor Skills Training Program Reinforces Crossing the Body’s Midline in Children with Developmental Coordination Disorder

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Abstract: Midline crossing problems have been associated with children with atypical development. When compared to typical development (TD) children, they are less likely to cross the midline into contralateral space with their preferred hand. A motor skills training program is the most beneficial intervention for children with developmental coordination disorder (DCD). However, there is not enough information on how this intervention will affect crossing the midline. The goal of this study was to find out midline crossing behavior after an intervention program for children with DCD. The Movement Assessment Battery for Children (MABC-2) was used to assess motor coordination, and Bishop’s card-reaching task measured the ability of children to cross the midline. The study included 48 right-handed children, 28 with TD and 20 with DCD (5.17 ± 0.70 years) from four preschools in the Khorezm region (Uzbekistan). Participants identified as having DCD were placed in an experimental group (EG: n = 15), receiving ten weeks of a motor skills training program, and a control group (CG: n = 5). Concerning midline crossing behavior before intervention, DCD children showed more contralateral and less midline right-hand use compared to TD children. After intervention, a significant group × position interaction was found between the EG and CG at positions 1 and 4, and between the EG and TD group at position 4. Concerning the midline reaching, fewer right-hand reaches were made by the EG group compared to the other two groups. The same could be seen at position 1 when compared to the CG group. It can be concluded that, after intervention, DCD children in the EG showed fewer right-hand reaches in the contralateral space, but they improved their right-hand reaches in the midline, showing a similar behavior to TD children.

Keywords: midline crossing; developmental coordination disorder (DCD); motor skills training program; children; laterality

1. Introduction

The midline is a hypothetical line drawn through the center of human bodies. Crossing the body midline is the ability to move over spontaneously with a body part, such as the arms or legs, to reach across the body’s center. The ability to cross the midline indicates that both sides of the brain are communicating, and that the child can coordinate both the left and right sides at the same time, which is required for learning skills and to perform movements efficiently [1]. Subsequently, crossing the midline is a necessary developmental milestone. This is because if the child learns to cross the midline, he/she will become more likely to use the preferred hand, and he/she will keep practicing every day or acquire sports skills more easily [2]. Moreover, the midline of the body has been credited with contributing to the formation of the spatial orientation, bilateral integration, body scheme, directionality, and laterality [2,3], indicating the integration of the body’s midline, which
makes bilateral coordination possible [4]. Postures of gross or body movements, such as standing upright, walking, turning, sitting, or lying, include both halves of the body, moving parallel to, on the opposite side of, or in a circular manner about the central axis of laterality [3]. Additionally, it has been hypothesized that midline behavior plays an important part in the development of ego capabilities [5,6]. These researchers advanced the hypothesis that individuals orient themselves in a manner that is directly tied to their symmetrical structure and that all motions in space are similarly related to this symmetry around the midline.

A developmental trend has been observed in typically developing (TD) children from age 3 to age 8 while crossing the midline for unimanual movements; the number of midline crossings developed with age, with younger children showing a lower incidence of crossing the midline (i.e., doing more right-hand reaches into the right hemispace) [4,7]. Moreover, this trend was independent of gender and the handedness of the participants [8]. When taking into consideration the spatial position of the crossing behavior, midline crossings happened more often near the middle of the body than in the mid-way and farthest positions [8–10].

Failure to participate in an adequate amount of midline behavior in early infancy is a forerunner of difficulties later in life, which, when interacting with other factors, unfold as disturbances in laterality, which may result in a learning disadvantage [5]. Midline crossing problems have been associated with children with atypical development, such as learning disabilities [2,4,11,12], attention deficit hyperactivity disorder and/or autism spectrum disorder [13], down syndrome [14], and developmental coordination disorder (DCD) [15,16]. Results of these studies show that those children tended to make fewer midline crossing reaches, tended to be less ready to cross the midline into contralateral space with their preferred hand, and tended to be less consistent in their hand preference within and across activities. Furthermore, they showed deficits for tasks in the contralateral workspace. A kinematic investigation carried out by Smits-Engelsman [16] provides a rigorous measurement of children with and without DCD in both accuracy and speed when aim-directed movements were made across the midline. In contrast to expectations, this research discovered that DCD children were not preferentially impaired when making movements in a contralateral workspace, even though they were not as good as their peers overall. This supported the findings of Zaia [17] in a reaching task performed by children with and without DCD under normal and perturbed vision. Specifically, in children with DCD, Smits-Engelsman [16] proposed a general neuromotor deficit hypothesis, suggesting that these children have a weakness in movement initiation, and contralateral inaccuracy is added to their overall inaccuracy. These findings are supported by numerous studies [18,19] that have established that children with DCD exhibit an unexplained inability to acquire necessary motor skills, such as maintaining balance or writing, despite the absence of any known medical condition or identifiable neurological disease. Performances of children with DCD tend to be slower, more dependent on vision, and more variable than those of TD children [20]. Nevertheless, for children with DCD, a motor skills training program can enhance the ability of their motor competence [21]. Sherick, Greenman, and Legg [5] stated that external stimulation helps myelination, vascularization, and dendritic arborization in the brain; all of which are thought to be necessary for the brain to reach its genetic potential and work well. Moreover, multiple researchers have stated that hand preference may be associated with sensory–motor experience [22–25]. Consequently, we hypothesized that a motor skill program would provide such stimulation, especially in midline crossing, because of the manual skills (manual dexterity and aiming and catching) activities proposed. Since a relationship has been reported between an inconsistency of using the preferred hand in children with DCD and less frequent use of the preferred hand in tasks requiring reaches across the midline, it was expected that a motor intervention program induces a more consistent handedness behavior expressed by more frequent midline crossing of the preferred hand. To our knowledge, there is no study that has compared midline crossing behavior after an intervention motor program. As a result, the purpose of this study was to
investigate the impact of an intervention program on midline crossing behavior for children with developmental coordination disorder compared to typical development children.

2. Methods

2.1. Study Design

With a control group, a quasi-experimental design was used with pre- and post-test measurements.

2.2. Participants

A selected sample of children from 4 preschools in Urgench (a city in the Khorezm region of Uzbekistan) was recruited during September 2020. The sample comprised 48 right-handed children: 28 (14 male) with TD, and 20 (12 male) with DCD, aged between 4 and 6 years old. Children with learning difficulties or children with attention deficit disorder, prenatal complications, neurological disorders, or sensory problems, preterm infants, and children with epilepsy or other chronic diseases were not included in the study. As a result, none of the participants suffered from any neurological or physical issues. These data were gathered from the preschool records of the children, as well as feedback from their parents. A total of 28 TD children (14 male) had: (1) no evidence of functional motor problems as observed by their teacher; (2) no MABC-2 score at or above the 16th percentile; (3) no serious medical diagnosis reported by parents or relatives; and (4) no cognitive or intellectual impairment as reported by their teacher. On the other hand, seven children (four of them were male) appeared to perform the parameter for DCD. In DSM-5 [26], they scored in the 5th percentile or lower on the MABC-2 (Criterion A), the teacher identified them as having a motor coordination problem (Criterion B), they were 3–6 years old (Criterion C), and their parents or relatives reported no significant medical condition that could affect motor performance, and their teacher confirmed the absence of intellectual or cognitive impairment (Criterion D). Thirteen children (eight male) fell between the 6th and 15th percentile, which means they were at risk for DCD. From these 20 DCD children, 15 children were randomly assigned to the experimental group (EG), and the remaining 5 children were assigned to the control group (CG). Prior to participation, the parents supplied verbal consent and the children provided informed consent. Through the permission given by parents and teachers, we selected 15 children in the EG to be engaged in a 10-week motor skills training program from October to December 2020 (Figure 1).

![Figure 1. CONSORT flow diagram.](image-url)
The approach provided in the MABC-2 was used to assess hand preference. A pen was placed on the table in front of the child, and he/she was asked to make a tiny drawing of a figure.

2.3. Instruments

The Movement Assessment Battery for Children—Second Edition (MABC-2) [27] was used to evaluate DCD. Besides being one of the most common instruments applied in this domain, MABC-2 is an assessment tool that can easily be used in a school setting, being a valid and reliable instrument [28,29]. Moreover, equal validity to the original UK version of the MABC-2 was shown in Greek, German, Japanese, and Thai studies [30–33]. The MABC-2 test is designed to identify and describe impairments in the motor performance of children and adolescents from 3 to 16 years of age, divided into three age bands (3–6 years, 7–10 years, and 11–16 years). The test consists of children completing a series of eight fine and gross motor tasks divided into three subscales: manual dexterity, aiming and catching, and balance [27].

Bishop’s card-reaching task (Quantification of Hand Preference, QHP) was used to evaluate the crossing midline behavior. Bishop and her colleagues proposed a card-reaching test to determine hand preference in 1996 [34]. The test measures the degree and direction of hand preference in a task that allows participants to cross their body midline (Figure 2).

Good metric qualities were found for the QHP [34]. The previous literature suggests that the QHP is a suitable measure of human handedness in children and adults. It should also be noted that the above instrument has been used by many researchers [4,5,10,18,21,35,36].

2.4. Procedures

Participants were intentionally allocated to a predetermined and unbalanced group. The reason for such imbalance was that since data were gathered in four kindergartens, children in one of the kindergartens were assigned to be the CG. As a result, the intervention program was carried out in each of the 3 remaining kindergartens (approximately 5 children in each) by two trained professionals. For ten weeks, children assigned to the EG participated in a 45 min, twice-weekly motor skills training program, with an average of 15 h of training. Each training session had two main parts: a 5 min warm-up and 40 min of working on motor skills. Detailed information about the training sessions can be obtained elsewhere [21]. All sessions were recorded with permission. All children continued to perform their physical education classes and regular classroom activities as scheduled. Moreover, in the EG, the motor intervention program replaced the daily walk of 45 min, an activity besides the physical education classes that all children performed in the indoor facilities of each school. During the study, enrolled children did not attend additional out-of-preschool sports. A variety of functional activities and exercises were used to improve common motor issues experienced by children with DCD, such as poor
agility, balance, core stability, movement coordination, and ball skills. It is worth noting that exercises involving hand skills were performed with each hand and with both hands, enhancing uni- and bi-manual skills. As the training progressed, the motor tasks were modified to ensure successful task execution while also providing a sufficient challenge to the child's motor ability. The assessment in pre- and post-tests was carried out by the same professional and recorded on video.

2.5. Ethics

The research was approved by the Ethics Committee of Urgench State University (Code 12356), in accordance with the recommendations of the Declaration of Helsinki.

2.6. Statistical Analysis

When a card was reached with the right hand at positions 1, 2, and 3, the subject crossed the midline of the body, and position 1 extended into the contralateral hemispace, the furthest point to the left, with position 3 being the closest point to the midline. When a card was reached with the right hand in positions 5, 6, and 7, the children reached into the ipsilateral hemispace, with position 5 being the farthest point to the right, and position 7 being the closest to the body (see Figure 2).

Gender was included as a factor in preliminary analyses, but no significant effect was found for any of the variables analyzed; therefore, data from males and females were pooled. Furthermore, as the number of participants was too small within each age group, with the majority being 5 years old, the age effect could not be analyzed. The hand use for the different groups at the 7 hemispace positions was analyzed by a multivariate analysis ANOVA. Following these analyses, a comparison between pre- and post-intervention was made by a non-parametric Wilcoxon test in each DCD group (EG and CG).

All statistical analyses were performed using SPSS software (SPSS v.25, IBM Corporation, New York, NY, USA). The statistical significance level was set at \( p \leq 0.05 \). Exact \( p \) values are provided. Post hoc comparisons were performed using the LSD (least small difference) procedure [37]. When possible, the size of the statistical effects (partial eta-squared, abbreviated as \( \eta^2 \), which indicates the part of the variance explained by the factor with other non-error sources if the variance is partially led out) [38] has been given.

3. Results

The results before the intervention, in terms of right-hand reaches (Table 1), indicate a main effect of group (\( F(12,82) = 3.514, p < 0.001, \eta^2 = 0.340 \)), and a group \( \times \) position interaction (\( F(10,84) = 4.167, p < 0.001, \eta^2 = 0.332 \)). Post hoc comparisons revealed significant differences between the EG and TD group at position 3 (\( p = 0.049 \)) and 4 (\( p = 0.002 \)). At position 3, more right-hand reaches were made by the EG, and the opposite was observed at the midline, where the DCD group appeared less right-handed than the TD children.

Table 1. Results of right-hand reaches to the hemispace before intervention based on the group type. Number of participants, mean, and standard deviation values.

| Group | EG | CG | TD |
|-------|----|----|----|
| N     | 15 | 5  | 28 |
| Position | Mean | SD | Mean | SD | Mean | SD |
| 1     | 0.67 | 1.18 | 0.80 | 1.10 | 0.32 | 0.82 |
| 2     | 0.47 | 1.10 | 0.00 | 0.00 | 0.39 | 1.00 |
| 3     | 1.27 | 1.49 | 0.40 | 0.89 | 0.50 | 1.04 |
| 4     | 1.87 | 1.25 | 1.89 | 0.70 | 2.71 | 0.54 |
| 5     | 2.87 | 0.52 | 3.00 | 0.00 | 2.93 | 0.38 |
| 6     | 3.00 | 0.00 | 3.00 | 0.00 | 2.93 | 0.40 |
| 7     | 3.00 | 0.00 | 3.00 | 0.00 | 2.93 | 0.40 |
Because of COVID-19, data from the TD group could not be collected after the intervention period, and only the DCD group could be reassessed. So, we decided to compare the results from the pre-intervention time of the TD group and the post-intervention of the DCD groups (experimental and control). The results of the comparisons between the groups, after applying the training program, are as follows (Table 2). A main influence of group was found (F(8,86) = 2.236, p = 0.023, ηp2 = 0.210), as well as a group × position interaction (F(8,86) = 2.801, p = 0.008, ηp2 = 0.207). Post hoc comparisons revealed significant differences between the EG and CG at position 1 (p = 0.015) and 4 (p = 0.040), and between the EG and TD group at position 4 (p = 0.033). Concerning the midline reaching, fewer right-hand reaches were made by the EG group compared to the other two groups. The same could be seen at position 1, when compared to the CG group.

Table 2. Results of right-hand reaches to the hemispace after intervention based on the group type. Number of participants, mean, and standard deviation values.

| Group | EG  | CG  | TD  |
|-------|-----|-----|-----|
| N     | 15  | 5   | 28  |
| Position | Mean | SD  | Mean | SD  | Mean | SD  |
| 1     | 0.00 | 0.00 | 1.00 | 1.40 | 0.32 | 0.82 |
| 2     | 0.00 | 0.00 | 0.00 | 0.00 | 0.39 | 0.99 |
| 3     | 0.20 | 0.77 | 0.40 | 0.89 | 0.50 | 1.04 |
| 4     | 2.20 | 1.08 | 3.00 | 0.00 | 2.71 | 0.53 |
| 5     | 3.00 | 0.00 | 3.00 | 0.00 | 2.93 | 0.38 |
| 6     | 3.00 | 0.00 | 3.00 | 0.00 | 2.93 | 0.38 |
| 7     | 3.00 | 0.00 | 3.00 | 0.00 | 2.93 | 0.38 |

A comparison between pre- and post-intervention in each DCD group, EG, and CG, was made. Results reveal that children in the CG were not different in pre- and post-test (p > 0.050). On the other hand, significant differences in the EG were found only in position 3 (p = 0.020), where, after intervention, fewer right-hand reaches were observed. The frequency of right-hand reaches was plotted for the seven different spatial positions comparing pre- and post-intervention in the EG (see Figure 3).

![Figure 3. Mean number of reaches as a function of the position of the card from the body midline in the EG. Ipsilateral hemispace: positions 5, 6, and 7; midline: position 4; and contralateral hemispace: positions 1, 2, and 3—see Figure 2.](image-url)
4. Discussion

The aim of this study was to investigate midline crossing behavior after an intervention program for children with DCD. For ten weeks, the acquisition and development of motor skills were meticulously applied, and the effectiveness of the motor skills training program for midline crossing was evaluated.

As expected, the results of this study indicate that the frequency of the right-hand use was dependent upon position in hemispace and the group. Typical development participants used the right hand primarily in ipsilateral space and the left hand to reach contralateral space. However, DCD children revealed a different behavior, showing less consistent right-hand use. While in position 3, the DCD group was more often willing to use the right hand, and then cross the hemispace, the opposite occurred in position 4 at the midline, where they exhibited a more inconsistent behavior. Within the TD children, the distribution of hand use in the hemispace indicated that almost all actions were carried out with the dominant hand in the ipsilateral hemisphere, while only a few were performed with the dominant hand in the contralateral hemisphere [39]. However, reaching into the opposite hemispace contralaterally is widespread and may be a result of the development of hand preference [40]. Namely, younger children have a weaker hand preference and are less likely to reach across the middle to grab an object, while older children use their preferred hand more and reach across the middle more often [41]. This stage of skill refining is necessary for creating a hand preference in childhood, supported by developed processing systems such as maturation of the interhemispheric pathways [42]. Concerning the DCD children, findings from this study do not support previous research with DCD children [15]. This was because we noticed that the right hand was less used to cross the contralateral hemispace. The explanation for these opposite results may rely on the age effect, because in Hill and Bishop [15], children were older than in this study. It could be said that reaching across the body’s midline requires more complex motor programming than an ipsilateral reaching behavior. When faced with the choice of making a hard and a more complex movement with the preferred hand, children with poor motor skills will choose the easy movement, using the non-preferred hand in the contralateral hemispace. Another possible explanation was provided by Verfaellie, Bowers, and Heilman [43] and Verfaellie and Heilman, [44] and later supported by Gabbard and Rabb [45]. The hemispheric bias hypothesis proposes a hemisphere (attentional) bias in favor of using the hand on the same side as the stimulus.

Another perspective proposed by Gabbard and Rabb [45] is the kinesthetic hypothesis, which proposes that the individual recognized the biomechanical restrictions (e.g., degrees of freedom) involved in carrying out the task and programmed the pleasant and most efficient response by using the hand closer to the object. This hypothesis was supported by Vasconcelos et al. [46], who found that fewer lateralized children seem to program hand selection based on biomechanical efficiency and proximity to the object to be grasped and not on motor dominance of the preferred hand, as more lateralized children do. Additionally, and according to Liedermen [47], manual midline crossing repeats a transition from extracellular to colossal control of interhemispheric communication and is, therefore, a prerequisite for increasing a skilled dominant hand [43–45]. Hand preference is a behavioral mirror of brain lateralization for handedness; it reveals how strongly a person prefers one hand over the other. In addition, and according to Smits-Engelsman et al. [16], an alternative explanation for the clinical monitor is that impairments for activities in the contralateral workspace are more obvious in DCD children because these children already have a deficit, and contralateral inaccuracy is added to the overall inaccuracy (general neuromotor deficit hypothesis).

After intervention, DCD participants were more willing to use the left hand in contralateral space, and the difference was particularly evident in position 3. Additionally, differences at the midline position were found, where the DCD group appeared to be less right-handed than the TD group, but with an increase in the right-hand reaches, confirming results of other studies [8,14]. The willingness of using the left hand in contralateral space
is in line with results from TD children [8,39], confirming that intervention programs seem to have an effect on the hemispace behavior and midline, showing that DCD children developed a more similar behavior to TD children.

So far, many researchers have tried using different intervention programs to develop motor skills in children with DCD. In a systematic review article, Saidmamatov et al. [36] documented that motor skill training programs are very useful for children with DCD. Moreover, results are scientifically substantiated in another study [21] that postulated a 10-week motor skills training program develops motor skills in children with DCD, and also noted that DCD problems do not go away on their own. Going beyond the investigation of Saidmamatov et al. [21], the present study concluded that a structured 10-week motor training program not only develops motor skills of children with DCD but also helps them to improve their midline crossing process. Additionally, those results partially support the hypothesis of many researchers that hand preference may be related to emotional–motor experience, along with the expected maturational process [22–25]. So, the results justify the initial research hypothesis that a motor skill program would provide external stimulation, especially in midline crossing, because of the manual skills (manual dexterity and aiming and catching) activities proposed. Moreover, the experiment provides new insight into the relationship between a motor skills training program and midline crossing.

5. Conclusions

It can be concluded from this study that right-handed children with DCD, after participating in a motor skills program, reinforced the handedness behavior and acquired the ability to form a left-handed working process in the contralateral space by engaging in an effective intervention program. Furthermore, results from this study demonstrate that by providing developmentally appropriate motor skills, such as crossing the midline of the body, through a structured motor training program, we can help young children build developmental readiness for competitive sports that rely on efficient cross-lateral processing speed.

Study Limitations

Certain limitations must be considered. Some methodological issues limit the validity of the research results, including convenience sampling. This study suffered from the limitations associated with the pandemic caused by COVID-19, which meant TD children were unable to be reassessed. Furthermore, the small sample size of DCD groups, especially in the CG, was also a limitation. The study only involved right-handers, so we suggest the inclusion of left-handed children in future investigations.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics Committee of Urgench State University (protocol code 12356 approved on 7 August 2020).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.
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