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Motor Imagery Training: A Tool to Improve Motor Planning in Children with Developmental Coordination Disorder

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Abstract

Children with Developmental Coordination Disorder (DCD) exhibit deficiencies in motor planning abilities and employ inefficient planning strategies. Motor imagery provides insight into the processes of motor planning and may serve as a beneficial intervention for improving action planning in children with DCD. Therefore, the aim of the present study was to investigate the impact of a motor imagery training program on the motor planning of children with DCD. Motor imagery training was implemented in two groups of children, one with DCD and one without. The ability to perform motor imagery was assessed using a task of End State Comfort (ESC). The study employed an experimental design with a pre-post-test format, involving 36 children with DCD aged 7-12 years, who were randomly assigned to experimental (n=18) and control (n=18) groups. The sword task was used to evaluate action planning in this study, employing a combined intervention of explicit and implicit imagery. The results of a repeated measures analysis of variance revealed a significant difference between the control and experimental groups ($p=0.008$), indicating that the experimental group demonstrated better planning strategies for end state comfort compared to the control group. These findings suggest that motor imagery training has the potential to improve motor planning in children with DCD.

Keywords: Developmental Coordination Disorder, Motor Imagery, Motor Planning.



Introduction

Overview of Developmental Coordination Disorder (DCD): Developmental Coordination Disorder (DCD) is a condition that affects children without any cognitive or neurological impairments, leading to difficulties in learning, development, and motor control. During motor activities, children with DCD often exhibit weaker motor skills compared to their peers, which imposes significant limitations on their daily lives. Recently, DCD has attracted serious attention from a variety of specialists, including physicians, psychologists, pediatricians, and experts in movement behavior. This increasing focus is likely due to the secondary consequences that arise from the inefficiencies associated with this disorder (Adams et al., 2014; Faal & Ghassemi, 2017; Lotfi et al., 2017).

Challenges Faced by Children with DCD: Empirical data indicates that individuals with Developmental Coordination Disorder (DCD) commonly exhibit delays in responsiveness to sensory stimuli, an increased reliance on visual feedback (Barnhart et al., 2003), deficiencies in spatial visual processing (Lee et al., 2017), and challenges in coordinating academic activities, including writing, drawing, and fine motor skills. Physically, children with Developmental Coordination Disorder (DCD) often lack the necessary readiness and are notably overweight or obese. Consequently, these children encounter difficulties in learning new motor skills and exhibit delays in motor development (Wilson et al., 2013). These outcomes lead to weakened motor skills and reduced motivation to participate in physical activities. Such factors underscore the importance of early diagnosis and intervention for this disorder, as well as the need to address the multifaceted requirements of this group of children.

The Role of Internal Modeling in Motor Skills: One of the hypotheses proposed for the weakness in the motor skills of children with Developmental Coordination Disorder (DCD) is a deficiency in predictive internal modeling, a notion supported by numerous studies. It is suggested that motor imagery training may help improve internal modeling. In performing motor tasks, the initial selection of the type of grip is determined by task constraints, goals, and intentions.

Action Planning and Grasping: Action planning refers to the processes of selecting movement patterns from among several possible forms of movement to achieve a goal (Bhoyroo et al., 2019). Among the most important theories in motor control are the internal model's theory, which consists of predictive modeling and inverse modeling. Inverse models facilitate action planning, while predictive modeling is used for the simultaneous and online control and correction of movements by predicting the body state after execution and the sensory consequences of the action. Many movements, including throwing and reaching, require both types of modeling. The initial phase of reach movements is controlled by both mechanisms, while the final phase, which is linked to sensory feedback loops, is governed by predictive modeling to allow adjustments at the endpoint of the trajectory when movement speed decreases (Hadnett, 2015; Teymuri Kheravi et al., 2018). These models provide a framework for ensuring the selection of an appropriate movement pattern and facilitate comfortable end-state effects. One method of evaluating action planning is through selective grasping tasks that facilitate the end-state comfort of the action. This effect is related to the tendency to grasp in a manner that allows for easier movements at the endpoint, even if comfort during initiation or throughout the movement is compromised. Razenbam et al. (2001) argued that

the state and form of grasping at the endpoint may be determined before the initiation of movement. Reviews conducted by Wilson (2013) and Adams (2014) suggest that one possible hypothesis for the motor difficulties in children with Developmental Coordination Disorder (DCD) is a weakness in generating and utilizing internal modeling. Consequently, action planning becomes incomplete, leading individuals to rely on slow feedback control. This weakness diminishes the learning ability of children with DCD (Adams et al., 2014; Wilson et al., 2013). Longitudinal studies have shown that motor impairments in these children, likely rooted in internal modeling deficits, can lead to persistent emotional, social, academic, and learning problems into adulthood (Adams et al., 2014).

The Promise of Motor Imagery: Motor imagery refers to the ability to represent (model) a movement without any overt physical action. The anticipation of sensory outcomes from visualized actions appears to necessitate the activation of the predictive modeling component of various internal models (Bhoyroo et al., 2019). In typically developing children, the efficiency of motor imagery is associated with a greater tendency to experience comfort at the endpoint of the action. Although this association is not observed in children with DCD, when asked to grasp and rotate an object, many choose a strategy that minimizes hand movement and rotation at the initiation to avoid discomfort at the endpoint. In sequential tasks, action planning with a precise definition of motor commands from a subset of movements is necessary for predicting sensory outcomes (Johansson & Flanagan, 2009). A study by Stöckel et al. (2012) examined action planning and the development of cognitive representations of grasping in typically developing children aged 7 to 9. The study found that mental representation training of specific grasping states improved the level of comfort at the endpoint in these children (Stöckel et al., 2012). Adams et al. (2017) also indicated, in a longitudinal study comparing the developmental trajectory of action planning in children with DCD to typically developing children, the inferiority of children with DCD relative to their age-matched peers. They found that this functional deficit is amenable to improvement over time. Therefore, it appears that training involving action representations, especially motor imagery, along with appropriate training programs, may be beneficial for developing internal modeling and action planning. Motor imagery is considered one of the valid and valuable methods for describing the internal modeling state, and it has been utilized in studies related to children with DCD (I. L. Adams et al., 2016; Adams et al., 2017; Ter Horst et al., 2010). Evidence indicates that the ability to engage in motor imagery is a prerequisite and crucial indicator for implementing concurrent modifications in reaching performance in both typical individuals (Hyde et al., 2013) and children with DCD (Fuelscher et al., 2015). Through anticipatory estimation of limb positions, motor imagery facilitates the rapid integration of afferent and efferent signals, thereby accelerating perceptual-motor responses. In goal-directed reaching actions, if intervention movements are introduced or if noticeable changes in the environment are detected by the visual system, the nervous system generates rapid adjustments in the movement trajectory during the flight phase. Concurrent and immediate modifications rely on the individual's ability to compare the potential sensory consequences of the impending action (based on the anticipatory internal model) with actual sensory feedback. In adults, motor imagery has contributed to improved sports performance and enhanced rehabilitation for individuals who have suffered strokes (Adams, 2018).

Research Objectives and Contribution to the Field: Therefore, the researcher aims to answer the question of whether motor imagery training can assist in the construction and development of internal models, addressing one of the hypotheses related to the deficiencies in motor skills of

children with Developmental Coordination Disorder (DCD). The effectiveness of motor imagery training on internal modeling may offer an intervention and solution for the common challenges faced by children with Developmental Coordination Disorder (DCD), while also shedding light on the cognitive processes underlying their deficits. If these exercises prove effective, they could significantly impact the quality of life and long-term developmental outcomes for these children. Considering longitudinal studies that highlight the potential for the development of internal modeling among children with Developmental Coordination Disorder (DCD), the effectiveness of motor imagery training may elucidate the role of cognitive strategies in addressing the challenges faced by these children. This provides evidence of the positive impact of motor imagery training on this population and suggests content for their therapeutic programs, emphasizing the importance of early interventions and the need to monitor long-term effects fundamental to future interventions. The goal of the study is to examine the impact of motor imagery training on the development and construction of motor representations, as well as the improvement of internal modeling in children with DCD.

Methodology

Population and Sampling

The current research employed an experimental design utilizing a pretest-posttest approach with a control group. The statistical population of the study comprised students aged 7 to 12 years in government girls' elementary schools in Region 3 of the Education Department in Tabriz during the academic year 1400-1401. The sample size was determined using G*Power software (version 3.1), considering a minimum power of 80%, a significance level of 5%, and the necessary effect size for repeated measures analysis of variance. The minimum required sample size was identified as 36 participants. Children with Developmental Coordination Disorder (DCD) were identified and selected based on specific inclusion and exclusion criteria. After identification, each child was randomly assigned to either the experimental or control group, with each group consisting of 18 participants. The criteria for selecting children with DCD, according to the DSM-5, involved the initial identification of children with movement problems by teachers (Criterion B - DCM-5) using the PMOQ-T questionnaire, which included 60 participants. The assessment of the identified children continued using the DCD-Q7 parent form (Criterion C, DCM-5) (Cools et al., 2009; Smits-Engelsman et al., 2015). Finally, the children who achieved the necessary scores at this stage (44 participants) were evaluated by the researcher using the MABC-2 test. Those scoring below the 16th percentile on the MABC-2 test (a total of 36 participants) were identified as having DCD (Badami et al., 2015; Salehi et al., 2016). Participants had no prior learning, psychological, or neurocognitive disabilities. Children with conditions that could potentially affect their performance were excluded from the study, with confirmation from a child and adolescent psychiatrist (Criterion D - DSM-5). None of the participants had prior familiarity with the specific tasks in the research. The questionnaires, tests, research protocol, and parental consent form were approved by the research and ethics committee, the Department of Education, and Payame Noor University.

Assessments

In this study, the Developmental Coordination Disorder Questionnaire (DCDQ-7), the Persian Movement Observation questioner for teachers (PMOQ-T), and the Movement Assessment Battery for Children (MABC) were used to identify children with DCD. For motor imagery



training, the software version of the Hand Rotation Task and a motor imagery training program based on previous studies were employed. To assess the dependent variable of motor planning functions, the Sword Displacement Task was used to measure the end-state comfort effect.

Developmental coordination disorder questioner

The scale for assessing parental awareness of motor control, gross and fine motor skills, and general coordination in children aged 5 to 15 consists of 15 questions, scored on a 5-point Likert scale, with a total score range of 15 to 75. According to DCD-Q7 assessment scores, children aged 5-7 years with scores between 15 and 46, children aged 8-9 years with scores between 15 and 55, and children aged 10-15 years with scores between 15 and 57 are classified as having or being susceptible to DCD. The reliability coefficients of this questionnaire, assessed through internal consistency (Cronbach's alpha) and test-retest reliability, are reported as 0.83 and 0.85, respectively. Additionally, concurrent validity is established with two subscales—object manipulation and object control—from the Movement Assessment Battery for Children-2, with correlation coefficients of 0.65 and 0.60, respectively (Snapp-Childs et al., 2015; zarezade et al., 2016).

Teachers' Movement Observation Checklist

This checklist comprises 18 items assessing the gross and fine motor skills of children aged 5 to 11, using a 4-point Likert scale with a score range of 18 to 72. The total score, based on teacher evaluations, is interpreted using a percentile system. Children whose overall scores fall within the 16th to 100th percentiles are considered within the healthy range, while those scoring at or below the 15th percentile are identified as at risk. In a normative study conducted on a sample of 505 male elementary school students and their teachers, the reliability of the checklist was reported as 0.91 (Salehi et al., 2012).

Movement assessment battery for children (MABC-2)

This test serves as a tool for identifying movement disorders, particularly for diagnosing children with Developmental Coordination Disorder (DCD) (Henderson, 1992). The assessment evaluates static and dynamic balance skills (such as single-leg balance, walking on a straight line with heel-to-toe steps, and consecutive jumps), catching and throwing skills (catching a tennis ball and throwing a beanbag), and fine motor skills (placing pins, stringing, and drawing mazes) across three age groups: 3-6 years, 7-10 years, and 11-16 years. Raw scores are converted into standard scores, which are further transformed into overall standard scores and percentile ranks. Individuals scoring below the 15th percentile are considered to have DCD. The test's validity has been reported at 80% in Iran (Akbaripour et al., 2018).

Hand Rotation Task

This program is primarily designed to assess the motor imagery abilities of children. In this task, participants determine the direction of rotation of a hand-shaped stimulus from various perspectives (front and back). When participants use motor imagery to visualize their own hand to determine the direction of rotation, this indicates the use of motor imagery. To evaluate motor imagery in children, a software program for two-dimensional image rotation of the palm and back of the hand (dimensions 9 × 8 cm) was created using the standalone PsychoPy program. Images were randomly rotated from 0 to 360 degrees in 45-degree increments (Adams et al., 2017). Each participant completed five initial practice trials followed by 80 trials for the main test, with ten trials at each angle (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°, 360°).

180°, 225°, 270°, and 315°). The average reaction time for each rotation angle and each clockwise and counterclockwise condition was calculated for each participant. Data from children who completed at least half of their trials were included in the analysis (Adams et al., 2017; Butson et al., 2014).

Sword task for action planning

This assessment is designed to evaluate action planning in children aged 3-12. It involves a wooden sword (dimensions: length 18 cm, width 2 cm, thickness 1.2 cm) with a 9.5 cm handle. The setup also includes a box (dimensions: 27x13x13 cm) featuring a hole (20.8 cm) for sword insertion, and a sheet of paper (30x28 cm) displaying a design with six possible positions for placing the sword. Initially, the sword is positioned according to the six available slots. Four positions (1, 4, 5, and 6 for right-handed children, or 1, 2, 3, and 4 for left-handed children) correspond to general and control conditions, while the remaining two positions (2 and 3 for right-handed children, or 5 and 6 for left-handed children) represent special conditions. Each child completes one practice trial in position 1 before starting the main assessment. During the main test, each position is randomly repeated three times, resulting in a total of 18 trials per participant. In special conditions, achieving a comfortable starting position requires compromising on the comfort of the end position. Conversely, in control conditions, ease of movement extends seamlessly from start to finish. A comfortable end position is indicated when the sword points toward the box, while an inappropriate end position is indicated when the sword points away from it. Children are instructed to grasp the sword by its handle and insert it into the box hole. Special conditions require careful action planning. The total score for the assessment is calculated based on comfortable posture scores for the end position across both special and control conditions. The test shows a test-retest reliability coefficient of 0.9 and an inter-rater reliability coefficient of 0.95 (Adams et al., 2017; Craje et al., 2010; Jongbloed-Pereboom et al., 2016).

Procedure

Following the selection and random assignment of children with Developmental Coordination Disorder (DCD) into two experimental groups (motor imagery training) and a control group, each comprising 18 participants, an initial assessment of the action planning abilities of the two experimental groups was conducted during the pre-test phase. The experimental group participated in 8 weeks of motor imagery training, which involved two sessions per week, each lasting 30 minutes. The duration of the program and the frequency of the sessions were determined based on previous studies and considerations regarding the accessibility for the students. Both groups engaged in daily educational activities. The motor imagery training programs utilized were the mental rotation exercise for the hand (I. L. Adams et al., 2016; EbrahimiSani et al., 2020; Toussaint et al., 2013) and motor imagery exercise (Wilson et al., 2016; Wilson et al., 2002), consistent with prior research. The latter covered six fundamental skills: catching a tennis ball, throwing a tennis ball, hitting a baseball, jumping in pairs, maintaining a ball on a racket while walking, and placing objects in designated locations based on their shapes. Children were instructed to watch a video demonstration of these skills performed by a peer (an expert model) of similar age at least two times. During the video, the instructor provided additional instructional points related to the execution of each skill. After viewing each skill, the video was paused, and children were encouraged to visualize and imagine both their own execution and that of their peer. The video playback speed remained constant for all participants, with occasional pauses for further explanations. At the end of each imagery training session, the children positioned themselves in the actual execution situation and made two attempts at each skill. Approximately 20 minutes were

allocated for practicing this program, with an additional 10 minutes dedicated to mental rotation task practice. The researcher carried out the random allocation of participants to the groups. Training and practice sessions, as well as pre-tests and post-tests, were administered under the supervision of the researcher in collaboration with two trained specialists in physical education in a school playground. Before participating in the training program, consent and necessary approvals were obtained from both the children and educational authorities. Following the mental imagery exercises, the post-test phase involved re-evaluating the motor planning abilities of both groups. There were no missing values, and the data from all participants were included in the analysis.

Statistical Analysis

The independent t-test was used to examine differences in age, intelligence quotient (IQ), and scores from the MABC-2, DCDQ, and PMOQ-T. The Shapiro-Wilk test was employed to assess the normality of the data distribution. Key assumptions, including the normality of errors, homogeneity of variances (evaluated using Levene's test), and independence of errors (assessed with Mauchly's test of sphericity), were thoroughly examined. To examine the research hypotheses during the pre-test and post-test stages, a repeated measures analysis of variance (ANOVA) was conducted, incorporating a 2-level group factor and a 2-level time factor. The assumptions for this analysis, including the normality of error distribution (assessed using the Shapiro-Wilk test), constant variance of errors (evaluated with Levene's test), and non-significant correlations among errors (checked using the Durbin-Watson test and Box's M test for homogeneity of covariance matrices), were verified and met ($p > 0.05$). All hypothesis tests were conducted at a significance level of 0.05. Statistical analyses were performed using SPSS software (version 26).

Results

Using the independent t-test, it was determined that during the pre-test stage, there were no statistically significant differences between the two groups regarding age, percentile rank scores on the MABC-2, and scores on the DCDQ and PMOQ-T questionnaires ($p > 0.05$). The findings from the comparison of the two groups in the pre-test stage for the selected indicators are summarized in Table 1. The p-values obtained from the independent t-test for each variable were all greater than 0.05, indicating no significant differences between the experimental and control groups at the pre-test stage for the selected indicators.

Table 1. The results of comparing two experimental and control groups in terms of intelligence quotient, age, mABC-2 test score, DCDQ, and PMOQ-T.

	Group	M±Sd	df	t	P value
MABC-2 percentile score	DCDE	6.95±5.3	34	-1.79	0.08
	DCDC	5.84±4.1			
age	DCDE	8.9±1.07	34	0.09	0.09
	DCDC	8.9±1.2			
DCDQ scores	DCDE	48.4±4.5	34	0.15	0.87
	DCDC	48.15±5.7			
PMOQ-T scores	DCDE	39.05±5.7	34	-1.46	0.15
	DCDC	41.75±5.9			

Children with Developmental Coordination Disorder-Control group (DCD-C), children with Developmental Coordination Disorder-Experimental group (DCD-E), Developmental Coordination Disorder Questionnaire (DCDQ), Persian version of movement Observation for Teachers (PMOQ-T), Movement assessment battery for children (mABC-2).

The Effect of a Motor Imagery Training Program on Action Planning

To investigate the effect of the motor imagery training program on action planning in two groups (control and experimental), a repeated measures (2x2) analysis of variance (ANOVA) was conducted, incorporating a between-subjects factor (group) and a within-subjects factor (time) across two pre-test and post-test periods. The results, presented in Table 2 and Figure 1, indicated significant main effects for both the group and time factors, as well as an interaction effect. Using a one-way analysis of variance (ANOVA), it was determined that there was no significant difference between the two groups in the pre-test stage ($p = 0.325$). However, in the post-test stage, a significant difference was found between the experimental group and the control group, $F(1,35) = 21.6; P < 0.001$. Additionally, the control group did not show a significant difference between the pre-test and post-test stages ($p = 0.13$), while the experimental group demonstrated significant improvement compared to the pre-test, $t(17) = -5.65; P < 0.001$.

Table 2. The results, derived from the analysis of variance with repeated measurements on the dependent variable of action planning, between the two groups across two stages: pre-test and post-test.

		Wilks' Lambda	F	df	P value	Partial Eta Squared
action planning	group	-	10.3	(1,34)	.003	.23
	time	.58	24.5	(1,34)	<.001	.42
	Time*group	.83	6.89	(1,34)	.013	.16

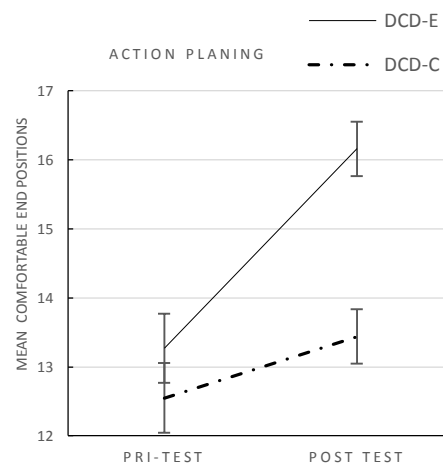


Figure 1. Performance of the experimental and control groups in action planning during the pre- and post-test stages

The p-values obtained from the statistical analyses indicate significant differences, demonstrating that the motor imagery training program had a substantial impact on action planning in the experimental group compared to the control group.

Discussion and conclusion

The objective of this research was to investigate the impact of Motor Imagery (MI) training on action planning in children with Developmental Coordination Disorder (DCD). To achieve this, the study examined the effects of motor imagery training—specifically hand rotation (implicit imagery)—combined with explicit motor imagery training on action planning in two experimental groups and one control group. The results indicated a significant positive difference in the action planning ability of the experimental group compared to the control group. It can be inferred that a combination of explicit and implicit motor imagery exercises enables children with Developmental Coordination Disorder (DCD) to develop and enhance their action planning abilities and internal model creation. Overall, based on the obtained results, we conclude that the strategy of internal modeling through motor imagery exercises in children with DCD is effective. Furthermore, the potential of exercises and interventions related to motor imagery can be harnessed to shape internal representations and improve action planning in these children. The obtained results align with previous studies, including those by Boviro et al. (2019) and Ebrahimi et al. (2020), providing evidence for the role of motor imagery exercises in developing internal modeling and action planning. Boviro and colleagues (2019) utilized explicit motor imagery with instructional guidance, while Ebrahimi and colleagues (2020) employed virtual reality exercises for imagery to investigate action planning in children with DCD. In the current study, a combination of implicit and explicit motor imagery exercises was used to examine action planning. It has been demonstrated that, in typically developing children, the effectiveness of motor imagery is associated with a greater tendency to attain a comfortable end position of action (action planning) (Bhoyroo et al., 2019; Fuelscher et al., 2016). Therefore, it can be inferred that the improvement in action planning functions in children with DCD, influenced by motor imagery exercises, is associated with the advancement of motor imagery abilities. This progression activates the predictive modeling cycle through motor imagery, resulting in an increased comfort effect at the endpoint of the action in the targeted task. To explain the role of motor imagery training in developing and enhancing motor skills, one can point to the functional equivalence and correlation between motor imagery and actual motor execution. According to the PETTLEP model (Physical, Environment, Task, Timing, Learning, Emotion, Perspective) introduced by Holmes and colleagues in 2001, motor imagery processes share the same physiological and neural mechanisms as real movements, providing a plausible explanation for the role of imagery in performance improvement. According to the PETTLEP model, motor imagery should encompass seven components for maximum efficacy: physical presence, environmental similarity, task similarity, timing similarity, matching learning stages, emotional factors, and perspective (Imke LJ Adams et al., 2016). At the neurocognitive level, motor imagery engages neural networks, including the premotor and parietal cortex, which are associated with action planning and execution. Motor imagery essentially involves the internal simulation of actual movements. Motor imagery has functional equivalence with real movements at multiple levels: neural (activation of motor areas in the frontal, parietal, and premotor regions), behavioral (speed and accuracy trade-off), physiological (changes in heart rate), and computational (predictive modeling of sensory outcomes) (Reynolds et al., 2015). Internal predictive modeling is considered a computational unit essential for precise and rapid execution. These models encode the dynamics of body segments in relation to the environment and predict the consequences of voluntary actions. This means that when a motor command is generated, a copy is sent to the predictive model, which then anticipates the body's post-execution state and the sensory consequences of the upcoming action (Imke LJ Adams et al., 2016). Given the relationship between motor imagery and motor planning, the

overlap of neural structures involved in these processes, and the enhancement of motor imagery ability through specific instructions, motor imagery training could serve as an effective intervention strategy for improving action planning skills in children with DCD. In addition to supporting skill development, motor imagery reflects an individual's capacity to plan movements and utilize anticipatory internal models (Reynolds et al., 2015). One challenge faced by children with DCD in anticipatory control is their reduced ability to mentally visualize motor actions from a first-person perspective (Gabbard, 2009). Using motor imagery from a first-person perspective encourages performers to assess task constraints, enabling them to internally represent appropriate bodily states for the task and facilitating a comfortable end position of the action (Bhoyroo et al., 2019). An important aspect of human interaction involves predicting the actions of others. According to the framework of predictive processing, inferring the intention and purpose of an observed action while minimizing prediction error occurs at all levels of the cortical hierarchy during the observation and execution of actions. Mirror neuron systems are activated both during the execution and observation of actions, playing a crucial role in these processes. These mirror neuron systems are located in the premotor areas, subcortical motor areas, and the superior parietal gyrus, with reciprocal connections between them. Engaging in purposeful activity training promotes neuroplasticity and changes in brain structures, particularly in the frontal, premotor, and parietal regions. Neuroplasticity via the mirror neuron system occurs during both real observation and execution of actions. In motor imagery training, individuals activate mirror neurons by observing their own actions and those of others, as well as by performing the same actions. This results in the activation of mirror neurons and the formation and strengthening of representational cycles of actions in similar cortical regions (Badia et al., 2013; Wuang et al., 2011). There is a clear association between perception and action.

Comparing mirror neuron activity in skilled and novice athletes during observation and prediction tasks reveals greater dysynchronization of mu waves (an index of mirror neuron activity) in skilled individuals compared to novices. Gaining experience in virtual reality environments and self-observation, compared to the control group, seems to enhance the performance of the mirror neuron system, which is effective in predictive motor control. Individuals' experience and expertise lead to variations in mirror neuron activity levels. Skilled individuals utilize their internal predictive models to recognize environmental information, whereas novices lack such developed internal models (Denis et al., 2017). According to motor learning theory, motor learning and retraining occur through repetitive exercises and functional activities in various environmental conditions, along with the provision of appropriate feedback.

The improvement in performance among children with Developmental Coordination Disorder (DCD) resulting from intervention exercises, such as motor imagery exercises, can be attributed to the repetitive nature of the exercises and the availability of multiple feedback sources. Furthermore, the observation and imitation of movements enhance the plasticity of the nervous system through mirror neurons (MEDICA, 2018). In the motor imagery task (mental rotation of the hand) used in this study, which involves directionality and judgment of stimulus type, the ability to represent the expected action coordinates is essential. The progress of children with DCD in the experimental group on the targeted task indicates an increased ability to activate mental representations and internal actions. It appears that specific task training leads to the activation of internal representation cycles, which are effective in predictive modeling.

Although the increase in mirror neuron activity has been inferred in this study to lead to the activation of internal representations, this inference requires further investigation. Given that cognitive functions may impact internal modeling, future studies should examine the effects of motor imagery exercises on executive functions and working memory. Additionally, it is recommended to explore the consolidation, transfer, and application of acquired abilities in the daily activities and motor skills of children with DCD through motor imagery training. Therefore, based on the studies that highlight the potential for the development of internal modeling functions (Imke LJ Adams et al., 2016; Hyde et al., 2014) and the findings of previous research (Bhoyroo et al., 2019; Reynolds et al., 2015), along with the current study on the effectiveness of motor imagery training for action planning in children with DCD, it appears that we can effectively utilize the high capacity of motor imagery training, both implicitly and explicitly. Additionally, by extensively employing the PETTLEP imagery model and activating the first-person perspective—which results in greater activation of mirror neurons—we can enhance the action planning ability of children with DCD. It seems that through motor imagery training, children with DCD were able to construct and develop motor representations. Alongside actual execution, they utilized visual and tactile information to make accurate predictions about their movements and reduce prospective planning errors. It is recommended that coaches integrate explicit and implicit motor imagery training into their sessions, emphasizing a first-person perspective to enhance children's anticipation of movements. This approach helps children assess task constraints and prepare their bodies. Furthermore, motor imagery training may improve action planning abilities in children with Developmental Coordination Disorder (DCD), boosting their confidence and engagement in physical activities for a more positive experience in sports and skill acquisition.

Conclusion

In conclusion, based on the results of the current study, it can be inferred that motor imagery training has been effective in improving and maintaining the functions of internal modeling and motor planning in children with Developmental Coordination Disorder (DCD). The progress in internal modeling functions likely contributes to enhanced motor control and the performance of skills that depend on such control. Therefore, motor imagery training is recommended as a cost-effective, efficient, and implementable intervention method for children with DCD in both home and educational environments. The findings of this study are crucial for rehabilitation specialists and educational professionals working with these children. Given that some previous studies have highlighted motor skill deficits in children with DCD compared to typically developing children and the impact of motor imagery training on improving their motor skills, future studies should further investigate the differences between these groups. Additionally, examining the transfer of acquired abilities to daily activities warrants exploration. As research in this field is still in its early stages, the obtained results serve as a starting point. Further research is necessary to confirm and expand upon these findings.

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