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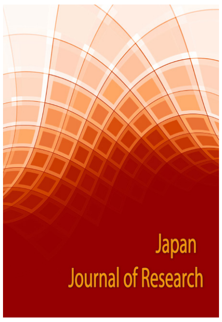

Visuomotor Skills, Executive Functions, and Academic Performance: A Comparative Analysis of Children With Developmental Coordination Disorder And Typical Development

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Abstract

Developmental Coordination Disorder (DCD) is known for impairments in performing and learning motor skills, and these impairments interfere with a child's daily life, school development, and leisure. A child with DCD tends to have impairments in visual input called visuomotor adaptation and deficits in inhibitory control, working memory, and planning, and these functions are related to executive functions (EF). These impairments are studied and demonstrate that children with typical development (TD) develop within the expected range for their age and improve throughout childhood. The objective of this study was to conduct a comparative analysis between children with DCD and children with TD to analyze and compare visuomotor skills, performance in the speed of sequential naming of common stimuli, reading comprehension skills, and academic performance through the application of reliable tests with a standardized norm. Children from 10 public schools in the northern region of Santa Catarina, Brazil, were recruited, and 230 children were selected, of whom 98 met all four criteria for the diagnosis of DCD, comprising 44 girls and 54 boys. The remaining 132 children were classified as a control group, called the TD group, comprising 74 girls and 58 boys, who participated in the application of the following tests: Nine Hole Peg Test (NHPT), which assesses visuomotor skills; Rapid Automated Naming (RAN) test, which evaluates the speed of sequential naming of common stimuli; Expository Text Reading Comprehension Assessment Test, which assesses comprehension skills; and a test to evaluate academic performance with 20 questions. Through a statistical analysis of each test, our results revealed differences between children with DCD and children with TD in visuomotor skills, rapid automatized naming, reading comprehension, and academic performance.

Introduction

Human beings are in constant interaction, which fosters the acquisition and improvement of various skills. Performing daily tasks requires precision and efficiency in each process, as well as the mastery of fundamental motor skills [1]. When motor demands are adequately met during a task, new motor achievements can emerge through necessary adaptations [2]. However, if these skills do not reach age-appropriate milestones, task execution may be impaired or result in outcomes that are suboptimal for the individual or their environment [3]. In children, such motor demands are particularly evident during school activities, where required skills directly influence academic performance and also play a crucial role in social interactions and participation in activities such as recess games and physical education [4].

Research has categorized procedural perceptual-motor learning into two main types: motor sequence learning and motor adaptation. Motor sequence learning involves the gradual improvement of movements, leading to the efficient execution of novel motor sequences [5]. In contrast, motor adaptation is the ability to adjust to environmental constraints or modify an internal motor representation [6]. During the learning process, motor skills progressively become more automated through repetitive practice, resulting in representational changes within neural networks [7,8]. Both forms of procedural learning engage similar brain structures during initial stages, such as motor cortical areas, prefrontal and parietal regions, the striatum, and the cerebellum [9,10]. Once consolidated, however, the learned skill is distributed across distinct network systems: the cortico-striatal system for motor sequence learning and the cortico-cerebellar system for

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motor adaptation [11]. Depending on the specific skill and stage of learning, one system may dominate over the other [12].

Children with Developmental Coordination Disorder (DCD) experience significant challenges in performing perceptual-motor tasks. Evidence shows that these children often write faster than their peers with typical development, yet their writing exhibits lower spatial precision and greater variability in trigram production [13]. Such difficulties are consistently observed in writing tasks performed by children with DCD [14]. The prevalence of DCD among school-aged children is estimated at 5% to 6% [15].

Visuomotor adaptation, a process involving motor adjustment in response to visual inputs, is often impaired in individuals with DCD [16]. This type of adaptation is mediated by the cerebellum, and cerebellar dysfunctions have been linked to several neurodevelopmental disorders, including DCD [17,18]. Research findings suggest that children with DCD exhibit increased movement oscillations alongside reduced movement accuracy and motor speed, indicating decreased motor proficiency [19].

DCD is characterized by significant impairments in the acquisition and execution of motor skills, independent of any underlying medical condition or neurological disorder [14,15]. Motor performance and learning are considerably below what is expected for age and developmental level [20]. These coordination difficulties are not attributable to intellectual disabilities or visual impairments and substantially interfere with daily activities, academic achievement, and leisure pursuits [21]. Children with DCD typically display motor deficits in both fine and gross motor tasks, which are closely associated with poor performance in reading, writing, and mathematics [22,23]. Furthermore, these motor impairments are linked to deficits in core cognitive functions, such as inhibitory control, working memory, and planning, all of which are integral components of executive functioning (EF). While children with typical development exhibit continuous improvements in EF throughout childhood, those with DCD demonstrate persistent deficits that negatively impact their academic performance and overall functional abilities.

Materials and methods

Participants

Initially, 603 children (277 girls and 326 boys) aged 8 to 9 years (mean age = 8.54 years) were invited to participate in the study. These participants were recruited from 10 public schools in the northern region of Santa Catarina, Brazil.

Participant selection adhered to strict inclusion and exclusion criteria, as outlined below:

- Demonstrated proficient school performance, as verified by official documents issued by the pedagogical team of their respective schools.
- Had an estimated Intelligence Quotient (IQ) above 80, assessed using the Wechsler Intelligence Scale for Children (WISC-IV).
- Current use of psychoactive medication.
- Presence of significant symptoms of inattention, hyperactivity, or impulsivity, as assessed by the SNAP-IV scale.
- Diagnosed with visual or auditory disorders, heart disease, orthopedic conditions, or behavioral disorders, as identified through medical evaluation during the study.
- Diagnosed with disabilities, syndromes, neurodevelopmental disorders, or other neurological conditions.

Following the initial screening, 133 children were excluded due to significant symptoms identified through the SNAP-IV evaluation. Additionally, 80 children were excluded for presenting diagnoses of disabilities, syndromes, neurodevelopmental disorders, or other neurological conditions. Another 160 children were excluded for scoring below 80 on the IQ assessment using the WISC-IV. As a result, 230 children were deemed eligible for inclusion in the study.

Of these 230 participants, 98 children met all four criteria for the diagnosis of Developmental Coordination Disorder (DCD), comprising 44 girls and 54 boys. The remaining 132 children, who did not meet the criteria for DCD diagnosis, were classified as the control group, referred to as the Typically Developing (TD) group, comprising 74 girls and 58 boys.

Procedures

Visuomotor Skills

To assess visuomotor skills, the Nine Hole Peg Test (NHPT) was employed as a standardized, quantitative assessment designed to measure hand-eye coordination and fine motor abilities. The test involves a square wooden board with nine holes arranged in a 3x3 grid and nine cylindrical pegs. The holes are evenly spaced 3.2 cm apart, with a depth of 1.3 cm and a diameter of 0.71 cm. The pegs measure 0.64 cm in diameter and 3.2 cm in length [24].

For this study, the NHPT was conducted using only the participant's preferred hand (P). The board was positioned on a stable table directly in front of the participant, centered at midline. Participants were instructed to remove all the pegs from the holes and then replace them one by one as quickly as possible.

Prior to the test, a brief demonstration was provided by the evaluator to ensure clear understanding of the procedure. Participants were given an opportunity to practice the task once with their preferred hand to familiarize themselves with the instrument.

The assessment was conducted in a quiet environment at room temperature, with only the participant and a trained evaluator present to minimize distractions and ensure consistency. Participants were seated comfortably, with their feet flat on the floor or supported by an adjustable wooden block if necessary. During the task, the non-preferred hand could be used to stabilize the board to prevent sliding. Timing began as soon as the participant touched the first peg and ended when the last peg was returned to the container. The NHPT score was recorded in seconds, representing the time required to complete the task using the preferred hand.

Rapid Automatized Naming

The Rapid Automatized Naming (RAN) test continuously measures performance in the sequential naming speed of common stimuli, specifically the speed with which a child sequentially verbalizes a list containing basic symbols. The test is composed of subtests for naming colors, digits, letters, and objects. In the present study, only the color-naming subtest was utilized [25].

This subtest consists of the following colors: green, red, yellow, black, blue, and yellow. The participant was required to name the colors as quickly as possible. The test was administered only after confirming that the child recognized all the colors to be presented.

The evaluation took place in a quiet, well-lit room within the school environment. The child was seated comfortably with their feet flat on the floor. If the child could not reach the floor, a footrest was provided to ensure stable support. The child was allowed to point to the colors but was instructed not to remove the test sheet from the table.

Comprehension Skills

The children were submitted to the Expository Text Reading Comprehension Assessment Test. This test is a compilation of texts tailored to each grade level of Elementary School. For the present study, considering the age group and grade of the participants, the text "O Bebê Elefante" was used [26].

The children were instructed to read the text following specific guidelines provided by the evaluator, which included:

- Keeping the text on the table throughout the entire reading process;
- Maintaining proper body posture during the evaluation;
- Starting the reading and continuing to the end of the text without interruptions, as any interruption would require restarting the reading.

During this analysis, the total reading time was recorded. Pauses caused by coughing, throat clearing, or nasal congestion due to colds were disregarded.

The evaluation was conducted in a well-lit room within the school environment, with only the child and a trained member of the research team present to ensure the assessment was performed under standardized and controlled conditions.

The videos were played in the software and the excerpts that presented pauses were excluded through the resources of the aforementioned software. Speed was calculated by words read per minute.

Academic Performance

Participants underwent an academic performance (AP) assessment through a test comprising 20 questions, including 10 focused on Portuguese language skills and 10 on mathematical abilities. The questions were selected from an item bank of the Basic Education Evaluation System (SAEB), ensuring the pedagogical relevance and rigor of the instrument. To maintain randomness, each child received a unique, randomized test, ensuring no evaluation was identical to another participants [27].

The assessment was administered in the participants' own classrooms, in a well-lit and organized environment designed to minimize external interference. The evaluation team consisted of two trained assessors, members of the study, who adhered to a standardized protocol to ensure process uniformity. Notably, the assessors had no prior knowledge of which children belonged to the DCD group or the TD group, ensuring impartiality and objectivity during the assessment process.

Statistical Analysis

For the statistical analysis, data were compared across several variables, including visuomotor skills (NHPT - Nine Hole Peg Test), rapid automatized naming (RAN - Denckla Test), reading comprehension skills, and academic performance (AP). The analyses differentiated between children with developmental coordination disorder (DCD) and those with typical development (TD). All variables were treated as continuous and analyzed using descriptive statistics, including mean, standard deviation (SD), standard error of the mean (SEM), coefficient of variation (CV), and confidence intervals (CI). These measures provided a detailed overview of central tendency, dispersion, and variability for each group.

To evaluate differences between the DCD and TD groups across all variables, an independent samples t-test was conducted. This approach allowed for the identification of statistically significant differences between the groups. Statistical significance was set at $p < 0.01$ to ensure the robustness of the findings. The analyses aimed to provide a comprehensive understanding of the impact of DCD on motor coordination, cognitive-linguistic abilities, and academic performance, highlighting the interrelationship between motor and cognitive development in children.

Results

When observing Table 01 regarding performance in the Visuomotor NHPT (Nine Hole Peg Test), the minimum and maximum values indicate that the TD group took between 14.72 and 24.49 seconds to complete the test, while the DCD group presented a significantly wider range, between 22.57 and 63.06 seconds. This greater range of times in the DCD group suggests more pronounced variability in performance.

The mean times further highlight a clear difference between the groups. The TD group completed the task in a mean of 19.45 seconds, while the DCD group required 40.48 seconds, more than twice the time. This reflects the motor difficulties associated with DCD. The standard deviation (SD) reinforces the greater data dispersion in the DCD group, with a value of 12.30 seconds compared to just 2.989 seconds in the TD group. Furthermore, the standard error of the mean (SEM) was lower in the TD group (0.3151 seconds), indicating greater precision in the mean estimates compared to the DCD group (1.297 seconds). Finally, the coefficient of variation (CV), which measures relative variability concerning the mean performance, was 15.37% for the TD group and 30.40% for the DCD group. This higher value in the DCD group demonstrates substantial heterogeneity in the performance of children in this group, contrasting with the greater consistency observed in the TD group.

In summary, the data reveal striking differences between the two groups. Children with DCD exhibit significantly higher times, greater dispersion, and variability in performance, characteristics consistent with the expected motor difficulties in this condition. Statistical analysis, using the t-test for two independent samples, revealed a significant difference between the groups, with $t = 15.76$, $df = 178$, and $p < 0.01$, confirming the relevance of the observed differences (Figure 1a).

When evaluating the ability for rapid automatized naming through the Denckla test, Table 01 shows the performance in this assessment. The minimum and maximum values indicate that the TD group completed the task in times ranging from 24.09 to 39.95 seconds, while the DCD group showed times ranging from 29.86 to 79.70 seconds, revealing a greater range and variability in performance in the latter group. The mean times further support a substantial difference between the two groups: TD children completed the task in a mean of 31.95 seconds, while DCD children required 56.33 seconds, nearly double the time. The standard deviation, which measures data dispersion, was 4.604 seconds in the TD group and 13.78 seconds in the DCD group, confirming that the performance in the DCD group is more heterogeneous. Furthermore, the standard error of the mean was lower in the TD group (0.4853 seconds) compared to the DCD group (1.452 seconds), indicating greater precision in the mean estimate for the TD group.

Table 01*: Statistical Comparison Between TD and DCD Groups in Performance Variables*

Variables	Groups	Minimum	Maximum	Mean	Standard Deviation	Standard Error	Coefficient of Variation
Visuomotor Skills – NHPT	TD	14,72	24,49	19,45**	2,98	0,31	15,37%
	DCD	22,57	63,06	40,48	12,30	1,29	30,40%
RAN	TD	24,09	39,95	31,95**	4,60	0,48	14,41%
	DCD	29,86	79,70	56,33	13,78	1,45	24,46%
Comprehension Skills	TD	53	74	63,60**	5,98	0,63	9,40%
	DCD	40	68	52,93	7,64	0,80	14,45%
Academic Performance	TD	11	19	15,31**	2,31	0,24	15,09%
	DCD	7	13	10,17	2	0,21	19,69%

** p <0.01 in one sense for intergroup comparisons TD X DCD

The coefficient of variation also highlights this difference in consistency: the TD group presented a CV of 14.41%, while the DCD group had a CV of 24.46%, reinforcing the greater relative variability in the performance of children with DCD. Statistical analysis, conducted through the t-test for two independent samples ($t = 15.92$, $df = 178$, $p < 0.01$), revealed significant differences between the two groups, confirming that children with DCD exhibited significantly higher execution times, greater dispersion, and superior relative variability compared to children with TD (Figure 1b).

Regarding the results obtained in the Reading Comprehension assessment, the TD group demonstrated superior performance, with minimum and maximum values ranging from 53 to 74 words per minute, while the DCD group presented values ranging from 40 to 68 words per minute. In terms of means, children in the TD group read an average of 63.60 words correctly per minute, while children in the DCD group achieved a mean of 52.93 words per minute, highlighting a clear difference in performance between the groups.

The analysis of standard deviation reveals greater dispersion in the DCD group (7.646) compared to the TD group (5.983), indicating higher variability in the results within the DCD group. This difference is corroborated by the coefficient of variation, which was 14.45% in the DCD group, in contrast to 9.407% in the TD group.

In summary, the data reflect those children in the TD group demonstrated better performance and greater consistency in reading, while children in the DCD group faced more difficulties, with higher variability in the number of words read correctly per minute. This difference was statistically confirmed through a t-test for two independent samples, with $t = 10.42$, $df = 178$, and $p < 0.01$, reinforcing the significance of the differences observed between the groups (Figure 1c).

Finally, when analyzing the results related to academic performance (AP), the TD group obtained scores ranging from 11.00 to 19.00 points, while the DCD group showed a smaller range, from 7.00 to 13.00 points. In terms of means, the TD group achieved a mean of 15.31 points, while the DCD group scored 10.17 points, indicating a significant difference in academic performance between the two groups.

The standard deviation was 2.311 for the TD group and 2.001 for the DCD group, reflecting slightly greater dispersion in the TD group. Nonetheless, the standard error of the mean was low in both groups, with values of 0.2436 for the TD group and 0.2110 for the DCD group, indicating good precision in the mean estimates. The coefficient of variation revealed a higher relative variability in the DCD group (19.69%) compared to the TD group (15.09%), suggesting greater heterogeneity in the performance of the DCD group.

In summary, the data show that children in the TD group exhibit superior and more consistent academic performance compared to children in the DCD group, who display more pronounced difficulties and greater variability in their results. This difference was statistically confirmed through a t-test for two independent samples, with $t = 15.96$, $df = 178$, and $p < 0.01$, further emphasizing the significance of the differences observed (Figure 1d).

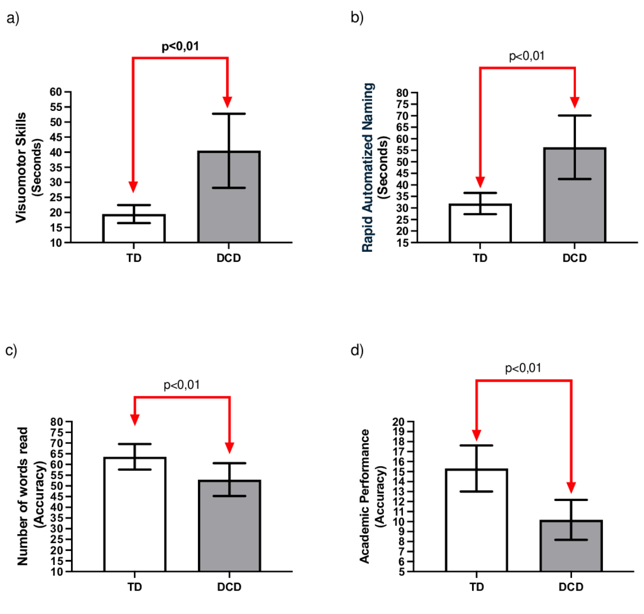

Figure 1. Comparison of Visuomotor Skills, Rapid Automatized Naming, Reading Comprehension, and Academic Performance between Children in the TD (n = 132) and DCD (n = 98) Groups. *The graphs represent the mean and standard deviation values for: (a) Visuomotor Skills - NHPT (Nine Hole Peg Test); (b) Rapid Automatized Naming - RAN (Denckla Test); (c) Reading Comprehension Skills; and (d) Academic Performance. Statistically significant differences were identified between the groups (p < 0.01) using the t-test for two independent samples.*

Discussion

The NHPT (Nine Hole Peg Test) results demonstrated significant differences in performance between children with typical development (TD) and those with developmental coordination disorder (DCD), emphasizing the motor challenges associated with DCD. Children in the DCD group required more than twice the time to complete the task compared to the TD group, with average times of 40.48 and 19.45 seconds, respectively. This difference reflects well-documented motor impairments in DCD, including reduced precision, increased effort, and prolonged task execution times for activities requiring fine motor coordination [28,29].

Comparable results have been observed in studies investigating visuomotor adaptation in children with DCD [29,30,31]. While their performance on internal modeling and visuomotor adaptation tasks was similar to that of TD children, execution times were notably more inconsistent, and their movement precision and motor speed were diminished [21]. These findings indicate that DCD impacts not only motor efficiency but also the consistency of task performance [32].

Research has shown that children with DCD experience deficits in sensorimotor integration, which negatively affect their ability to plan and execute complex motor tasks [33]. These deficits may account for the slower and less precise performance observed in tasks like the NHPT, which require fine motor coordination and controlled movements within a confined space [14,34,35].

Additionally, evidence suggests that children with DCD frequently rely on compensatory strategies, such as breaking movements into smaller segments or depending more heavily on visual feedback to complete motor tasks. While these strategies enable task completion, they often result in longer execution times and decreased motor efficiency, aligning with findings that highlight the motor challenges faced by children with DCD.

The statistical significance of the differences between the groups ($t = 15.76$; $p < 0.01$) underscores the relevance of motor limitations in DCD. These results highlight the need for targeted interventions to improve visuomotor skills in children with DCD. Programs based on intensive motor training and sensory feedback could be particularly effective in reducing performance variability and improving movement precision [34- 36].

The results of the RAN test indicated striking differences between the TD and DCD groups. Children in the DCD group exhibited significantly higher and more variable times, with a mean of 56.33 seconds, while children in the TD group completed the task with a mean of 31.95 seconds. This substantial difference reflects difficulties related to automated processing and verbal fluency in children with DCD. Our findings demonstrated that children with DCD performed significantly worse on visuospatial working memory tasks, such as the RAN test (Denckla), compared to TD children [34-37]. These results are consistent with previous studies that highlight greater difficulty with visuospatial executive function tasks compared to verbal tasks in children with DCD [38]. The relationship between motor difficulties and visuospatial limitations was evident even in a task like the RAN, which involves minimal motor demands [39,40]. Nevertheless, the reduced performance observed in children with motor difficulties, compared to the TD group, aligns with prior findings using similar assessments [41,42].

These visuospatial difficulties are corroborated by the inferior performance in the NHPT, reinforcing that the visuomotor limitations characteristic of DCD directly contribute to deficits in automated naming tasks [35,36,41,42]. These findings align with literature suggesting that motor deficits can interfere with executive functions, including working memory [43,44]. The connection between motor skills and working memory supports the hypothesis that motor difficulties may limit the ability to store and manipulate information, negatively impacting performance in tasks reliant on these cognitive functions [45-47].

Additionally, the interaction between working memory and language skills may contribute to the inferior performance observed in the DCD group [40,47,48]. Working memory is known to constrain the amount of information that can be processed simultaneously. In children with developmental challenges, these limitations can lead to delays in word retrieval and difficulties in planning sequential tasks, ultimately increasing the time required to complete naming tasks [42,44,45]. This aligns with findings that associate working memory deficits with challenges in tasks demanding rapid and sequential processing, such as automated naming [43,46,47].

This is further supported by our reading comprehension results, which indicated superior performance by the TD group, with a higher mean of correctly read words per minute (63.60) compared to the DCD group (52.93). This significant difference ($t = 10.42$; $p < 0.01$) reflects reading difficulties often reported in children with DCD, which may be related to deficits in visual and motor coordination essential for fluent reading [49]. Previous research suggests that children with motor coordination difficulties experience challenges with inhibitory control, working memory, and planning [50,51].

Reading comprehension, for instance, requires a complex integration of visuomotor skills and executive functions, such as planning, information retention, and coordination of eye movements during reading [52]. Our results revealed that children with DCD performed worse in this skill, reflecting difficulties in motor coordination and the ability to quickly process and interpret information [44,53]. These limitations extend to overall academic performance, where children with DCD also showed significantly lower results compared to TD children, emphasizing the impact of motor and cognitive limitations in the school environment [53,54].

Completing motor and academic tasks often requires understanding different approaches to execute activities, whether in adopting strategies for school tasks or resolving social conflicts, such as interactions with peers and teachers [55]. These demands, involving both motor skills and executive functions, present substantial challenges for children with DCD, hindering their full participation in school and physical activities [56].

The study's findings revealed distinct executive function profiles in children with DCD compared to TD children, with more pronounced difficulties in tasks combining executive and motor demands. These limitations were evident not only in inferior performance on tests like the NHPT but also in reading and academic performance evaluations. This underscores the need for interventions addressing these interconnected areas, such as programs integrating motor and cognitive challenges into practical activities.

Difficulties in reading comprehension and academic performance in children with DCD may be related to challenges in visuomotor processing, affecting fluency and accuracy in executing school tasks, rather than being solely the result of general cognitive limitations [55,57,58]. These children often struggle to recognize patterns and differences in textual information and academic activities, leading them to allocate more visual attention and time to complete these tasks [59,60. Consequently, these difficulties directly affect their ability to interpret texts, solve problems, and organize information efficiently, limiting their capacity to analyze different perspectives and structure coherent responses in academic tasks, while negatively influencing participation in activities requiring visuomotor processing and sensory integration [55-60].

These findings highlight the importance of specific interventions combining executive and motor tasks, such as structured practice activities involving dual tasks. Such interventions can help improve learning mechanisms, promote better academic performance, and facilitate the social and educational integration of children with DCD.

Conclusion

This study highlighted significant differences between children with Developmental Coordination Disorder (DCD) and those with Typical Development (TD) across visuomotor skills, rapid automatized naming, reading comprehension, and academic performance. The findings underscore the pervasive impact of DCD on both motor and cognitive functions, demonstrating that children with DCD exhibit slower, less precise, and more variable performance compared to their TD peers.

Visuomotor deficits, as evidenced by the NHPT, directly influence tasks requiring fine motor coordination, while challenges in rapid automatized naming and reading comprehension highlight the interconnected nature of motor, cognitive, and linguistic skills. These limitations extend to broader academic performance, further emphasizing the multifaceted challenges faced by children with DCD.

The study's results reinforce the importance of implementing targeted interventions that integrate motor training and cognitive strategies to improve the visuomotor and executive function abilities of children with DCD. Such programs can enhance not only academic performance but also the overall quality of life and social participation of these children. Future research should explore longitudinal approaches to intervention effectiveness and further investigate the interplay between motor and cognitive deficits in this population.

Conflicts of Interest

The authors declare no conflicts of interest related to this study.

References

1. Makaruk H, Porter JM, Webster EK, et al. The FUS test: a promising tool for evaluating fundamental motor skills in children and adolescents. BMC Public Health. 2023;23:1912.
2. Hill PJ, McNarry MA, Mackintosh KA, et al. The influence of motor competence on broader aspects of health: a systematic review of the longitudinal associations between motor competence and cognitive and social-emotional outcomes. Sports Med. 2024;54(2):375-427.
3. Fuschlberger T, Leitz E, Voigt F, et al. Stability of developmental milestones: insights from a 44-year analysis. Infant Behav Dev. 2024;74:101837.
4. Liu D, Huang Z, Liu Y, et al. The role of fundamental movement skills on children's physical activity during different segments of the school day. BMC Public Health. 2024;24:1283.
5. Jefferson-Buchanan R. Teaching fundamental movement skills through play-based pedagogy. J Phys Educ Recreat Dance. 2022;93(8):28-33.
6. Jefferson-Buchanan R. Teaching fundamental movement skills through play-based pedagogy. J Phys Educ Recreat Dance. 2022;93(8):28-33.
7. Kogan E, Lu J, Zuo Y. Cortical circuit dynamics underlying motor skill learning: from rodents to humans. Front Mol Neurosci. 2023;16.
8. Koester D. The (cognitive) future of motor control and learning. Front Sports Act Living. 2023;5:1181808.
9. Geiger LS, Wüstenberg T, Zang Z, et al. Longitudinal markers of cognitive procedural learning in fronto-striatal circuits and putative effects of a BDNF plasticity-related variant. NPJ Sci Learn. 2024;9:72.
10. Zhang P, Duan L, Ou Y, et al. The cerebellum and cognitive neural networks. Front Hum Neurosci. 2023;17:1197459.
11. Park S, Kim J, Kim S. Corticostriatal activity related to performance during continuous de novo motor learning. Sci Rep. 2024;14:3731.
12. Anderson DI, Lohse KR, Videira Lopes TC, et al. Individual differences in motor skill learning: past, present and future. Hum Mov Sci. 2021;78:102818.
13. Smits-Engelsman B, Denysschen M, Lust J, et al. Which outcomes are key to the pre-intervention assessment profile of a child with developmental coordination disorder? A systematic review and meta-analysis. Biomed J. 2024;100768.
14. Gao J, Song W, Zhong Y, et al. Children with developmental coordination disorders: a review of approaches to assessment and intervention. Front Neurol. 2024;15:1359955.
15. Li H, Ke X, Huang D, et al. The prevalence of developmental coordination disorder in children: a systematic review and meta-analysis. Front Pediatr. 2024;12:1387406.
16. Knaier E, Meier CE, Caflisch JA, et al. Visuomotor adaptation, internal modelling, and compensatory movements in children with developmental coordination disorder. Res Dev Disabil. 2023;143:104624.
17. Rinat S, Izadi-Najafabadi S, Zwicker JG. Children with developmental coordination disorder show altered functional connectivity compared to peers. Neuroimage Clin. 2020;27:102309.
18. Gill KK, Lang D, Zwicker JG. Cerebellar and brainstem differences in children with developmental coordination disorder: a voxel-based morphometry study. Front Hum Neurosci. 2022;16:921505.
19. Al-Yahya E, Esser P, Weedon BD, et al. Motor learning in developmental coordination disorder: behavioral and neuroimaging study. Front Neurosci. 2023;17:1187790.
20. Meachon EJ, Zemp M, Alpers GW. Developmental Coordination Disorder (DCD): relevance for clinical psychologists in Europe. Clin Psychol Eur. 2022;4(2):e4165. doi:10.32872/cpe.4165.
21. Pinero-Pinto E, Romero-Galisteo RP, Sánchez-González MC, et al. Motor skills and visual deficits in developmental coordination disorder: a narrative review. J Clin Med. 2022;11(24):7447.
22. Danna J, Lê M, Tallet J, et al. Motor adaptation deficits in children with developmental coordination disorder and/or reading disorder. Children. 2024;11(4):491.
23. Persson I, Sampaio F, Samkharadze T, et al. Impact of developmental coordination disorder in childhood on educational outcomes in adulthood among neonatal intensive care recipients: a register-based longitudinal cohort study. BMJ Open. 2023;13(9):e071563.
24. de Lala NRS, Cardoso FB. Validation study for the Brazilian population of the Nine Hole Peg Test visumotor evaluation instrument. Eur J Med Health Sci. 2022;4(3):34-37.
25. Denckla M, Rudel R. Rapid automatized naming (RAN): Dyslexia differentiated from other learning disabilities. Neuropsychology. 1976;14(1):471-479.
26. Saraiva RA, Moojen SMP, Munarski R. Avaliação da

compreensão leitora de textos expositivos para fonoaudiólogos e psicopedagogos. São Paulo: Casa do Psicólogo; 2006.

27. Cardoso FB, Loureiro VS, Souza S, et al. The effects of neuropsychopedagogical intervention on children with learning difficulties. Am J Educ Res. 2021;9(11):673-677.
28. Nobusako S, Osumi M, Furukawa E, et al. Increased visual bias in children with developmental coordination disorder: evidence from a visual-tactile temporal order judgment task. Hum Mov Sci. 2021;75:1-12.
29. Norouzi Seyed Hosseini R, Norouzi E, Soleymani M. Effects of quiet eye training on performance of bimanual coordination in children with DCD. Iran J Child Neurol. 2021;15:43-54.
30. Rafique SA, Northway N. Reliance on visual feedback from ocular accommodation on motor skills in children with developmental coordination disorder and typically developing controls. Hum Mov Sci. 2021;76:1-10.
31. Delgado-Lobete L, Montes-Montes R, Pértega-Díaz S, Santos-Del-Riego S, Hartman E, Schoemaker MM. Motor performance and daily participation in children with and without probable developmental coordination disorder. Dev Med Child Neurol. 2022;64:220-7.
32. Barhoun P, Fuelscher I, Kothe EJ, He JL, Youssef GJ, Enticott PG, et al. Motor imagery in children with DCD: a systematic and meta-analytic review of hand-rotation task performance. Neurosci Biobehav Rev. 2019;99:282-97.
33. Smits-Engelsman B, Verbecque E. Pediatric care for children with developmental coordination disorder, can we do better? Biomed J. 2022;45(2):250-64.
34. Valverde AA, Araújo CRS, Magalhães LC, Cardoso AA. Relationship between visual-motor integration and manual dexterity in children with developmental coordination disorder. Cad Bras Ter Ocup. 2020;28(3):890-9.
35. Morghade S, Qureshi MI, Kovela RK. Developmental coordination disorder, impact of fine motor skills on handwriting and academic performance in school-going children: a research protocol. J Pharm Res Int. 2021;33(59A):847-52.
36. Li R, Fu H, Zheng Y, Gou S, Yu JJ, Kong X, et al. Behavior analysis with integrated visual-motor tracking for developmental coordination disorder. IEEE Trans Neural Syst Rehabil Eng. 2023;31:2164-73.
37. Orefice C, Cardillo R, Lonciari I, Zoccante L, Mammarella IC. "Picture this from there": spatial perspective-taking in developmental visuospatial disorder and developmental coordination disorder. Front Psychol. 2024;15:1349851.
38. Wang C-H, Tseng Y-T, Liu D, Tsai C-L. Neural oscillation reveals deficits in visuospatial working memory in children with developmental coordination disorder. Child Dev. 2017;88:1716-26.
39. Lin CC, Hsieh SS, Huang CJ, Kao SC, Chang YK, Hung TM. The unique contribution of motor ability to visuospatial working memory in school-age children: evidence from event-related potentials. Psychophysiology. 2023;60(3):e14182.
40. Leonard HC, Bernardi M, Hill EL, Henry LA. Executive functioning, motor difficulties, and developmental coordination disorder. Dev Neuropsychol. 2015;40(4):201-15.
41. Tsai CL, Chang YK, Hung TM, Tseng YT, Chen TC. The neurophysiological performance of visuospatial working memory in children with developmental coordination disorder. Dev Med Child Neurol. 2012;54:1114-20.
42. Gentle J, Shakur A, Ivanova M, Gilligan-Lee K. Navigation abilities and spatial anxiety in individuals with and without developmental coordination disorder (DCD/Dyspraxia). Res Dev Disabil. 2024;146:104672.
43. Lachambre C, Proteau-Lemieux M, Lepage JF, Bussières EL, Lippé S. Attentional and executive functions in children and adolescents with developmental coordination disorder and the influence of comorbid disorders: A systematic review of the literature. PLoS One. 2021;16(6):e0252043.
44. Fogel Y, Stuart N, Joyce T, Barnett AL. Relationships between motor skills and executive functions in developmental coordination disorder (DCD): A systematic review. Scand J Occup Ther. 2023;30(3):344-56.
45. Bernardi M, Leonard HC, Hill EL, Botting N, Henry LA. Executive functions in children with developmental coordination disorder: a 2-year follow-up study. Dev Med Child Neurol. 2018;60(3):306-13.
46. Wallinheimo AS, Gentle J. Maths performance of adults with and without developmental coordination disorder (DCD): the role of working memory and maths anxiety. Acta Psychol (Amst). 2024;247:104292.
47. Maleki S, Alizadeh Zarei M. Correlation between executive function behaviors and educational achievement of children with developmental coordination disorder. Middle East J Rehabil Health Stud. 2016;3(3):e37378.
48. Alloway TP, Archibald L. Working memory and learning in children with developmental coordination disorder and specific language impairment. J Learn Disabil. 2008;41(3):251-62.
49. Di Brina C, Averna R, Rampoldi P, Rossetti S, Penge R. Reading and writing skills in children with specific learning disabilities with and without developmental coordination disorder. Motor Control. 2018;22(4):391-405.
50. Joyce T, Vanzan S, Stuart N, Barnett A. Inhibition skills in children with developmental coordination disorder. Dev Neuropsychol. 2023;48(4):147-61.
51. Michel E, Molitor S. Fine motor skill automatization and working memory in children with and without potential fine motor impairments: an explorative study. Hum Mov Sci. 2022;84:102968.
52. Cheng HC, Chen JY, Tsai CL, Shen ML, Cherng RJ. Reading and writing performances of children 7–8 years of age with developmental coordination disorder in Taiwan. Res Dev Disabil. 2011;32(6):2589-94.
53. Couto-Fortuna B, Machado MO, Araújo CRS, Cardoso AA, Magalhães LC. Cognitive motor therapy: description and clinical analysis of children with developmental coordination disorder (DCD). Cad Bras Ter Ocup. 2023;31:e3340.
54. Dionne E, Majnemer A, Beauchamp MH, Brossard-Racine M. Factors associated with mathematical capacity in children with developmental coordination disorder. Res Dev Disabil. 2024;147:104710.
55. Harrowell I, Hollén L, Lingam R, Emond A. The impact of developmental coordination disorder on educational achievement in secondary school. Res Dev Disabil. 2018;72:13-22.
56. Meachon EJ. Perspective: Acknowledging complexity to advance the understanding of developmental coordination disorder. Front Hum Neurosci. 2023;16:1082209.
57. Wilson P, Ruddock S, Rahimi-Golkhandan S, Piek J, Sugden D, Green D, Steenbergen B. Cognitive and motor function in developmental coordination disorder. Dev Med Child Neurol. 2020;62(11):1317-27.
58. Van Dyck D, Baijot S, Aeby A, De Tiège X, Deconinck N. Cognitive, perceptual, and motor profiles of school-aged children with developmental coordination disorder. Front Psychol. 2022;13:860766.
59. Sumner E, Hutton SB, Kuhn G, Hill EL. Oculomotor atypicalities in developmental coordination disorder. Dev Sci. 2018;21:e12501.
60. Van Dyck D, Deconinck N, Aeby A, Baijot S, Coquelet N, De Tiège X, et al. Atypical procedural learning skills in children with developmental coordination disorder. Child Neuropsychol. 2023;29(8):1245-67.