


The Role Of Fine Motor Abilities In Reading Components: A Cross-Sectional Study In Children With And Without Dyslexia

How to Cite This Article: Barghandan R , Dadgar H , Raji P, Maroufizadeh S. The Role Of Fine Motor Abilities In Reading Components: A Cross-Sectional Study In Children With And Without Dyslexia. Iran J Child Neurol. Autumn2023; 17 (4): 23-33

**Reza BARGHANDAN, MSc, SLP¹,
Hooshang DADGAR, PhD, SLP²,
Parvin RAJI, PhD³,
Saman MAROUFIZADEH,
PhD³**

1. Department of Speech therapy, School of Rehabilitation, Tehran University of Medical Sciences, Tehran, Iran.

2. Department of Occupational Therapy, School of Rehabilitation, Tehran University of Medical Sciences, Tehran,

3. Department of Biostatistics, School of Nursing and Midwifery, Guilan University of Medical Sciences, Rasht, Iran.

Corresponding Author

Dadgar H. PhD
Assistant Professor,
Department of Speech therapy,
School of Rehabilitation,
Tehran University of Medical
Sciences, Tehran, Iran.
Email: hdadgar@tums.ac.ir

Abstract

Objectives

This study aimed to investigate the relationship between fine motor skills and reading components and compare the fine motor skills of normal children and children with dyslexia.

Materials & Methods

In this study, 47 children with dyslexia children and 47 normal children in the first to the third grade of elementary school in the age range of seven to nine years were examined with the Bruininks-Oseretsky Test of Motor Proficiency and NEMA reading test. Data were analyzed using Kolmogorov-Smirnov, Shapiro-Wilk, U Mann-Whitney methods, multiple linear regression, and Spearman correlation coefficient.

Results

The results showed children with dyslexia were significantly weaker in fine motor skills than normal children ($p < 0.001$). In addition, a relationship existed between the subtest of response speed and reading accuracy in normal children, but it was in normal children. A significant relationship was found between visual-motor control subtests and Upper-limb speed and dexterity with reading accuracy and speed. None of the motor subtests were related to reading comprehension. In children with dyslexia, no association was found between motor subtests and reading components.

Received: 26-Jun-2022

Accepted: 04- Dec-2022

Published: 26-Oct-2023

Conclusion

Seemingly, fine motor skills can be used as an essential factor along with other effective factors in improving the reading skills of children with reading disabilities.

Keywords: Reading, Motor skills, Fine motor, Dyslexia

DOI: 10.22037/ijcn.v17i4.38710

Introduction

Developmental dyslexia is a common neurological condition defined as a specific and persistent disability to acquire efficient reading skills despite appropriate economic-cultural and educational opportunities, natural intelligence, and healthy sensory abilities (1-3). This disorder is characterized by difficulties with accurate and/or fluent word recognition and poor spelling and decoding abilities (4). Developmental dyslexia is the most common learning disability, and its prevalence varies from 5% to 17.5% due to overlap with such disorders as speech impairment, attention deficit, and developmental coordination (5, 6). The results obtained from more than four decades of extensive research have shown that dyslexia is a biological syndrome that affects reading and can be inherited. Brain imaging studies also indicate detailed differences in symmetry, laterality, and gray matter volume in children with dyslexia compared to normal ones (7). Reportedly, children with dyslexia show minimal brain dysfunction associated with a general learning disability (5). Although phonological deficits are considered the leading cause of reading problems, dyslexia is now defined as a problem beyond reading disorder. Therefore, most people believe that phonological deficits have more basic causes, which should be sought in visual, auditory, and motor domains (7,

8). Various hypotheses have been presented to justify dyslexia, including visual impairment (9), phonological deficit (10), linguistic processing deficit (11), auditory processing deficit (12), deficits in the speed of information processing (5), and cerebellar deficit hypothesis (13).

A theoretical interpretation of the co-occurrence of movement disorders and dyslexia is the cerebellar deficit hypothesis, first presented by Nicolson et al. in 2001. The question at hand is why a structure, primarily associated with motor functions, could be the cause of a reading disorder. (4, 13). However, recent studies of motor skills, the cerebellum's complementary role in cognitive and language skills and its connection with the frontal, prefrontal, and temporal regions can provide a more substantial theoretical interpretation for reading and writing disorders (7, 14). This hypothesis is based on the observation of children with dyslexia who often show a range of movement disorders such as clumsy, imbalance, and poor hand coordination (15).

Based on the evidence that children with dyslexia have sensory-motor deficits, proposedly, dyslexia may have a cerebellar cause. However, other studies have shown that structural neuronal changes in people with dyslexia are not limited to the cerebellum and affect several brain areas. For example, the posterior parietal cortex and

cerebellum are jointly involved in visual-motor processing, and these visual-motor skills are significantly associated with academic achievement in reading and mathematics(3, 16).

The cerebellum plays an active role in language functions such as reading(17). Potential reading-dependent cerebellar functions include attentional guidance, error detection, sequencing, and scheduling. The cerebellum's role in planning and predicting activities for fluent reading is also essential(10). Cerebellar activity has been observed in reading or reading-related tasks. This hypothesis also refers to the cerebellum's contribution to reading skills through two indirect processes: phonological/ articulatory ability and skill automation (18). The results obtained from behavioral tests and brain imaging techniques such as PET, SPECT, and MRI also support structurally and metabolically the role of the cerebellar deficit in developmental dyslexia (1, 6, 19-21). To explain the hypothesis of cerebellar defects, we can refer to many studies that have suggested motor disorders in children with dyslexia. Accordingly, Lerner (1997) stated that 70% of children with dyslexia suffer from motor defects(22), and also Kaplan et al. 63% of children with dyslexia reported(23). Undeniably, a meta-analysis of 17 studies found that motor deficits were associated with dyslexia but may not be directly related(15). Studies of co-occurring clinical cases have revealed motor disorders with other neurodevelopmental disorders in 40% of the cases(24). Hill (1998) indicated that 72 children aged 5 to 13 years were divided into four groups: Children with specific language impairments, children with motor coordination disorders, children in the control group who were age-matched, and children younger in the control group. Children with specific language impairments

struggle with motor tasks significantly(25). The results of Wolfe's studies show that people with dyslexia have problems performing tasks that require finger integration(26). Various studies of children with poor reading have shown signs of gaucherie and poor fine motor control(27).

Recent studies show that fine motor skills in the early years predict future academic achievement, specifically reading and math, and are also linked to school adaptation, appropriate social behavior, second-grade classroom interaction, and literacy skills(28). A study by Suggate (2018) of 144 children with an average age of 6.1 years shows that fine motor skills are related to reading skills, including reading words, non-words, and high-frequency words, and writing, but do not play a significant role in early reading development(27). Additionally, brain imaging shows that motor learning problems in people with dyslexia are associated with cerebellar abnormalities and report fine motor learning as a factor in academic success(29, 30).

In addition to playing an essential role in coordination and motor skills, the cerebellum plays a key role in cognitive skills (5). Since people with dyslexia are significantly impaired in a wide range of cerebellar cognitive processes, cerebellar dysfunction can be considered a significant factor contributing to the co-occurrence of reading disabilities and movement disorders (2). Despite many studies examining motor deficits in children with dyslexia, none have examined the relationship between the motor and the reading variables involved. Studies show the association of motor items associated with cerebellar function with reading accuracy, reading comprehension, and reading speed. As described, motor disorders are relatively common in people with dyslexia, and

if dyslexia is associated with other disorders, we will see more motor problems. This study aimed to investigate the relationship between the fine motor skills and reading components and to compare fine motor skills of normal and children with dyslexia.

Materials & Methods

2.1. Participants

The present research was a cross-sectional study. The study population comprised 7-9-year-old children with dyslexia (35 boys and 12 girls) and normal children (23 boys and 24 girls). The sample was selected available using the convenience sampling method. Inclusion criteria for children with dyslexia and normal children included being third-grade students of the elementary school, right-handed, monolingual Persian-speaking students, having no intellectual disability, sensory-motor disorders, and no neurological and syndromic disorders. The parents of all children included in the study signed an informed consent form. The children were tested for reading and motor skills. According to the educational record, all children had normal intelligence.

2.2. Ethics

The Ethics committee of the Tehran University of Medical Science granted ethics approval. All participants signed informed consent forms, in addition to their parents or caregivers.

2.3. Reading components assessment

The Reading and Dyslexia Test (NEMA) was administered to all participants. Kormi Noori and Moradi developed and standardized this test in 2005 for the first to the fifth year of elementary school. This test has an internal stability of 82%.

NEMA test has ten sub-tests, including sub-tests of word reading, word chain, rhyme, naming pictures 1 and 2, text comprehension, word comprehension, deletion of sounds, reading non-words, letter signs, and category signs(31).

Reading speed is measured by the ratio of the number of words read at the specified time of the word reading subtest. Reading comprehension is measured by the ratio of correct questions answered from the subtest of NEMA test text comprehension to the total number of questions. Reading accuracy is measured by the ratio of the number of words a child reads correctly from the word reading subtests to the total number of words read.

2.4. Fine motor assessment

Fine motor skills were assessed using the Bruininks-Oseretsky Test of Motor Proficiency. This test is used for children who are 4.5 to 14.5 years old. The complete set of this test consists of eight subtests (46 separate sections) that assess motor proficiency or motor disorders in gross and fine motor skills. A complete set of this test takes 60-45 minutes. The fine motor skills section includes three subtests: Response speed, Visual-motor control, and Upper-limb speed and dexterity. The test-retest reliability coefficient of the test has been reported to be 87%, and its validity is equal to 84% (32).

2.5. Procedure

Each participant was tested individually. In line with the BOT manual's testing procedure, the therapist explained and demonstrated all motor tasks. Whenever appropriate, extra information was provided. Whenever appropriate, extra information was provided. The NEMA reading test assessed all participants. The NEMA reading test diagnosed children with dyslexia. The answers

of all subjects were recorded. Then, the motor proficiency test was performed for all children. The infrastructure from the local schools was used for the test administration of the normal children.

2.6. Statistical analysis

In this study, the values of quantitative variables were presented as "mean (standard deviation)" and "median (interquartile range), " and the values of qualitative variables were presented as "(percentage) frequency." Kolmogorov-Smirnov and Shapiro-Wilk tests were used to assess the normality of the scores of normal and children with dyslexia in fine motor skills and reading components. Mann-Whitney U test was used to compare the scores of normal and children with dyslexia in fine motor skills and reading components. Additionally, multiple linear regressions were used to compare the scores of normal children and with dyslexia ones in fine motor skills by controlling for the variables of gender and educational level. The relationship between the scores of fine motor skills and reading components was assessed using Spearman's correlation coefficient. The absolute values of the correlation coefficient of 0.1-0.3, 0.3-0.5, and >0.5 indicate low, medium, and high correlation, respectively (33). Data were analyzed using IBM SPSS Statistics V22.0, and the significance level was considered 0.05.

Results

Table 1 presents the comparison of the scores of normal children and children with dyslexia in fine motor skills using the Mann-Whitney U test. The values of the median (interquartile range) for the subtest of response speed were significantly lower among children with dyslexia than among normal children ($r = 0.355$, $P < 0.001$, $U = 656.5$).

The values of the median (interquartile range) for the subtest of upper-limb speed and dexterity were significantly lower among children with dyslexia than in normal children ($r = 0.715$, $P < 0.001$, $U = 473.0$).

Note. r values of 0.1-0.3, 0.3-0.5, and >0.5 were considered small, moderate, and large effect sizes, respectively.

Multiple linear regression was used to compare the scores of normal children and children with dyslexia in fine motor skills by controlling for the variables of gender and educational level. As can be seen in Table 2, by controlling for the variables of gender and educational level, the scores of children with dyslexia in the response speed were lower than normal children ($P < 0.001$) by 2.38 points (1.18-3.57; 95% confidence interval). The scores of children in the vision-motor control test in children with dyslexia were lower than normal children ($P < 0.001$) by 4.90 points (3.65-6.16; 95% confidence interval). Similar results were observed for the subtest of upper-limb speed and dexterity so that the scores of children with dyslexia in this subtest were lower than normal children ($P < 0.001$) by 6.16 points (3.70-8.61; 95% confidence interval).

Spearman's correlation coefficient was used to assess separately the relationship between the scores of fine motor skills and reading components in normal children and children with dyslexia.

As can be seen in Table 3, a weak positive correlation was observed between response speed and reading accuracy for typical children who were the first to third graders in elementary school, although this relationship was not statistically significant ($r_s = 0.244$, $P = 0.098$). According to the findings, the response speed had no statistically significant correlation with reading comprehension ($r_s =$

The Role Of Fine Motor Abilities In Reading Components: A Cross-Sectional Study In Children With And Without Dyslexia

0.098, P = 0.513) and reading speed (rs = 0.176, P = 0.237). The subscale of vision-motor control had a significant positive correlation with reading accuracy (rs = 0.424, P = 0.003) and reading speed (rs = 0.341, P = 0.019), while there was a statistically significant relationship between the vision-motor control and reading comprehension (rs = 0.104, P = 0.488). Upper-limb speed and dexterity subscale had a significant positive correlation

with reading accuracy (rs = 0.352, P = 0.015) and reading speed (rs = 0.396, P = 0.006). At the same time, a statistically significant relationship was found between upper-limb speed and dexterity and reading comprehension (rs = 0.101, P = 0.500). For children with dyslexia, unlike normal children, no statistically significant correlation was observed between fine motor skills and reading components (P < 0.05).

Table 1. Comparison of the scores of normal and dyslexic children in the subtests of fine motor skills.

	Group		U	P	Effect size (r)
	Normal	Dyslexic			
Response speed					
Mean (SD)	4.47 (3.26)	2.21 (2.18)			
Median (IQR)	4 (2-7)	2 (0-4)	656.5	<0.001	0.355
Vision-motor control					
Mean (SD)	19.70 (3.04)	14.49 (3.19)			
Median (IQR)	20 (19-22)	15 (12-17)	235.5	<0.001	0.985
Upper-limb speed and dexterity					
Mean (SD)	21.13 (7.13)	14.45 (4.15)			
Median (IQR)	20 (16-26)	14 (12-18)	473.0	<0.001	0.715

SD: Standard Deviation; IQR: Interquartile Range.

Note. r values of 0.1-0.3, 0.3-0.5, and >0.5 were considered as small, moderate, and large effect size, respectively.

Table 2: Comparison of the scores of normal and dyslexic children in the subtests of fine motor skills by controlling for the variables of gender and educational level using multiple linear regression.

Subtest	Adjusted mean difference ^a (Normal- Dyslexic)	95% confidence interval of adjusted mean difference	P
Response speed	-2.38	(-1.18, -3.57)	<0.001
Vision-motor control	-4.90	(-3.65, -6.16)	<0.001
Upper-limb speed and dexterity	-6.16	(-3.70, -8.61)	<0.001

^aadjusted for gender and education level

The Role Of Fine Motor Abilities In Reading Components: A Cross-Sectional Study In Children With And Without Dyslexia

Table 3. The relationship between the scores of fine motor skills and reading components for normal and dyslexic children.

	Reading components					
	Reading accuracy		Reading comprehension		Reading speed	
	r_s	P	r_s	P	r_s	P
Normal						
Response speed	0.244	0.098	-0.098	0.513	0.176	0.237
Vision-motor control	0.424	0.003	0.104	0.488	0.341	0.019
Upper-limb speed and dexterity	0.352	0.015	0.101	0.500	0.396	0.006
Dyslexic						
Response speed	-0.124	0.407	-0.175	0.239	-0.223	0.132
Vision-motor control	0.213	0.151	0.020	0.894	0.061	0.685
Upper-limb speed and dexterity	0.122	0.412	0.016	0.914	0.051	0.735

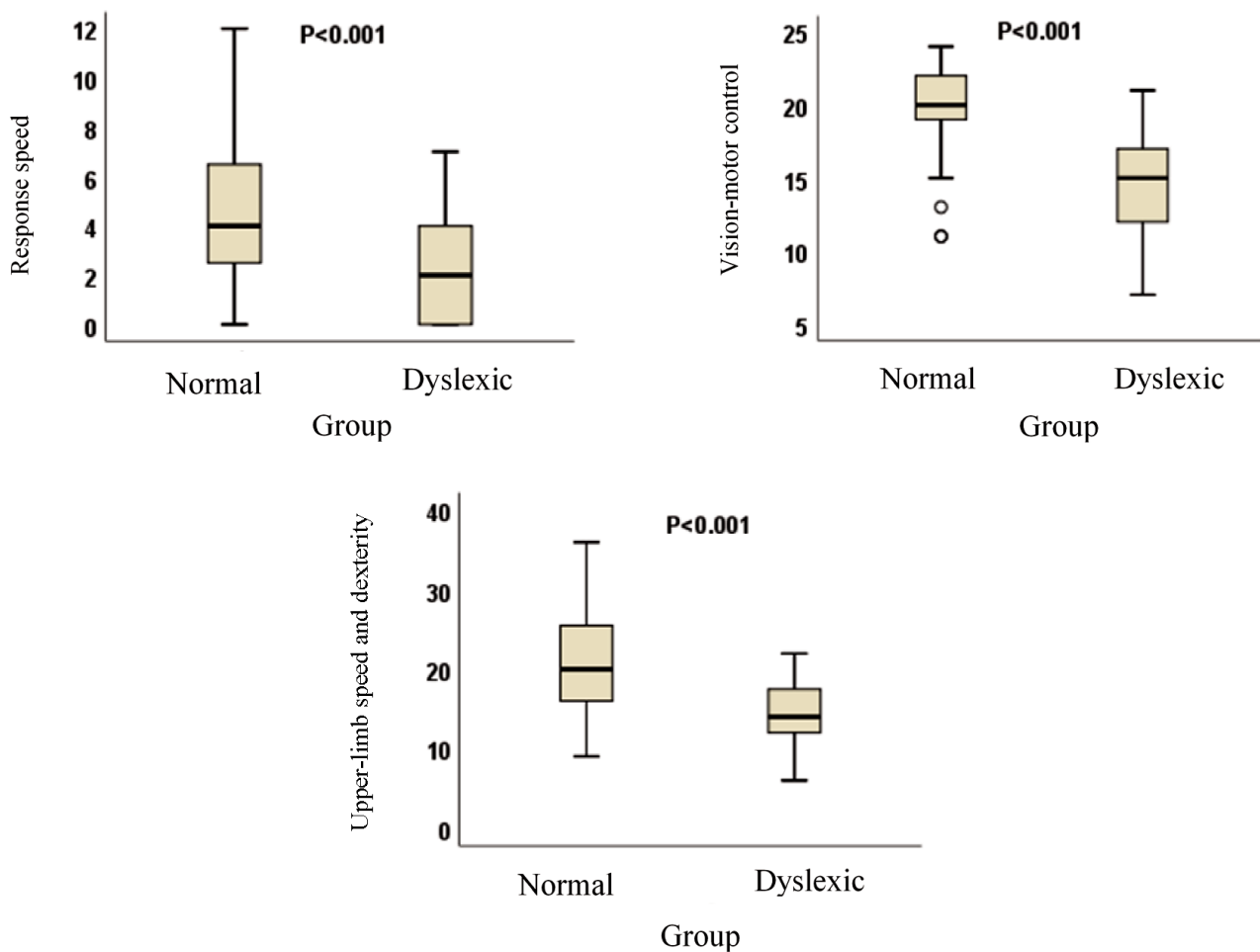


Figure 1: Comparison of scores of normal and dyslexic children in subtests of fine motor skills (Notes: the box diagram shows the minimum, first quartile, second quartile (median), third quartile, and maximum, respectively. The symbol O indicates outlier).

Discussion

The results of this study showed a significant difference between normal children and children with dyslexia in terms of fine motor skills. Besides, a significant correlation was found between fine motor skills and reading components in typical children, but no relationship in children with dyslexia.

Previous studies have found statistically significant differences between children with dyslexia and normal children regarding fine motor skills. Niecheiwiej-Szwedo et al. (2017) showed that children with dyslexia significantly differed from normal children in threading beads(34). In addition, Fawcett and Nicolson (1995) and Iversen (2005) demonstrated that the speed of movement in children with dyslexia was lower than in normal children(35, 36). Research by Iversen (2005) and O'Hare and Khalid (2002) also found that children with dyslexia had poorer performance in visual-motor control than normal children(19, 36).

The results indicate a co-occurrence of movement disorders and dyslexia, and considering the role of the cerebellum in motor, cognitive, and linguistic activities (5), this difference in motor skills of children with dyslexia can indicate cerebellar defects in these children. The cerebellum is also involved in the speed of visuomotor processing, eye movement control, and visual attention (5). Additionally, according to the magnocellular theory, children with dyslexia also have defects in the posterior parietal cortex, playing a role in visuomotor processing along with the cerebellum (3). Children with dyslexia also have difficulties with handwriting and two-handed coordination, and abnormal cerebellar activity has been reported in these children when doing these tasks (37, 38). The cerebellum's role in dyslexia is essentially characterized by failure to acquire

and automatize reading and writing skills, and impairment of automatization and time-evaluation deficits in dyslexia have been linked to cerebellar dysfunction (39). According to imaging studies, significant structural and functional differences exist in the cerebellum of children with dyslexia, and fine motor skills have been reported as one of the factors contributing to academic success (29, 30). Furthermore, the result of the study is different from the results of the study by Brookman et al. 2013 (40). Motor symptom analysis shows that motor deficits in children with dyslexia are not general defects but have problems in certain areas of motor skills (4).

In previous studies, the general relationship between reading and fine motor skills has been examined. A study by Son and Meisels (2006) showed that motor skills played an essential role in the achievement of first graders in primary school (41). Jean Clark (2010) found a significant relationship between reading and handwriting measures (42). The relationship between reading and some fine motor skills was also found in the research by O'Hare and Khalid (2002), Iversen (2005), and Suggate (2018) (19, 27, 36).

Recent studies indicate that fine motor skills in the early years can predict later academic achievement, especially in reading and mathematics, and are also related to school adaptation, appropriate social behavior, classroom engagement at the end of second grade, and literacy skills (28). Essentially, 50% of children with reading difficulties show a low level of motor development. Similar findings also indicate a relationship between movement disorders and problems in daily life and school activities (38). Students with dyslexia show some executive function problems related to weakness in general motor skills (37). Evidence from the research also demonstrates that children

with developmental motor problems in their early years tend to have a degree of motor, educational, and social difficulties when they age. Similarly, according to cohort studies, attaining motor milestones in infancy is associated with later adult physical development and cognitive performance. Since the cerebellum plays an active role in language functioning, including reading, movement exercises can be considered essential for improving cerebellar functioning and reading problems as a treatment for dyslexia (17).

However, the results obtained in this study showed a lack of relationship between reading components and motor components in children with dyslexia. The reason for this lack of relationship can be due to the personal preferences of children with dyslexia and self-competence beliefs and the time spent on educational and physical activities (43). Correspondingly, children who spend more extended periods in kindergarten perform better in fine motor skills (28), and this period may be less in children with dyslexia than normal children. Although according to clinical observations, children with dyslexia were less interested in reading tests, they showed more interest in performing the motor tests, although they had poorer performance than the control group. Seemingly, this issue can affect the results obtained.

In Conclusion

This study aimed to investigate the relationship between fine motor skills and reading components in normal children and those with dyslexia. According to the results obtained, fine motor skills were significantly higher in normal children than with dyslexia. Besides, a significant relationship was observed between fine motor skills and reading components in normal children, but there was not

such a relationship in children with dyslexia. This lack of relationship can be attributed to the fact that dyslexia can be approached from three behavioral, cognitive, and biological domains (44), all three or some of which can be involved in this disorder. Due to the importance of motor skills in acquiring other cognitive skills and the central role of motor exercises in improving cerebellar functioning, paying attention to them during the evaluation and treatment of children with dyslexia can be of great importance.

Acknowledgement

This study was approved by the Ethics Committee of Tehran University of Medical Sciences (IR.TUMS.FNM.REC.1400.116) All participants signed informed consent forms, in addition to their parents or caregivers.

Authors' Contribution

Reza Barghandan: Data collection, drafting and revision of the manuscript, Hooshang Dadgar: supervision of the study, drafting and revision of the manuscript, Parvin Raji: Study concept and design, Saman Maroufizadeh: Analysis and interpretation of data, Statistical analysis, revision of the manuscript. All authors agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved

Conflict of Interest

The authors declare no conflict of interest.

References

1. Chaix Y, Albaret J-M, Brassard C, Cheuret E, De Castelnau P, Benesteau J, et al. Motor impairment in dyslexia: the influence of

- attention disorders. *European Journal of Paediatric Neurology*. 2007;11(6):368-74.
2. Biotteau M, Albaret J-M, Lelong S, Chaix Y. Neuropsychological status of French children with developmental dyslexia and/or developmental coordination disorder: Are both necessarily worse than one? *Child Neuropsychology*. 2017;23(4):422-41.
 3. de Freitas PB, Pedao ST, Barela JA. Visuomotor processing and hand force coordination in dyslexic children during a visually guided manipulation task. *Research in developmental disabilities*. 2014;35(10):2352-8.
 4. Getchell N, Pabreja P, Neeld K, Carrio V. Comparing children with and without dyslexia on the movement assessment battery for children and the test of gross motor development. *Perceptual and motor skills*. 2007;105(1):207-14.
 5. Nicolson RI, Fawcett AJ. Dyslexia, dysgraphia, procedural learning and the cerebellum. *Cortex*. 2011;47(1):117-27.
 6. Kaltner S, Jansen P. Mental rotation and motor performance in children with developmental dyslexia. *Research in developmental disabilities*. 2014;35(3):741-54.
 7. Stoodley CJ, Stein JF. Cerebellar function in developmental dyslexia. *The Cerebellum*. 2013;12(2):267-76.
 8. Malek A, Amiri S, Hekmati I, Pirzadeh J, Gholizadeh H. A comparative study on diadochokinetic skill of dyslexic, stuttering, and normal children. *ISRN pediatrics*. 2013;2013.
 9. Eden GF, VanMeter JW, Rumsey JM, Zeffiro TA. The visual deficit theory of developmental dyslexia. *Neuroimage*. 1996;4(3):S108-S17.
 10. Laycock R, Crewther SG. Towards an understanding of the role of the 'magnocellular advantage' in fluent reading. *Neuroscience & Biobehavioral Reviews*. 2008;32(8):1494-506.
 11. Parker F. Dyslexia: An overview. *Journal of Basic Writing*. 1985;4(2):58-67.
 12. Landerl K, Willburger E. Temporal processing, attention, and learning disorders. *Learning and individual differences*. 2010;20(5):393-401.
 13. Nicolson RI, Fawcett AJ, Dean P. Developmental dyslexia: the cerebellar deficit hypothesis. *Trends in neurosciences*. 2001;24(9):508-11.
 14. Ito M. Control of mental activities by internal models in the cerebellum. *Nature Reviews Neuroscience*. 2008;9(4):304.
 15. Ramus F, Pidgeon E, Frith U. The relationship between motor control and phonology in dyslexic children. *Journal of Child Psychology and Psychiatry*. 2003;44(5):712-22.
 16. Wenande B, Een E, Petok JR. Dyslexia-related impairments in sequence learning predict linguistic abilities. *Acta psychologica*. 2019;199:102903.
 17. Brown CG. Improving fine motor skills in young children: an intervention study. *Educational Psychology in Practice*. 2010;26(3):269-78.
 18. Alvarez TA, Fiez JA. Current perspectives on the cerebellum and reading development. *Neuroscience & Biobehavioral Reviews*. 2018.
 19. O'Hare A, Khalid S. The association of abnormal cerebellar function in children with developmental coordination disorder and reading difficulties. *Dyslexia*. 2002;8(4):234-48.
 20. Lyddy F. Cerebellar symmetry in dyslexics. *Trends in cognitive sciences*. 2002;6(6):233.
 21. Eckert MA, Leonard CM, Richards TL, Aylward EH, Thomson J, Berninger VW. Anatomical correlates of dyslexia: frontal and cerebellar findings. *Brain*. 2003;126(2):482-94.

22. Janet WL. Learning disabilities: Theories, diagnosis and teaching strategies (seven edition). Boston, New York: Houghton Mifflin Company College Division; 1997.
23. Kaplan BJ, Wilson BN, Dewey D, Crawford SG. DCD may not be a discrete disorder. *Human movement science*. 1998;17(4-5):471-90.
24. Gomez A, Sirigu A. Developmental coordination disorder: core sensori-motor deficits, neurobiology and etiology. *Neuropsychologia*. 2015;79:272-87.
25. Hill EL. A dyspraxic deficit in specific language impairment and developmental coordination disorder? Evidence from hand and arm movements. *Developmental Medicine & Child Neurology*. 1998;40(6):388-95.
26. Wolfe CB. Motor control and reading fluency: Contributions beyond phonological awareness and rapid automatized naming in children with reading disabilities. 2007.
27. Suggate S, Pufke E, Stoeger H. Do fine motor skills contribute to early reading development? *Journal of Research in Reading*. 2018;41(1):1-19.
28. Pitchford NJ, Papini C, Outhwaite LA, Gulliford A. Fine motor skills predict maths ability better than they predict reading ability in the early primary school years. *Frontiers in psychology*. 2016;7:783.
29. Macdonald K, Milne N, Orr R, Pope R. Relationships between motor proficiency and academic performance in mathematics and reading in school-aged children and adolescents: A systematic review. *International journal of environmental research and public health*. 2018;15(8):1603.
30. Nicolson RI, Fawcett AJ, Berry EL, Jenkins IH, Dean P, Brooks DJ. Association of abnormal cerebellar activation with motor learning difficulties in dyslexic adults. *The Lancet*. 1999;353(9165):1662-7.
31. HOSSEINI M, MORADI A, KORMI NR, HASSANI J, PARHOON H. Reliability and validity of reading and dyslexia test (NEMA). 2016.
32. Bruininks-Oseretsky R. Test of motor proficiency: Examiner's manual. Circle Pines, MN: American Guidance Service. 1978.
33. Cohen J. Statistical power analysis for the behavioral sciences. 3rd ed. New York: Academic Press; 1988.
34. Okuda PMM, Ramos FG, Santos LCAD, Padula NAdMR, Kirby A, Capellini SA. Motor profile of students with dyslexia. *Psychology Research*. 2014:31.
35. Ibrahim S, Harun D, Baharudin S, Hui EJT. Motor performance and functional mobility in children with specific learning disabilities. *Med J Malaysia*. 2019;74(1):35.
36. Démonet J-F, Taylor MJ, Chaix Y. Developmental dyslexia. *The Lancet*. 2004;363(9419):1451-60.
37. Milne N, Cacciotti K, Davies K, Orr R. The relationship between motor proficiency and reading ability in Year 1 children: a cross-sectional study. *BMC pediatrics*. 2018;18(1):294.
38. Sun Y-F, Lee J-S, Kirby R. Brain imaging findings in dyslexia. *Pediatrics & Neonatology*. 2010;51(2):89-96.