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Motor Behavior Disorders in Children with Developmental Dyslexia: a Comprehensive Narrative Review of the Literature

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SUMMARY

Background. Difficulty with literacy acquisition is only one of the symptoms of developmental dyslexia. Dyslexic children also show poor motor coordination and postural control. Several studies have shown that dyslexic children and adults perform worse than non-dyslexic children in tasks that also involve postural control.
Methods. In January 2022 the main online databases were accessed. All the articles that investigate possible concomitance between the developmental dyslexia with motor behavior disorders were considered.
Results. The association between developmental dyslexia and motility disorders would deserve investigations on larger patient cohorts. The evidence of relationships between impaired motor behavior and dyslexia is inconclusive, partly because few studies have been undertaken and partly because tests and procedures differed between studies.
Conclusions. If an association between motor behavior and dyslexia can be confirmed, tests of motor skills could be included as tools in screening batteries, thereby potentially improving diagnostic accuracy, optimizing the management of patients with this disease, and designing more effective physiotherapy programs. Such measures might also be used to identify prereaders at risk of developing dyslexia prior to the manifestation of any reading difficulties.

KEY WORDS
Developmental; dyslexia; reading; learning; motor; motility; motion; disorders.

INTRODUCTION

Developmental dyslexia is a learning disability characterized by an inability to achieve the expected literacy skills for a given age despite adequate intelligence and adequate educational opportunities (1). Individuals with dyslexia have difficulties with accurate or fluent word recognition and spelling despite adequate instruction and intelligence and intact sensory abilities (2). The ultimate goal of reading is comprehension, which is a function of both decoding ability and oral language comprehension (3). Dyslexia is defined by difficulties with decoding, whereas by comparison, listening comprehension is typically more intact. The prevalence of dyslexia varies from 2 to 17% of the school-aged population (4, 5), making dyslexia one of the most common developmental disorders, enormously impacting the educational system. A number of comprehensive theories have been suggested to explain the underlying causes of dyslexia, such as a phonological deficit caused by neurological abnormalities in the language areas of the brain (6, 7), a sensory deficit hypothesis based upon evidence of reduced sensitivity to visual and auditory stimuli (8, 9), and a hypothesis about the reduced speed of information processing (10, 11). A cerebellar deficit hypothesis has been advocated by Nicolson *et al*. (12, 13). The latter suggests that children with dyslexia demonstrate deficits in some motor skills. A crucial role is played by central pattern generators (CPGs), *i.e.*, spinal neuronal networks that control the basic rhythms and patterns of motoneuron activation during locomotion and other rhythmic behaviors (14-16). The association between dyslexia and attention deficit hyperactivity disorder (ADHD) is frequent and widely described (17), with a reported incidence of 18-42% (18). Instead, weaker are the evidence on the correlation of dyslexia to developmental disorder of coordination (DCD) and dyspraxia (19). If an association between motor behavior and dyslexia can be confirmed, motor skills tests could be included as tools in the screening batteries, thus potentially improving diagnostic accuracy, optimizing the management of patients with this disease, and designing more effective physiotherapy programs. These measures could also have a predictive role, that is, they could be used to identify subjects at risk of developing dyslexia even before reading difficulty occurs.

MATERIALS AND METHODS

Search strategy

The literature search of the present narrative review was conducted according to this protocol:

- patients: developmental dyslexia;
- comparison: motor behavior disorders;
- outcomes: concomitance of motility disorders in dyslexic subjects.

Literature search

In January 2022 the following databases were accessed: Pubmed, Embase, Scopus, Web of Science, Google Scholar. The following keywords were used in combination: developmental, dyslexia, motion, disorder, motor, behavior, motility, problems, posture, balance, gait, poor, reading, learning. If title and abstract matched the topic, the full text was accessed. The bibliographies of the full-text articles were also screened for inclusion. Disagreements were solved by a third author (**). All the articles that investigate possible concomitance between the developmental dyslexia with motor behavior disorders were considered. According to the authors language capabilities, articles in English, French, German, Italian, and Spanish were considered.

RESULTS

Four articles were included in our database that meet the criteria (**table I**). All articles studied children with range age 8 < 16 years old for a total of 219 males and 73 females.

DISCUSSION

The relationship between developmental dyslexia and impaired motor behavior is a topic of increasing interest, justified by the potential benefits of a tailored treatment for those patients. Nevertheless, the available evidence is still meagre and conflicting, and the argument is strongly debated. Postural stability tests and walking tests are useful in assessing motor skills of dyslexic patients. Postural stability tests have already provided some evidence of a link between motor skills deficits and developmental dyslexia. Postural stability is known to be task dependent (20-22). Therefore, balance measurements during quiet standing may not be valid estimates of balance during perturbed standing. Furthermore, standing balance may not reflect balance control during walking. Common gait parameters, such as stride frequency, stride length, and walking speed, can be sensitively and reliably measured outside the laboratory environment. Therefore, they may only be suitable as part of a dyslexia screening tool to assess motor skills, after careful distinction between disabled and normal readership groups. Nicolson *et al*. (12) argued that standard motor skill batteries do not capture the range of deficits associated with cerebellar abnormalities, and that classic cerebellar tests depend to some extent on clinical judgements. To devise a more objective procedure, they devised a postural stability test in which the subjects' balance was perturbed by calibrated pushes to the small of the back. Using this method, however, postural sway ratings still depend on the clinical judgment of the experimenter, who is not always blind to the child's state. If manual perturbations (*i.e.*, thrust) are not modified relative to each person's body weight, then the validity of this test would also suffer. In the study by Moe-Nilssen *et al.* (23) it was investigated whether the previous results of a lack of balance control during the upright position could be confirmed with an objective posturography by researchers who were blind to the group membership of the subjects. The assessment of gross motor skill assessments was also expanded to include balance control during walking using established gait cycle parameters. These measures can add discriminatory power to any motor skill component of a dyslexia screening test. Their primary aim was to investigate whether continuous-scale gait and body swing parameters could provide new information on balance control during standing and walking in developmental dyslexia. Timed testing and trunk accelerometry measurements allow field data to be obtained at different locations to ensure ecological validity. It was investigated whether these parameters could

Table I. Comparison of dyslexia studies.

Author, year	Journal	Groups	Sex	Participants (n)	Purpose	Results
Brookes *et al.* 2010 (1)	*Dyslexia*	Dyslexic adults 18-26y	11 males, 9 females	20	clarify between-study heterogeneity, employing quantitative, continuous measures of balance and blindfolded balance, and using both adult and child participants without comorbid ADHD	there is a significant incidence of balance difficulties in children and adults with dyslexia, even for those without comorbid attention deficit
		Matched adult controls 20-24y	14 males, 16 females	30		
		Dyslexic children 11-14y	11 males, 5 females	16		
		Matched child controls 10-13y	11 males, 14 females	25		
Fawcett *et al.* 1999 (29)	*Journal of Motor Behaviour*	Children with dyslexia 8-16y	59 males	59	establish whether cerebellar difficulties found in laboratory research with dyslexic children are representative of the dyslexic population at large	the dyslexic children showed highly significant impairments on the cerebellar tests, with deficits on postural stability and muscle tone comparable in magnitude with their reading and spelling deficits. Furthermore, over 95% of the dyslexic children showed clear evidence of deficit on muscle tone or stability
		Controls children 8-16y	67 males	67		
Moe-Nilssen *et al.* 2003 (23)	*Exp Brain Res*	Children with dyslexia 10-12y	15 males, 7 females	22	investigate if continuous-scaled measures of standing balance and gait could discriminate between groups of impaired and normal readers when investigators were blind to group membership during testing	confirmed the previous finding of an association between deficient balance control during standing and developmental dyslexia
		Controls children 10-12y	9 males, 9 females	18		
Stoodley *et al.* 2005 (27)	*Exp Brain Res*	Children with dyslexia 8-14y	11 males, 5 females	16	investigate low-level sensory and motor deficits which have been found in dyslexic populations	dyslexic children were less stable than the control children in both eyes-open conditions (left foot, right foot). While there were no group differences during the eyes-closed conditions, the dyslexic children dropped a foot to correct balance significantly more often than control children.
		Controls children 8-11y	11 males, 8 females	19		

differentiate between two groups of children aged between 10 and 13 years with and without developmental dyslexia. They found that when subjects walked on uneven surfaces, very fast walking speeds, as well as cadence and step length at common normalized walking speeds, correctly classified 77.5% or more of the subjects into their respective group, and the effect was controlled by gender. The children with dyslexia in their study walked with shorter steps and higher cadence than the controls when compared at normalized speed and with body height controlled. When cadence was compared at the preferred speed, however, no significant differences between groups were found. This observation stresses the importance of controlling for differences in walking speed when comparing speed-dependent parameters between subjects. It is well documented that a subject walking at preferred speed will demonstrate a natural cadence, which can be explained by pendulum characteristics (24-26). Discriminatory power was generally lower for tests of walking on an even surface, and for tests of quiet standing with the eyes open. Tests of quiet and perturbed standing with the eyes closed did not discriminate significantly between groups. The same finding was supported by Stoodley *et al.* (27), but is in opposition to the results of Fawcett, Nicolson and Dean (28) and Nicolson and Fawcett (29). In the study of Stoodley *et al.* normal readers (n = 19) and children with developmental dyslexia (n = 16) were asked to perform various cognitive, literacy, and balancing tasks. Children balanced on the left or right foot, with eyes open or closed, for a period of 10 seconds during which their movements were recorded with a motion-tracking system. Dyslexic children were less stable than the control children in both eyes-open conditions (left foot $p = 0.02$, right foot $p = 0.012$). While there were no group differences during the eyes-closed conditions, the dyslexic children dropped a foot to correct balance significantly more often than control children ($p < 0.05$). Samson *et al.* (30) found that step length but not cadence decreased with age in adults (aged 19–90 years) walking at preferred speed. Shortening of step length may therefore be a compensatory strategy in balance control, and may explain why the children with dyslexia in Moe-Nilssen *et al.* study (23) demonstrated similar cadence at preferred speed, but not at normalized speed, compared to controls. Use of the same compensatory strategy would also explain why the group with reading impairments, demonstrated similar cadence as controls, but with shorter step length and consequently lower maximal speed, when instructed to walk very fast. It is interesting that controlling for gender consistently increased the statistical significance of the group differences found on the walking tests. The differences in motor skills between boys and girls found in Moe-Nilssen *et al.* study (23) are in agreement with previous findings for normal children and adolescents (31-33). Their data also indicate that the group of children with dyslexia were consistently impaired relative to controls on tests of undisturbed standing balance when they were instructed to look at a target 0.6 m away, but not on the same test when performed with eyes closed. Thus, as a group, the poor readers in their study seemed not to take adequate advantage of the visual cue. This may have resulted from some impaired readers' inability to maintain steady fixation, a visual impairment that would also be disadvantageous during reading. Fixation instability and jerking eye movements have been claimed to be associated with developmental dyslexia, but opinions differ as to whether eye movement differences are a cause or consequence of reading difficulties (34-38). They also found that the children with dyslexia were of smaller physical stature than the controls and that this could not be explained simply by a difference in gender ratios between the groups. This height difference is interesting and warrants further study. Their study confirmed the previous finding of an association between deficient balance control during standing and developmental dyslexia (29). They have further shown that gait parameters, when appropriately adjusted for differences in body size and walking speed and controlled for well-known gender differences in motor performance (31-33), may effectively discriminate between children with dyslexia and age-equivalent controls with up to 85% accuracy. We cannot rule out the possibility that factors other than reading skills, such as intelligence, have modulated the effects of the group. An overall effect of IQ differences between groups is expected to impact the performance of all psychophysical and psychometric tests to some extent. However, there is no *a priori* reason to expect intelligence to affect certain tests more than others. The finding that the dyslexic group differed from controls on specific posturography measures is therefore consistent with a more specific deficit rather than with a generalized decrease in performance resulting from differences in IQ. Previous studies have emphasized the importance of cerebellar function in discriminating between groups of impaired and normal readers and have provided a pathogenetic hypothesis that explains the connection between sensory and motor functions in developmental dyslexia (12). The literature to-date indicates that studies have shown differences (between and within experiments) according to age, balance position, method of measurement, dual/single task paradigms, blindfolded/unblindfolded conditions, type of standing surface and length of test. For example, found that balance deficits were not observed when participants were blindfolded. The reasons for these differences could be due to the specific measurement techniques employed across the studies, the measurement scales, and stance. The study by Brookes *et al.* (1) attempted to clarify these issues, employing quantitative, continuous measures of balance and blindfolded balance, and using both adult and child participants. Eighty-seven individuals participated: dyslexic adults (n = 17), matched adult controls (n = 30), dyslexic children (n = 16) and matched child controls (n = 24). The study found significant balance deficits for the child dyslexic group in the eyes-open task and a result approaching significance in the blindfolded task. By contrast, the adult dyslexic group showed significant deficits in the blindfolded task only. This highlights the need for the use of age-appropriate tests, and may explain some of the heterogeneity in the literature. It is concluded that there is a significant incidence of balance difficulties in children and adults with dyslexia. Given the range of techniques and participants that were employed, it is not surprising that balance and dyslexia studies yielded different results. However, there is sufficient evidence of balance deficits in dyslexia to make this report worthy of further investigation. Clinical gait tests are easy to perform, and the evaluated parameters can be obtained without the use of expensive equipment. Currently there are no scientifically approved clinical tests available that can correlate these aspects, so the development of a screening test that can evaluate motor disorders to make early diagnosis of developmental dyslexia would be of absolute importance. These elements can therefore prove to be valuable in addition to the development of screening tests for developmental dyslexia, although further studies are needed to better define the role of the visuomotor system in controlling balance and its contribution to reading difficulties.

CONCLUSIONS

The association between developmental dyslexia and motility disorders would deserve investigations on larger patient cohorts. The evidence of relationships between impaired motor behavior and dyslexia is inconclusive, partly because few studies have been undertaken and partly because tests and procedures differed between studies. Furthermore, tests with a greater discriminatory component between the various components of motor skills should be carried out. Meanwhile, these findings may provide new insights into the motor disorders associated with developmental dyslexia, useful for optimizing the management of patients with this disease and for designing more effective physiotherapy programs. The identification of these disorders will allow to establish the subjects who can benefit from specific rehabilitation protocols. Current scientific evidence suggests the integration of adequate exercises in a multidisciplinary context to treat the young patients involved, or even prevent those most at risk. Ultimately, a tailored treatment for the individual is potentially useful for children with developmental dyslexia.

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DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

GV, ET: literature revision and analysis, manuscript writing. MC, JP: articles for study eligibility assessment and literature analysis. NM, FO: study supervision and manuscript revision.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

REFERENCES

1. Brookes RL, Tinkler S, Nicolson RI, Fawcett AJ. Striking the right balance: motor difficulties in children and adults with dyslexia. Dyslexia 2010;16(4):358-373.
2. Lyon GR, Shaywitz SE, Shaywitz BA. A definition of dyslexia. Ann Dyslexia 2003;53(1):1-14.
3. Hoover WA, Gough PB. The simple view of reading. Reading and Writing 1990;2(2):127-60.
4. Yule W, Rutter M, Berger M, Thompson J. Over- and under-achievement in reading: distribution in the general population. Br J Educ Psychol 1974;44(1):1-12.
5. Shaywitz SE. Dyslexia. N Engl J Med 1998;338(5):307-12.
6. Bradley L, Bryant PE. Difficulties in auditory organisation as a possible cause of reading backwardness. Nature 1978;271(5647):746-7.
7. Paulesu E, Demonet JF, Fazio F, *et al*. Dyslexia: cultural diversity and biological unity. Science 2001;291(5511):2165-7.
8. Tallal P. Auditory temporal perception, phonics, and reading disabilities in children. Brain Lang 1980;9(2):182-98.
9. Wright BA, Bowen RW, Zecker SG. Nonlinguistic perceptual deficits associated with reading and language disorders. Curr Opin Neurobiol 2000;10(4):482-6.
10. Denckla MB, Rudel RG. Rapid "automatized" naming (R.A.N): dyslexia differentiated from other learning disabilities. Neuropsychologia 1976;14(4):471-9.
11. van der Leij A, van Daal VH. Automatization aspects of dyslexia: speed limitations in word identification, sensitivity to increasing task demands, and orthographic compensation. J Learn Disabil 1999;32(5):417-28.

12. Nicolson RI, Fawcett AJ, Dean P. Developmental dyslexia: the cerebellar deficit hypothesis. Trends Neurosci 2001;24(9):508-11.
13. Nicolson RI, Fawcett AJ, Berry EL, Jenkins IH, Dean P, Brooks DJ. Association of abnormal cerebellar activation with motor learning difficulties in dyslexic adults. Lancet 1999;353(9165):1662-7.
14. Grillner S. Biological pattern generation: the cellular and computational logic of networks in motion. Neuron 2006;52(5):751-66.
15. Kiehn O. Development and functional organization of spinal locomotor circuits. Curr Opin Neurobiol 2011;21(1):100-9.
16. Lacquaniti F, Ivanenko YP, Zago M. Patterned control of human locomotion. J Physiol 2012;590(10):2189-99.
17. Langer N, Benjamin C, Becker BLC, Gaab N. Comorbidity of reading disabilities and ADHD: Structural and functional brain characteristics. Hum Brain Mapp 2019;40(9):2677-98.
18. Germano E, Gagliano A, Curatolo P. Comorbidity of ADHD and dyslexia. Dev Neuropsychol 2010;35(5):475-93.
19. Moody S. Dyslexia, dyspraxia, and ADHD in adults: what you need to know. Br J Gen Pract 2014;64(622):252.
20. Brandt T, Strupp M, Benson J. You are better off running than walking with acute vestibulopathy. Lancet 1999;354(9180):746.
21. Cho CY, Kamen G. Detecting balance deficits in frequent fallers using clinical and quantitative evaluation tools. J Am Geriatr Soc 1998;46(4):426-30.
22. Winter DA, Patla AE, Frank JS. Assessment of balance control in humans. Med Prog Technol 1990;16(1-2):31-51.
23. Moe-Nilssen R, Helbostad JL, Talcott JB, Toennessen FE. Balance and gait in children with dyslexia. Exp Brain Res 2003;150(2):237-244.
24. Cavagna GA, Willems PA, Heglund NC. The role of gravity in human walking: pendular energy exchange, external work and optimal speed. J Physiol 2000;528(Pt 3):657-68.
25. Holt KG, Hamill J, Andres RO. Predicting the minimal energy costs of human walking. Med Sci Sports Exerc 1991;23(4):491-8.
26. Wagenaar RC, van Emmerik RE. Resonant frequencies of arms and legs identify different walking patterns. J Biomech 2000;33(7):853-61.
27. Stoodley CJ, Fawcett AJ, Nicolson RI, Stein JF. Impaired balancing ability in dyslexic children. Exp Brain Res 2005;167(3):370-80.
28. Fawcett AJ, Nicolson RI, Dean P. Impaired performance of children with dyslexia on a range of cerebellar tasks. Ann Dyslexia 1996;46(1):259-83.
29. Fawcett AJ, Nicolson RI. Performance of Dyslexic Children on Cerebellar and Cognitive Tests. J Mot Behav 1999;31(1):68-78.
30. Samson MM, Crowe A, de Vreede PL, Dessens JA, Duursma SA, Verhaar HJ. Differences in gait parameters at a preferred walking speed in healthy subjects due to age, height and body weight. Aging (Milano) 2001;13(1):16-21.
31. Riach CL, Hayes KC. Maturation of postural sway in young children. Dev Med Child Neurol 1987;29(5):650-8.
32. Wheelwright EF, Minns RA, Law HT, Elton RA. Temporal and spatial parameters of gait in children. I: Normal control data. Dev Med Child Neurol 1993;35(2):102-13.
33. Wheelwright EF, Minns RA, Elton RA, Law HT. Temporal and spatial parameters of gait in children. II: Pathological gait. Dev Med Child Neurol 1993;35(2):114-25.
34. Olson RK, Kliegl R, Davidson BJ. Dyslexic and normal readers' eye movements. J Exp Psychol Hum Percept Perform 1983;9(5):816-25.
35. Pavlidis GT. Do eye movements hold the key to dyslexia? Neuropsychologia 1981;19(1):57-64.
36. Pavlidis G. Dyslexia: eye movements in reading and beyond. Nurs Mirror 1980;150(3):22-6.
37. Dossetor DR, Papaioannou J. Dyslexia and eye movements. Lang Speech 1975;18(4):312-7.
38. Stein J, Walsh V. To see but not to read; the magnocellular theory of dyslexia. Trends Neurosci 1997;20(4):147-52.