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RELATIONSHIP BETWEEN INTELLIGENCE AND COMPLEX MOTOR SKILLS IN CHILDREN WITH AND WITHOUT DEVELOPMENTAL DYSLEXIA

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The study investigates the relation between developmental dyslexia, IQ and complex motor skills involving some cognitive and executive functions. The mechanisms underlying the co-existence of disabilities related to reading and writing on the one hand and motor skills on the other hand, still need to be clarified. In the current study it was hypothesised that the level of intelligence may contribute to complex motor skills in dyslexia. The study involved 58 students with developmental dyslexia (age 9.08 yrs; *SD* = .06) and 50 students constituting a control group (age 9.09 yrs; *SD* = .06). The measurements were performed using WISC-R, two subtests from the Dyslexia 3 Test, and four complex motor tasks. Children with dyslexia present problems in complex motor tasks, which involved learning of movement sequences and mental rotation. This finding may support the cerebellar deficit hypothesis in dyslexia. Complex motor skills are significantly related to children's intelligence level or to the interaction of intelligence and dyslexia. Child's intelligence explains from 7.5% to 35% of the variance in complex motor skills.

Keywords: complex motor skills; intelligence; dyslexia; cognitive functions; executive functions.

According to the fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5, 2013), developmental dyslexia is a cognitive disorder

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defined as one of the specific learning disabilities, and classified in the category of neurodevelopmental disorders. Essentially, dyslexia is associated with severe and persistent reading disability reflected by decoding difficulty, low reading rate, as well as poor reading and comprehension accuracy, which do not directly result from low intelligence, insufficient motivation, sensory problems or ineffective teaching process, and which may be accompanied with severe difficulties related to spelling abilities (DSM-5, 2013; Lyon et al., 2003). Dyslexia may be diagnosed in children with varied intellectual capacities, in the population with IQ > 70. The level of IQ does not predict reading skills in individuals with dyslexia (Ferrer et al., 2010), and individuals with varied IQ level present similar difficulties in reading acquisition (Elliott & Grigorenko, 2014; Krasowicz-Kupis, 2019). Currently, dyslexia tends to be treated as a disorder manifested by numerous deficits in various domains of development, related to language as well as visual, auditory, motor and executive functions (Francuz & Borkowska, 2013). It is a multifactorial phenomenon which is not limited exclusively to phonological deficits even though the latter are still seen as a major factor leading to the manifestation of the main symptoms, i.e., reading difficulties (Pennington, 2006).

Dyslexia frequently co-exists with other neurodevelopmental disorders, such as ADHD, communication disorders or motor disorders (Pennington, 2006; Elliott & Grigorenko, 2014; Lipowska, 2011). However, the nature of such comorbidity is still unclear. This article discusses the relationships between dyslexia and complex motor skills, in which cognitive functions are involved. Studies investigating motor impairments in children with dyslexia do not provide consistent evidence. Some studies report poorer motor performance in children with dyslexia (Nicolson & Fawcett, 2011; Viholainen et al., 2002; Viholainen et al., 2006), or hypothesise that there is a relation between language and motor development (Reynolds et al., 2003). Most frequently, consistent results are reported with regard to deficits in whole-body movements, balance and body posture (Gouleme et al., 2015), far more varied results are observed in tasks involving fine motor skills, such as inserting pegs or stringing beads (Marchand-Krynski et al., 2017). Nicolson et al. (2001) found that 80% of dyslexic people have motor dysfunctions in balance, muscle tone or co-ordination. Ramus et al. (2003) reported motor impairment in 59% of the cases in a group of dyslexic children aged between 8 and 12 years. In a study by Chaix et al. (2007), the rate of children with motor symptoms ranged from 40% to 57% depending on the adopted cut-off value for severity, respectively 2 *SD* and 1 *SD*. This variability might relate to the methods applied for assessing these disorders. Other studies show that children with and without dyslexia do not differ in three broad motor skill categories: manual dexterity, ball skills, and balance. They found differences between dyslexic and non-dyslexic children only in a mental rotation task (Kaltner & Jansen, 2014). Approximately 40% of children with developmental dyslexia exhibit no motor impairment (Chaix et al., 2007).

Earlier studies aimed to verify the hypotheses about the common cause of the two disorders, linked it to cerebellar deficit (Nicolson & Fawcett, 2011). The cerebellum is involved in language, reading-related activities, automation, implicit learning and motor skills. The cerebellum deficit hypothesis assumes that such impairment would lead to problems in learning to read (Biotteau et al., 2015). Some children with learning disorders present particular difficulty acquiring skills related to procedural learning or automaticity, including impairments in motor or language functions, working memory, executive functions (attention, planning), visuospatial regulation, oculomotor and visuoperceptual functions (Biotteau et al., 2015).

Some studies have proposed that motor deficit in dyslexia is partly an artefact, because motor symptoms, particularly poor balance and motor coordination, are caused by ADHD, or more specifically by attention disorder, frequently co-occurring with dyslexia (Chaix et al., 2007). Therefore, motor deficits are observed only in the sub-group of children exhibiting dyslexia. Moreover, motor impairment appears to be independent from reading skills because no correlations have been found between reading performance and motor scores (Chaix et al., 2007). If there is no association with reading, perhaps motor skills may be linked to IQ. That potential association between motor skills in dyslexia and IQ has not been investigated. Yet, it is one of the factors which may be of importance in whether or not motor deficits appear in dyslexia because motor and cognitive systems are inter-related. Studies provide strong evidence for a relation between motor experience and cognitive, social, or perceptual progress at different stages of development, and delays in motor skills are associated with impaired cognitive, social, or perceptual development as well (Libertus & Hauf, 2017). General movements, as assessed using the Prechtl's General Movement Assessment tool, at 2, 3, or 5 months of age are predictive of subsequent cognitive development in children born preterm. Likewise, levels of gross motor skills, levels of locomotion skills, levels of object manipulation skills are positively associated with cognitive development in toddlers (Veldman et al., 2019). In older children (aged 4–16 years) weak-to-strong evidence was found for some correlations between complex motor skills and higher order cognitive skills (van der Fels et al., 2015).

In a study by Smits-Engelsman & Hill (2012), analyses of IQ and motor skill data took into account a group of 460 children with or without motor difficulties. Individuals with a lower IQ more often showed poorer motor performance than those with a higher IQ. Loss of 10 percentile in motor tasks points was observed for lowering IQ of each *SD*. On the other hand, typical and atypical motor development has been observed in children representing all IQ levels, and intelligence explains 19% of the variance in motor deficits (Smits-Engelsman & Hill, 2012).

Therefore, for the needs of this study it was assumed that there is a group of children with dyslexia with IQ-related motor skills. It was hypothesised by the author, that children with dyslexia differ in complex motor abilities from their peers with good reading abilities, and the identified motor difficulties are related to IQ of the children. The first aim of the study was to assess and compare performance in complex motor tasks presented by school-age children with and without dyslexia. Since earlier research mainly focused on gross motor skills and fine motor skills, the current study was designed to assess performance in complex motor tasks which, besides the motor function, involve kinaesthetic function and motor precision, visual control and mental rotation, as well as executive control and implicit motor learning. Additionally, the study aimed to investigate the relationship between performance in the complex motor tasks and IQ levels observed in children with/without dyslexia.

METHOD

Participants

The study involved 108 primary school children, namely, 74 grade 3 students (at the end of the school year) and 34 grade 4 students (at the beginning of the school year), who were enrolled in either the study group of children with developmental dyslexia (58 subjects) or in the control group of children with no symptoms suggesting reading or writing difficulties (50 subjects). The subjects' mean age in the group with dyslexia was 9.08 years ($SD = .06$), and 9.09 years ($SD = .06$) in the control group. The groups did not differ in terms of age ($t(106) = -.45$, n.s.). To ensure homogeneity of the group, only right-handed children were enrolled for the study.

Measures

Intelligence

Intelligence was diagnosed using WISC-R test (Matczak et al., 2008) in both groups. A cut-off point $IQ = 90$ was used to divide both groups into subgroups with low ($IQ < 90$) and high ($IQ > 90$) intelligence. According to the WISC-R test manual

(Matczak et al., 2008), the cut-off point IQ = 90 was chosen on the basis of measurement error.

Reading

Reading abilities were assessed using two subtests from the Dyslexia 3 battery (Bogdanowicz et al., 2008): reading meaningful words (an indicator of decoding ability) and deleting phonemes (an indicator of phonological awareness). In line with the definition of developmental dyslexia (Krasowicz-Kupis, 2019), these indicators seem to confirm whether or not a given child experiences difficulties in reading and writing.

Motor Tasks

Our assessment of complex motor skills was based on four tasks. Two of these, assessing the ability to imitate finger gestures (FG) and to learn movement sequences (MS), were from the Paediatric Neuropsychological Diagnosis (PND) battery (Borkowska & Daniluk, 2019). PND is a battery used for neuropsychological assessment of children with various central nervous system pathologies. It comprises 54 tasks in 11 domains covering all aspects of the child's development, from motor abilities to selected executive functions. The neuropsychological evaluation of the child enabled by the battery is based on an integrative model combining psychometric diagnosis with experimental and clinical approach. The battery can be used as a whole to conduct a complete neuropsychological evaluation; alternatively, its specific parts can be applied to assess selected processes. The present study applied only two complex motor tasks from PND battery: FG and MS. The other two tasks were designed based on neuropsychological evaluation model (Lezak et al., 2012). In accordance with the theory of dynamic functional systems in the brain proposed by Luria (1976), in addition to the motor functions, different mental processes are engaged in specific motor tasks. Description of the complex motor tasks includes motor functions and mental processes involved in each task.

The first task assessed the ability to imitate finger gestures (FG) i.e., five patterns of finger gestures, e.g., a circle, a beak (thumb and middle finger), a beak (thumb and ring finger), horns (index finger and little finger), and horns made with the thumb and the little finger (Borkowska & Daniluk, 2019). The child observed the arrangement of fingers shown as a model by the examiner, and then positioned his/her fingers accordingly, while watching the process. Only the dominant hand was assessed in this task. Such tasks involve movement planning, fine motor precision and visual motor control. The possible scores were in the range 0–15 points in five trials.

The second task assessed the ability to learn movement sequences (MS). The child watched the examiner performing a sequence of hand placements twice: a) a hand with its side on the table, flat on the table, closed into a fist on the table; and b) a fist with its side on the table, a hand with its side on the table or flat on the table) (Borkowska & Daniluk, 2019). Subsequently the child was to join in and repeat the sequence three times with the examiner, and then five times without the examiner. In addition to motor sills, the trials engage motor sequence learning, hence working memory and executive control. The participants could score from 0 to 6 points in two trials.

The third task comprised five conflicting motor tasks (CM), which require cognitive flexibility, e.g., the child is to respond to a single knock with two knocks, or she is asked to change the initial placement of both hands (where one hand is placed on the table palm down and the other palm up), so that the two hands are being reversed simultaneously; one hand made into a fist and the other flat on the table, followed by a simultaneous change of the arrangement; the examiner raises one hand (e.g., right), and the child raises the opposite hand (in this case left); the examiner places their hands on the knees and the child claps their hands, and then the examiner claps their hands and the child places their hands on the knees (Lezak et al., 2012). Each task was performed five times. The possible scores were in the range of 0–15 points in five trials.

The fourth task assessing fine motor skills was based on the performance of mirrored movements (MM), which means that spatial perception and mental rotation were involved in addition to the motor function (Lezak et al., 2012). The child stood opposite the examiner who performed five activities in a sequence. The child was to perform the same activity, such as touching the right eye with the left hand, raising the right hand to the face and bending the wrist, touching the right ear with the right hand, touching the left eye with the right hand, touching the right knee with the left hand. The participants could score 0–15 points in five trials.

All the motor trials were rated on a scale from 0 to 3 points. A zero score was awarded to an accurate completion of a trial; mild inaccuracy and moderate inaccuracy was reflected by a score of 1 or 2 points, respectively; inaccurate performance was awarded the highest score of 3 points. The children's performance in the motor tasks was recorded (hands exclusively), and then assessed by three competent judges—practicing paediatric psychologists. The final score corresponded to the points awarded by at least two raters (if the child received 1 point from one judge and 2 points each from the other two judges—the final score amounted to 2 points). The judges were "blind", they were not aware of the dyslexia status of participants.

In this way five motor indicators were acquired: scores for the four tasks, and a total score for all the tasks as an overall indicator.

Procedure

Targeted sampling was used in qualifying the children for the dyslexic group. Various methods were applied to contact parents of the children with a diagnosis of developmental dyslexia issued by a psychological and educational counselling centre. The snowball method, and meetings with parents at schools were predominantly used in the process. Similar methods were applied to contact parents of the children selected for the control group. Parents of all the children gave their written consent to the examination of the children; in addition, the children also gave their consent orally.

At the first stage, the records of the children with dyslexia were reviewed for information about their intelligence quotient. The children in the study group were diagnosed with dyslexia in the preceding year, therefore their diagnosis and the scores related to their reading skills and intelligence level were up-to-date. Subsequently, the intellectual abilities were tested in the controls, using the WISC-R (Matczak et al., 2008). (The examinations were carried out in 2018 and 2019.) The information retrieved from the counselling centre and related to the IQ of the children with dyslexia was used in the study because all the children were uniformly assessed using WISC-R during the preceding year. Hence, the results were valid. Furthermore, examination with the intelligence test could not be conducted again. It was assumed, in line with the psychological evaluation methodology, that WISC-R as a psychometric tool provides similar results irrespective of the examiner involved. Both the group with dyslexia and the control group included children with varied levels of intelligence, they were divided into subgroups with $IQ<90$ and $IQ>90$. In order to acquire comparable indicators reflecting the presence or lack of dyslexia, all the children were asked to perform two subtests from the Dyslexia 3 battery. Subsequently, complex motor functions were assessed in both groups.

RESULTS

Intelligence Level, Reading Indicators and Indicators of Complex Motor Functions in Dyslexic and Control Groups

The obtained results on IQ, reading and deleting phonemes scores in dyslexic and control groups and comparisons between groups are shown in Table 1.

Table 1

Descriptive Statistics of IQ, Reading and Deleting Phonemes in Dyslexic and Control Groups and Between Group Comparisons

	Dyslexic group $N = 58$ M (SD)	Control group $N = 50$ M (SD)	t-test (106)	Cohen's d
IQ	102.37 (23.34)	109.71 (22.25)	1.64 n.s.	.32
Reading meaningful words (sten scores)	2.43 (.57)	6.41 (1.13)	–22.94***	4.44
Deleting phonemes (sten scores)	2.59 (.81)	6.19 (1.06)	–19.62***	3.81

*** $p < .001$; n.s. = not significant at $p > .05$.

The results of complex motor functions in the dyslexic and control groups and in the same children divided into two groups on the basis of intelligence level IQ > 90 and IQ < 90 are shown in Table 2.

Table 2

Descriptive Statistics of Complex Motor Functions in Dyslexic and Control Groups and IQ > 90 and IQ < 90 Groups

	Dyslexic group $N = 58$ M (SD)	Control group $N = 50$ M (SD)	IQ > 90 group $N = 58$ M (SD)	IQ < 90 group $N = 50$ M (SD)
FG (0–15)	8.06 (1.96)	7.75 (1.72)	7.47 (1.55)	8.50 (2.05)
MS (0–6 points)	4.91 (1.15)	4.35 (1.25)	4.63 (1.17)	4.66 (1.31)
CM (0–15 points)	6.87 (2.04)	6.25 (1.95)	5.83 (1.72)	7.52 (1.98)
MM (0–15 points)	8.94 (2.11)	8.02 (2.30)	7.38 (2.14)	10.00 (1.29)
Overall indicator	28.78 (4.62)	26.33 (4.66)	25.31 (3.99)	30.68 (3.94)

Note. FG = imitation of finger gestures, MS = movement sequence learning, CM = conflicting motor tasks, MM = performance of mirrored movements.

The descriptive statistics in Table 3 are related to the scores obtained by the study group (with dyslexia) and the control group, each divided into subgroups with IQ >90 and with IQ <90, and pertaining to the relevant variables, i.e., indicators of dyslexia and motor functions.

Table 3

Means and Standard Deviations in the Assessed Variables in Four Groups: With Dyslexia and Without Dyslexia, Divided According to IQ < 90 and IQ > 90

Variables	Dyslexic group *N* = 8		Control group *N* = 50	
	IQ > 90 *N* = 30 *M* (*SD*)	IQ < 90 *N* = 28 *M* (*SD*)	IQ > 90 *N* = 28 *M* (*SD*)	IQ < 90 *N* = 22 *M* (*SD*)
Reading meaningful words (sten scores)	2.33 (0.55)	2.54 (0.59)	6.62 (1.12)	6.31 (1.03)
Deleting phonemes (sten scores)	2.67 (0.84)	2.50 (0.78)	6.14 (1.13)	6.05 (1.10)
FG (0–15 points)	7.53 (1.48)	8.71 (2.29)	7.39 (1.64)	8.25 (1.74)
MS (0–6 points)	5.23 (0.86)	4.50 (1.35)	4.00 (1.13)	4.85 (1.27)
CM (0–15 points)	6.07 (1.70)	7.88 (2.00)	5.57 (1.73)	7.10 (1.72)
MM (0–15 points)	7.87 (1.99)	10.29 (1.33)	6.86 (2.21)	9.65 (1.18)
Overall indicator	26.70 (3.72)	31.38 (4.35)	23.82 (3.79)	29.85 (3.30)

Note. FG = imitation of finger gestures, MS = movement sequence learning, CM = conflicting motor tasks, MM = performance of mirrored movements.

ANOVA Results (Intelligence and Dyslexia) in Complex Motor Tasks

Participants' scores on each motor task were submitted to a series of 2 (group: dyslexia, control) x 2 (IQ: low, high) analyses of variance (ANOVAs) with both between-subject factors. Significant interactions were followed up by Bonferroni-corrected pairwise comparisons (Table 4).

Table 4

ANOVAs Results in Four Complex Motor Tasks and Overall Indicator

	Dyslexia		IQ		IQ*dyslexia	
	F(1, 104)	η^2	F(1, 104)	η^2	F(1, 104)	η^2
FG (0–15 points)	.69 n.s.	.004	7.99**	.075	.20 n.s.	.002
MS (0–6 points)	3.73*	.036	.065 n.s.	.001	11.98**	.108
CM (0–15 points)	3.01 n.s.	.003	20.75***	.175	.146 n.s.	.001
MM (0–15 points)	5.29*	.051	52.80***	.350	.26 n.s.	.003
Overall indicator	8.25**	.078	48.77***	.332	.78 n.s.	.008

Note. FG = imitation of finger gestures, MS = movement sequence learning, CM = conflicting motor tasks, MM = performance of mirrored movements.
*** $p < .001$, ** $p < .01$, * $p < .05$; n.s. = non-significant at $p > .05$.

The results for the FG task showed that Intelligence is a source of variability while Dyslexia and interaction of the two variables are not. This shows that the Intelligence level explains only 7.5% of variance in the results related to this variable. Children with higher IQ performed the FG task better than children with lower IQ.

The results for MS show that Intelligence does not significantly affect variance of this variable, but a significant effect is found for Dyslexia itself. On the other hand, the interaction of Intelligence and Dyslexia was found to be significant as it explains nearly 11% of the variance of this variable. Pairwise comparisons (Bonferroni-corrected) in complex motor functions indicators show that in the group with dyslexia, children with lower IQ made fewer mistakes than with higher IQ (p=.021), while in the control group higher IQ corresponded to fewer errors (p=.012). Dyslexic children with higher IQ performed that task worse than controls with higher IQ (p<.000).

In the case of CM, variance is related to Intelligence. No significant effects are found for Dyslexia or interaction of the two variables. Intelligence explains nearly 18% of the variance in CM results. Children with higher IQ, regardless of whether they were dyslexic or not, made fewer mistakes than children with lower IQ.

Analysis of MM results suggests that the scores achieved by the children are explained by Intelligence (35% of variance), and to a small degree by Dyslexia (5%). No statistically significant effect was found for interaction of the two variables. In MM task, children with higher IQ made fewer mistakes than children with lower IQ and students without dyslexia made fewer mistakes then group with dyslexia. The similar result was obtained in Overall indicator.

The Correlations Between IQ Level or Reading Indicators and Indicators for the Complex Motor Functions

The last stage involved analysis of the correlations between IQ level or reading indicators and indicators for the complex motor functions. The results are shown in Table 5.

Table 5

Correlations Between IQ Level or Reading and Complex Motor Functions

	FG	MS	CM	MM	OI
Control group					
IQ	–.620**	–.360*	–.467**	–.282 n.s.	–.703**
Reading	–.052 n.s.	–.164 n.s.	–.131 n.s.	–.122 n.s.	–.169 n.s.
Dyslexic group					
IQ	–.395**	.224 n.s.	–.321*	–.536**	–.498**
Reading	.063 n.s.	–.082 n.s.	.146 n.s.	.193 n.s.	.159 n.s.

Note. FG = imitation of finger gestures, MS = movement sequence learning, CM = conflicting motor tasks, MM = performance of mirrored movements, OI = overall indicator.
** $p < .01$, * $p < .05$; n.s. = non-significant at $p > .05$.

The findings show that reading does not correlate with indicators of complex motor function in any of the groups. There is a significant negative correlation between intelligence and FG, CM as well as the overall indicator in both groups. Intelligence correlates significantly with MM scores only in the group with dyslexia, and with MS scores in the control group. It is worth noting the negative sign of all correlations indicate that higher IQ is associated with better performance in all motor tasks (fewer errors).

DISCUSSION

Developmental dyslexia is a cognitive disorder which makes it difficult for the affected children to learn about the world. Additional deficits, including those related to the motor function, may aggravate these negative effects. Earlier research in motor deficits faced by children with dyslexia investigated motor impairments as a comorbidity or focused on cerebellar deficit as a cause contributing to both these conditions. However, effects of IQ have not been investigated. The current study was designed to apply four complex motor tasks which additionally engage the processes of implicit motor learning, kinaesthetic function and motor precision, visual and executive control and mental rotation. In the present study, children with dyslexia, irrespective of their intelligence level, differ significantly from the controls as regards the overall motor indicator, which is consistent with findings reported by other researchers (Nicolson & Fawcett, 2011; Viholainen et al., 2002; Viholainen et al., 2006). However, a detailed analysis of the results shows that the two groups differ only in two types of tasks, those which involve learning of movement sequences (MS) and performing mirrored movements (MM). Therefore, it appears that motor difficulties are related to the type of task, which was shown in other studies, as well (Marchand-Krynski et al., 2017; Berninger et al., 2008; Ramus, 2003).

While performing MS tasks, children with dyslexia did not learn as quickly as the controls, which is indicative of impaired implicit motor learning, reported in other publications (Hedenius et al., 2013; Stoodley et al., 2006; West et al., 2019). This finding also supports the assumptions of the cerebellar hypothesis of dyslexia, since implicit motor learning correlates with the operation of cerebellar networks (Nicolson & Fawcett, 2011). At the same time, this type of task requires executive control and is thought to be an indicator of executive functions (Luria, 1976), therefore the difficulties observed in the group with dyslexia are suggestive of executive deficit in dyslexia, which is consistent with other studies (cf. Helland & Asbjørnsen, 2020). Scores of the whole group in tasks involving learning of movement sequences showed that Intelligence does not significantly affect variance of this variable. On the other hand, the interaction of Intelligence and Dyslexia was found significant. Children with dyslexia and lower IQ made fewer mistakes, while in the control group higher IQ corresponded to fewer errors. This was an unexpected finding. Possibly, children with dyslexia and higher IQ, being aware of their motor difficulties, while performing the task tried to use auditory memory strategy, which involved naming specific movements (this in fact was observed during the tasks). This, however, proved to be ineffective and made it more difficult for the children to perform the task, because auditory sequential memory is also impaired in dyslexia (Lipowska, 2011). However, this interpretation is hypothetical because during the current study the children were not asked to report the strategies applied, therefore further research related to this aspect is necessary.

In MM tasks, where mirrored movements required involvement of spatial perception and mental rotation, performance of the children with dyslexia was significantly poorer than in the control group. Mental rotation in dyslexia has been investigated by researchers because symptoms of dyslexia include difficulties in accurate identification of letters which are similar in shape but differ in terms of spatial arrangement. Most studies report poorer performance in tasks assessing mental rotation, however the materials commonly used in the related tests are of visual nature and comprise letters or shapes similar to letters (Rusiak et al., 2007; Russeler et al., 2005; Kaltner & Jansen, 2014). In the current study, the mental rotation function was involved in a motor activity. The findings show that children with dyslexia are significantly less successful in this type of task than their peers with good reading abilities, which suggests that difficulties in mental rotation also appear in motor activities. These results confirm that dyslexia may be associated with cerebellar deficits, because this brain region is involved in motor functions as well as mental rotation. The quality of performance in the entire study group was significantly related to Intelligence, and to a small degree to dyslexia. As much as 35% of the variance in the task performance is linked to Intelligence, and 5% to diagnosed dyslexia. Children with higher IQ made fewer mistakes than children with lower IQ and students without dyslexia made fewer mistakes than the dyslexics. Hence, it is possible that some children with dyslexia present difficulties in complex motor tasks mainly because of the lower level of intelligence.

The remaining two tasks, i.e., imitation of finger gestures and conflicting motor tasks, did not differentiate the children with and without dyslexia. Results of the two-way ANOVA, taking into account effects of Intelligence and Dyslexia, showed that intelligence level is a source of variance in the finger gesture imitation task, while Dyslexia alone and interaction of the two variables are not. This shows that deficits in precision of motor performance can be observed in children with lower IQ, whether or not they are affected by Dyslexia. A similar situation was found in the case of conflicting motor tasks (CM). Difficulties in performing CM tasks (which require switching of movements) were observed in children with lower intellectual abilities, irrespective of the diagnosis of dyslexia. Executive functions play an important role in such tasks, and this may explain the finding. Other studies involving subjects with dyslexia reported deficits in executive functions, including inhibitory control and shifting, which were engaged in this task (Varvara et al., 2014; Moura et al., 2015; Chung et al., 2020). Hence, students with dyslexia, lower IQ and presenting executive deficits will have difficulties performing complex motor tasks of conflicting nature.

The analyses suggest that reading ability does not correlate with indicators of complex motor functions in any group. There are significant negative correlations between Intelligence and FG, CM or the overall indicator in both groups differing in reading ability. The conclusion that performance in FG and CM tasks and in the overall indicator to some degree depends on Intelligence is also supported by ANOVA results where Intelligence explains 7.5% of the variance in FG, 17.5% of the variance in CM and 33% of the variance in the overall indicator. Intelligence correlates significantly to the scores in the MM task only in the group with dyslexia and in the MS task in the control group. These are the tasks in which the findings show inter-group differences between the children with and without dyslexia. This suggests that the varied relationships between intelligence and complex motor functions in the two groups may contribute to the existing differences. A high negative correlation in the group with dyslexia was found between intelligence and motor task with mental rotation. Higher IQs coincided with fewer errors. Since children with dyslexia have problems with mental rotation, they may use higher intelligence as a compensatory mechanism (Pietsch et al., 2017).

CONCLUSION

Students with dyslexia present problems in complex motor tasks, but this depends on the type of motor task and the functions involved. Children with dyslexia and the controls were differentiated by the difficulties in the tasks which involved learning of movement sequences, and in motor tasks requiring mental rotation, which supports the hypothesis of cerebellar deficit in dyslexia. At the same time, analysis of performance effectiveness in the whole group showed that the level of complex motor skills is significantly related to children's intelligence level or to the interaction between intelligence and dyslexia. Child's intelligence explains from 7.5% to 35% of the variance in motor skills. The present study contributes to our understanding of the motor skills in dyslexia and their association with intelligence level.

LIMITATIONS

The testing of intelligence in the dyslexia group was done in the psychological clinics, whereas the testing of the control group was done by the author of the text. These differences may have had some bearing on the results obtained in the WISC-R. However, the assumptions and psychometric properties of the intelligence test state that the results are independent of the examinee.

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