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Does neuromotor immaturity represents a risk for acquiring basic academic skills in school-age children?

Da li neuromotorna nezrelost predstavlja rizik za usvajanje bazičnih akademskih veština kod dece školskog uzrasta?

Lidija B. Ivanović, Danijela Ilić Stošović , Snežana Nikolić, Veselin Medenica

University in Belgrade, Faculty for Special Education and Rehabilitation, Belgrade, Serbia

Abstract

Background/Aim. Studies that investigated the presence of soft neurological signs in terms of neuromotor immaturity and impact on the ability of reading, writing and calculation are rare. At school age, cognitive development in children of the typical population is monitored over, while much less was focused on motor development. This is one of the important reasons for conducting this research. The aim of this study is to determine whether neuromotor immaturity of children poses a risk for the adoption of the basic academic skills in school children. Most authors investigated the presence of dysgraphia, dyslexia and dyscalculia in clinically diagnosed conditions. **Methods.** The data were obtained by testing. To assess neuromotor maturity, The Developmental Screening Test was used. The quality of handwriting was evaluated according to the criteria proposed by Simner and Eidlitz. Quality of reading skills is assessed by the Three-dimensional Reading Test. Evaluation of the presence of difficulties in numeracy was performed by a series of adapted tasks, taken from the Romanian Screening Instrument for Dyscalculia. **Results.** The sample was divided into two groups of pupils according to the results. The groups consisted of students with and without the presence of neuromotor immaturity. There was a significantly higher prevalence of students with difficulties in reading, writing and numeracy in the group of neuromotor immature students. **Conclusion.** The results clearly indicated that neuromotor immaturity of children represents a risk to the adoption of the basic academic skills in children in school age. We believe that the school age is very important time to monitor motor development of a child to the same extent as the cognitive development. In this way, we would have the opportunity to intervene on time and reduce a possibility of school failure. Wider studies in this area are urgently needed.

Key words:
specific learning disorder; child development; child; risk factors.

Apstrakt

Uvod/Cilj. Retka su istraživanja koja istražuju prisustvo blagih neuroloških simptoma u smislu neuromotorne nezrelosti i uticaj na sposobnosti usvajanja čitanja, pisanja i računanja. U školskom uzrastu najviše se prati kognitivni razvoj dece opšte populacije, a mnogo manje motorni, te je ovo jedan od bitnih razloga za sprovođenje ovog istraživanja. Cilj ovog rada je bio da se utvrdi da li neuromotorna nezrelost dece predstavlja rizik za usvajanje bazičnih akademskih veština dece u školskom uzrastu. Uobičajeno se ispituje prisustvo disgrafije, disleksije i diskalkulije kod klinički dijagnostikovanih stanja. **Metode.** Podaci su dobijeni testiranjem. Za procenu neuromotorne zrelosti korišćen je *Developmental Screening Test.* Kvalitet rukopisa je procenjen prema kriterijumima koje su predložili Simner and Eidlitc. Kvalitet čitanja je procenjen Trodimenzionalnim testom čitanja. Prisustvo poteškoća pri računanju procenjeno je adaptiranim Rumunskim skrining testom za procenu prisustva diskalkulije. **Rezultati.** Uzorak je prema dobijenim rezultatima podeljen u dve grupe učenika, onih sa i onih bez prisustva neuromotorne nezrelosti. Nađena je statistički značajno veća prevalencija učenika sa poteškoćama čitanja, pisanja i računanja u grupi neuromotorno nezrelih učenika. **Zaključak.** Dobijeni rezultati nedvosmisleno pokazuju da neuromotorna nezrelost dece predstavlja rizik za usvajanje bazičnih akademskih veština kod dece školskog uzrasta. Zbog toga smatramo da je u školskom uzrastu veoma bitno pratiti i motorni razvoj deteta u istoj meri kao i kognitivni, kako bi se na vreme intervenisalo i kako bi se smanjila mogućnost neuspeha deteta u školi. Potrebna su dalja istraživanja u ovoj oblasti.

Ključne reči:
učenje, poremećaji; deca, razvoj; deca; faktori rizika.

Correspondence to: Veselin Medenica, University in Belgrade, Faculty for Special Education and Rehabilitation, Juhorska 33, 11 000 Belgrade, Serbia, Email: veselin.medenica@gmail.com

Introduction

The growth and development of each child follow, to some extent, certain norms [1–5], however, the maturation of certain structures do not happen simultaneously in all children, but has an individual character [6, 7]. This means that in a group of peers, maturation of neural structures in some children comes earlier and in some later. When a child comes to a school setting, i.e., education system, certain expectations appear in front of him. A child should achieve designed educational and behavioral goals. Achieving these objectives will be realized through learning and interaction with peers. The achievements of each child are expressed through the evaluation of acquired materials and behavior. The question is to what extent the immature neurological structure can affect failure in school.

In order to answer this question we need to know in which way we can estimate the level of neuromotor maturity of child. The appearance and disappearance of primitive reflexes in babies show maturation of the central nervous system (CNS). The assessment of presence, or absence of these reflexes determines degree of maturity of the CNS. In this way, one can follow the development of the child and, if necessary, intervene. Primitive reflexes never disappear completely, but should be inhibited, as higher-order centers in the mature brain. They can remain active in damaged higher centers at an early age, such as in the cerebral palsy, or they are present at a later age due to the brain injury and stroke, or as a result of various diseases such as Alzheimer's disease or multiple sclerosis. Goddard [1] states that according to the medical theories, primitive reflexes should not be active in a typical population after six months, and after six months they are considered to be pathological. On the other hand, increasing evidence support the fact that traces of primitive reflexes (residual reflexes) in the general population can remain active even after this age, while any pathological changes that cause this phenomenon cannot be identified [8–13]. Therefore, Goddard [1] defines the presence of primary reflexes in children older than six months as an indicator of neuromotor immaturity. The same author suggests that neuromotor immaturity represents the retention of immature forms of motor control. Goddard [1] states that the retention of immature forms of motor control includes persistent primitive aberrant reflexes in children of school age, as well as posture problems as a reflex of antigravity adaptation of the body and difficulty in balance. The balance represents a dynamic process which is related to relations of different forces of gravity and skeletal muscles. The balance is the final product between the proprioception, vestibular function and vision. The mediator of this process is the cerebellum. Therefore, the author states that neuromotor immaturity means problems in the fields of postural control, coordination, control of movement of the eyeball, perception (vertigo, a sense of direction) and vegetative symptoms (dizziness, disorientation). For the purposes of this study, we accept this kind of approach.

Studies that show that in a number of school-age children remain to persist primitive reflexes to some extent are scarce [8–13]. These studies mainly deal with the population of children with neurodevelopmental disorders and clinically verified behavioral problems, and to a much lesser extent, with learning difficulties and behavioral problems in the typical population of school-age children. Basic academic skills are those skills that are the basis for the success of students in school. According to Wittrock [14] and his extensive review of the relevant literature, there are seven areas of academic skills: writing, reading, mathematics, science, art and aesthetics, moral and educational values and social studies. As Wittrock states, some of these areas, represent the core or basic academic skills for most people. In this paper, as basic academic skills we considered reading, writing and numeracy. The difficulties in acquiring the basic academic skills were seen as “difficulties in reading”, “difficulties in writing” and “difficulties in numeracy”.

McPhillips and Sheehy [12] researched the prevalence of presence of primitive reflexes and motor disorders in the children who had difficulties in reading on a sample of school-age children in Ireland. The analysis showed that there was a difference in the degree of presence of asymmetric tonic neck reflex (ATNR) between the group of children who were the best and the group of children who were the worst readers. This is one of researches that clearly indicates the connection between persistence of primitive reflexes and acquiring reading skills in children. McPhillips, Hepper and Mulhern [10] published the results of research which evaluated the effects of a program that aimed to make the inhibition of ATNR in order to improve reading skills. In a sample of 98 children (27 girls and 71 boys) the program proved to be successful. The degree of presence of reflexes was reduced in the experimental group in which the children received a treatment, and consequently, improved the quality of reading.

Similar results were encountered in the study of Goddard [8]. The methodology proposed by Goddard [8] , unlike previous research, examined not only reflexes but also the presence of many aspects of neuromotor maturity.

The author examined the presence of neurological dysfunctions as a significant factor in the children with dyslexia. A variety of tests investigated the presence of primitive reflexes, postural reactions of ocular-motor functioning, visual-perceptual performance, cerebellar signs, presence of dysdiadochokinesia. In respect of reflexes, there were ATNR and tonic labyrinthine reflex (TLR) in all children. The Moro reflex, symmetric tonic neck (STN), spinal Galant reflex, palmar grasp reflex and hand-to-mouth reflex were present only in a certain percentage. The oculomotor dysfunctions were found in 92% of the sample, in which 83% of children had difficulties in the eye-hand coordination, 42% had difficulties in visual discrimination, 98% had problems in the field of visual-motor integration. McPhillips and Sheehy [12] examined only persistence of reflexes in the children with reading difficulties while Goddard [8] used more comprehensive methodology and examined not only the persistence of reflexes but also other aspects of neuromotor immaturity in the children with reading difficulties. Taylor et al. [13] used the methodology by Goddard [8], but examined some aspects of neuromotor immaturity in the children with the attention deficit hyperactivity disorder (AD/HD).

Most of the research started by isolating a group with specific learning difficulties, and then the presence of neuromotor immaturity aspects were analyzed. This approach is justified when studing clinically diagnosed specific learning difficulties (dyslexia, dysgraphia, dyscalculia) because in this case a characteristic of pathological condition is studied. When a disorder is not diagnosed, we believe that it would be preferable to observe from the opposite perspective, i.e., to examine whether neuromotor immaturity affects the acquiring basic academic skills. We believe that it would be appropriate to first identify the children with neuromotor immaturity, and then deal with the level of maturity and then with the relationship of the level of maturity and the presence of learning difficulties.

The basic academic skills, stage of intellectual development and behavior of children are some of the preconditions for the success in educational and pedagogical outcomes, and thus, of academic achievement. The field of studying neuromotor maturity of children and its impact on these preconditions has not been researched enough. Also an important research related to the relationship of neuromotor maturity and difficulties in numeracy are scarce. Therefore, there is a need to pursue research in this area and to indicate the possible existence of risk of neuromotor immaturity for academic achievements and ability to meet the basic educational and pedagogical goals for the school-age children.

The main objective of this research is to determine the relationship between the presence of neuromotor maturity of school-age children and acquiring basic academic skills.

Methods

The research was conducted in primary schools in the municipalities of Topola and Aranđelovac in Serbia in 2015. A sample consisted of pupils from three primary schools: the primary school "Živko Tomić" (Topola), the primary school "Dušan Radonjić" (Aranđelovac) and the primary school "Ilija Garašanin" (Aranđelovac). The conditions for the inclusion of pupils in the sample were written consents of the institution and parents. First graders were not included in the sample because of the possibility of insufficient data on school achievements, as well as the fact that the teachers did not know them sufficiently to be able to give expert opinions about the school life of pupils. The sample did not include those pupils who are classified in the group of persons with disabilities as well as the pupils who were diagnosed with some of the diseases of the nervous and muscular system, the pupils who were diagnosed with some psychiatric illness, the pupils with intellectual disabilities, autism spectrum of disorders, those with a history of pregnancy, the familial antecedents and the neuropsychomotor development problems.

Before conducting research and sampling, we obtained the written consents of these schools, as well as the approval of teachers, class masters and the parents of children planne ed to be included in the sample. The preliminary sample consisted of 327 pupils of the second, third and fourth grades. Of that number, for 21 pupils, it was not possible to obtain the necessary parental consents. The criteria for inclusion in the sample were not fulfilled for 18 pupils. The final sample consisted of 288 pupils. At the time of testing, 29 pupils were absent from class. For 3 pupils, the teachers did not submit the complete documentation regarding demographic caracteristics. Therefore, the final sample consisted of 256 tested pupils. Of the total sample, 51.20% were males. The pupils were 9.73 year old on average [standard deviation (SD) = 0.88]. The youngest pupil was 7.75 year old, and the oldest was 11.42 year old. The sample was balanced by the number of pupils who participated from each grade, by gender and by age.

The general data on pupils were collected from the general documentation and from their parents. The data on the degree of neuromotor maturity, difficulties in writing, reading and numeracy were collected directly from the pupils through techniques of observation, scaling and testing capabilities.

Assessment tools

The general data were obtained by a specially designed questionnaire. The questionnaire included information on gender, age, school attended, grade, class, dwelling place.

Neuromotor maturity of pupils was estimated by the Developmental Screening Test for Use with Children from 7 Years of Age [1]. The Developmental Screening Test consisted of the Tests of rough muscle coordination and balance [15, 16], the Tests of pathological reflexes [17, 18], the Tests for the assessment of oculomotor function [19] the Tests of visual language recognition [1], the Tests of visual perception and visual-motor integration [20, 21]. Each of the tests scored at five-point scale from 0–4. The total score of all tests was calculated as the sum of scores of all individual tests which was divided by the maximum possible achievement and then multiplied by 100.

The evaluation of the presence of difficulties in writing was done with the use of handwriting samples of children that was obtained by a dictation. The generally accepted pangram was used for the testing in this field [22]. The children wrote the handwriting samples in capital letters in Cyrillic script on white paper without lines. The evaluation of sampled handwriting was performed by the criteria proposed by Simner [2] and Eidlitz [3]. The authors defined 28 types of errors that can occur and be noticeable in a handwriting sample obtained from a child. For each error type, the frequency of occurrence was counted. A total score represented the sum of frequencies of occurrence of all types of errors.

The evaluation of the presence of difficulties in reading was performed by the Three-dimensional reading test [4], which was adapted for the use in domestic conditions at the Institute for Experimental Phonetics and Speech Pathology in Belgrade. The test examined the number of irregularities and errors as well as the understanding of the text. The duration of the test was 5 minutes. The test examined the presence of errors in reading. The total number of errors was recorded on an individual list. When the child read the text, his task was to reword that text. The test had a list of 10 facts which the student should indicate by rewording the text. The individual list recorded the number of words the student said while rewording [4].

The evaluation of the presence of difficulties in numeracy was performed by a series of adapted tasks, taken from the Romanian screening instrument for dyscalculia [5]. The original version of test consisted of 13 tasks. For the purpose of this study we selected 6 tasks found by the factor analysis, that were very important in the context of the test [5]. The tasks were adapted to the educational standards for the subject of mathematics of the Ordinance on education standards for the end of the first cycle of compulsory education for subjects of Serbian language, mathematics and nature and society, but with adjustment to the age levels and grades curriculum. Each task was scored as 0 or 1. The maximum score was 7.

Results

We used the scoring guidelines in order to get the scores on the instruments. The Table 1 shows the results on all used instruments.

Table 1

Scores on all used instruments

Instrument	mean (SD)
DST	17.91 (9.50)
TRMCBR	11.79 (10.63)
TVMI	30.91 (19.46)
TASR	6.71 (8.92)
TVPVMI	21.08 (14.21)
Writing errors	8.58 (9.51)
Reading	
Reading errors	5.03 (5.16)
Remembered facts	3.01 (1.51)
Test of numeracy	4.82 (1.64)

DST – Developmental Screening Test; TRMCBR – Tests of rough motor coordination, balance and reflexes; TVMI – Tests of visual monitoring and integration; TASR – Tests of auditory – speech recognition; TVPVMI – Tests of visual perception and visual-motor integration; SD – standard deviation.

After we obtained the results, we calculated the z-scores for each pupil, for all instruments. The z-scores were calculated relative to the average scores of grades on the individual instruments.

After calculating the z-scores, we created two groups, a group of neuromotor immature pupils and a group of neuromotor mature pupils. If the z-score was equal or less than 1, we considered that the pupil belonged to the group of pupils who had a proper neuromotor maturity. If the z-score was greater than 1, we considered that the pupil had neuromotor immaturity.

To compare the prevalence of difficulties in acquiring basic academic skills and behavior in these two groups, we also calculated the z-scores for each pupil on each instruments. By the same token, the pupils were classified into the group of those with difficulties and those without noted dificulties. As a suitable statistical technique for determining existence of a statistically significant difference in the difficulties prevalence in the group of neuromotor mature and neuromotor immature pupils, we used the nonparametric χ^2 test.

Comparison of groups of pupils with and without neuromotor delay according to the percentage of pupils with difficulties in writing

According to the z-scores in the Test of writing, the pupils were also divided into two groups. The first group consisted of those pupils whose z-scores were equal or less than one. This was a group which we called the group without problems in the field of writing. The second group consisted of those pupils whose scores were greater than one. This was a group with difficulties in writing.

Using the χ^2 test, we compared whether the group of pupils with neuromotor immaturity had a higher percentage of pupils with difficulties in writing than the group of mature pupils. The expected frequency in a cell (25%) was not greater than 5, and we used the Fisher's test besides the χ^2 test. The χ^2 test of independence (with use of the Fisher's test) showed a statistically significant relationship between the status of neuromotor maturity and the status of writing ability, χ^2 (1) = 7.100, p = 0.008. The Fisher's test was significant at the 0.015 level, φ = 0.17. The differences between groups are presented in Table 2.

Table 2

Comparison of groups of pupils with and without neuromotor delay in relation to the level of writing acquisition

Group	WODW	WDW
	n (%)	n (%)
NMM	194 (90.65)	20 (9.36)
NMI	32 (76.19)	10 (23.81)

NMM – neuromotor mature; NMI – neuromotor immature; WODW – without difficulties in writhing; WDW – with difficulties in writing.

Comparison of groups of pupils with and without neuromotor delay according to the percentage of pupils with difficulties in reading (errors)

Using the χ^2 test, we compared whether a higher percentage of pupils with reading difficulties (errors noticeable when reading) was in the group of pupils with neuromotor immaturity than in the group with the neuromotor mature pupils.

According to the z-scores on the Three-dimensional test of reading (reading error), the pupils were also divided into two groups. The first group consisted of those pupils whose z-scores were equal or less than one. This is a group which we called the group without difficulties in reading. The second group consisted of those pupils whose scores were greater than one. This was the group with difficulties in reading.

The expected frequency in a cell (25%) was not greater than 5, and we used the Fisher's test besides the χ^2 test. The χ^2 test of independence (with use of the Fisher's test) showed a statistically significant relationship between the status of neuromotor maturity and the status of reading ability, χ^2 (1) = 29.745, $p < 0.001$. The Fisher's test was significant at $p < 0.001$, φ = 0.34 (Table 3).

Table 3

Comparison of groups of pupils with and without neuromotor delay in relation to the level of reading acquisition (errors)

Group	WODR	WDR
	n (%)	n (%)
NMM	200 (93.46)	14 (6.54)
NMI	27 (64.29)	15 (35.71)

NMM – neuromotor mature; NMI – neuromotor immature; WODR – without difficulties in reading (errors); WDR – with difficulties in reading (errors).

Comparison of groups of pupils with and without neuromotor delay according to the percentage of pupils with difficulties in reading (memorizing facts)

Using the χ^2 test, we compared whether there was a higher percentage of pupils with reading difficulties (memorizing the reading text) in the group of pupils with neuromotor immaturity than in the group with the neuromotor mature pupils.

According to the z-scores of the Three-dimensional test of reading (memorizing facts), the pupils were also divided into two groups. The first group consisted of those pupils whose z-scores were equal or greater than minus one. This was a group which we called the group without difficulties in remembering the text they had read. The second group consisted of those pupils whose scores were lower than minus one. This is the group with difficulties in remembering the text they had read.

The expected frequency in all cells was greater than 5. The χ^2 test of independence showed a statistically significant relationship between the status of neuromotor maturity and the status of capability to remember the text they had read, χ^2 (1) = 12.116, p <0.001, φ = -0.22, p < 0.001 (Table 4).

Table 4

Comparison of groups of pupils with and without neuromotor delay in relation to the level of reading acquisition (memorizing facts)

Group	WODR	WDR
	n (%)	n (%)
NMM	185 (86.45)	29 (13.55)
NMI	27 (64.29)	15 (35.71)

NMM – neuromotor mature; NMI – neuromotor immature; WODR – without difficulties in reading (facts); WDR – with difficulties in reading (facts).

Comparison of groups of pupils with and without neuromotor delay according to the percentage of pupils with difficulties in numeracy

According to the z-scores of the Screening test for evaluation of presence of dyscalculia, the students were also divided into two groups. The first group consisted of those pupils whose z-scores were equal or greater than minus one. This is a group which we called the group without difficulties in the field of numeracy.

The second group consisted of those pupils whose scores were lower than minus one. This is a group with difficulties in the field of numeracy.

The expected frequency in all cells was greater than 5. The χ^2 test of independence showed a statistically significant relationship between the status of neuromotor maturity and the level of ability in numeracy, χ^2 (1) = 46.815, p <0.001. φ = -0.43, p < 0.001 (Table 5).

Table 5

Comparison of group of pupils with and without neuromotor delay in relation to the level of numeracy acquisition

Group	WODN	WDN
	n (%)	n (%)
NMM	198 (92.52)	16 (7.48)
NMI	22 (52.38)	20 (47.62)

NMM – neuromotor mature; NMI – neuromotor immature; WODN – without difficulties in numeracy; WDN – with difficulties in numeracy.

Discussion

Neuromotor maturity and writing ability

The study showed a difference in the prevalence of writing difficulties in the neuromotor mature pupils compared to the group with neuromotor delay. In the group of neuromotor mature pupils, even 90.65% had no difficulties in writing, while this percentage was significantly lower for the group of pupils with neuromotor delays and was 76.19%. These percentages were consistent with researches of foreign authors stating the prevalence of dysgraphia in the typical population of children and amounts between 5%–33% [22]. In our research, we did not clinically determine the presence of dysgraphia but we evaluated the presence of difficulties in writing skills acquisition. In the group of neuromotor mature pupils, the percentige of difficulties in writing was closer to the lower limit of dysgraphia prevalence, while the prevalence of difficulties in writing in the neuromotor immature children was closer to the upper limit of reported prevalence of dysgraphia.

Writing is an ability that belongs to a group of basic academic skills. Pupils are expected to learn writing in first grade. Already in the second grade, the writing acquisition was a default for performing schoolwork and evaluation. Writing serves to express the acquired knowledge planned by the curriculum. Delays in the adoption, or non-adoption of writing can cause a failure in school.

There are no studies dealing with the relationship of neuromotor immaturity and writing. For this reason, we compare obtained results with the results of other research covering the relationships of some of the aspects of neuromotor maturity and writing. Since neuromotor immaturity by definition we gave in the introduction involves persistence of pathological reflexes, problems of postural control, coordination, control of the eyeball movement, perception and vegetative symptoms (dizziness, disorientation), we will observe difficulties in writing in the context of these problems.

Our research clearly shows that there is a greater risk of reporting difficulties in writing with the neuromotor immature children compared to neuromotor mature ones. Our goal was just to point out the existence or absence of risk of neuromotor immaturity.

Other authors have dealt with the relationship of certain aspects of immaturity and writing, however, it should be noted that this issue has been mainly dealt in the population of children with diagnosed disabilities and verified diagnoses but not in the typical population of children.

Marović et al. [23] investigated the relationship of the presence of neurodevelopmental delays in children of typical population of children aged between two and five years and drawing. Drawing contains certain elements necessary for the adoption of writing, but certainly we cannot put a sign of equality between drawing and writing. However, this study is one of the few that is related to the typical population of children and has a similar methodological approach as our research. The authors confirmed that the presence of neurodevelopmental delay negatively affected drawing skill and especially at the age of three to four years, i.e., the period in which the child should begin to draw the first simple geometric figures. Children who have more experience in drawing, especially drawing geometric shapes learn to write much easier [24]. In the neuromotor maturity testing, we used the Visual-motor integration test (VMI), which involved copying geometric shapes and it was a recognized indicator of ability of learning to write. Besides visual-motor coordination, the motor planning, cognitive and perceptual abilities and precise and accurate processing of tactile and kinesthetic information are indicators for the adoption of writing [25]. Most of these aspects is contained in the concept of neuromotor immaturity in the way we defined it.

The presence of residual reflexes may also negatively affect learning how to write. Abnormal and primitive postural reactions negatively impact on the eye-hand coordination that is much needed for the learning to write. Literature recognizes residual ATNR as the cause for not adopting writing skills. When conducting research, we saw an example of a 12-year-old boy with the presence of residual ATNR. When writing, the boy was sitting on the left leg and his arm was slightly flexed. His head was turned slightly to the right and he read mainly by left eye. A pencil grip was too tight. The boy was so focused to maintain control over his own body, that he was not able to listen, visually monitor, nor to take notes. Residual ATNR, according to the literature, may compromise the hand-hand control when head is turned to one side, the ability of crossing the midline of the body which affects the left-right orientation [26, 27]. It can also impair control of the hand in writing [28], and visual skills necessary for reading and visual tracking [29, 30]. If residual symmetrical tonic neck reflex (STNR) is not repressed in school age, this can negatively affect posture when sitting, and to a great extent determines the quality of writing. If the residual STNR is present, the child does not have the ability to sit still and can lead to coordination problems. Residual palmar reflex can jeopardize the correctness of grip in writing.

The influence of eye movement and vestibular ocular reflex on reading and writing is verified [31]. Sales and Colafêmina found that the pathological changes of saccades and pendulous movements of the eye that serve tracking opened up the possibility for appearing the difficulties in reading and writing. The survey was conducted on a sample of children aged from 9 to 14 years with and without disabilities in reading and writing.

One study, that examines the verified pathological conditions in children, compared three groups of children, clumsy, children with dysgraphia and children of typical population according to the quality of handwriting and perceptual-motor skills [32]. Of all tested perceptual-motor skills only the visual-motor integration predicted the quality of handwriting in the whole sample of 59 ten-year-old children. It was confirmed that the quality of handwriting is very strongly associated with the visual integration, visual perception and tracking at the level of the entire sample. What is interesting and may help to explain the results of our research is the fact that children with dysgraphia had the lowest scores on the tests of visual-motor integration compared to the other two groups of children.

Persistence of reflexes, problems with coordination, posture, balance, visual perception and integration can affect the acquiring and quality of writing in children. All these difficulties, when are not an integral part of a verified pathology in the children, can be subsumed under a single umbrella term – neuromotor immaturity. Based on these results and the results of other authors supporting and valorizing the results of this study, we can conclude that each of the aspects of neuromotor maturity individually can have an impact on the acquisition of writing, and neuromotor immaturity of children undoubtedly represents a risk to the acquisition of writing in the school- age children.

Neuromotor maturity and reading skills

In the research, we evaluated two aspects of reading, namely, errors in the production from the reading text and memorizing facts from the text they had read. Analysing errors of pupils made in reading we found a difference in the quality of reading in the neuromotor mature and neuromotor immature children. The vast majority (93.46%) had a very small number of errors in reading, so they practically have no difficulties in reading. In the neuromotor immature children, only 64.29% of them had no difficulties in reading. The difference in the prevalence of reading difficulties is very large and statistically significant.

Analyzing the second aspect of reading that we examined, i.e., memorizing facts from the reading text, we found the similar tendencies in the prevalence of difficulties between the two mentioned groups of children. In the group of neuromotor mature pupils, the vast majority, or 86.45% of them had no difficulties in memorizing the text they read. Only 64.29% of the pupils belonging to the group of neuromotor immature pupils had no difficulties to remember facts from the reading text.

Neuromotor immaturity of children is a risk for learning how to read in children. Possible reasons can be sought in the relationship of certain aspects of neuromotor maturity and reading skills in children of school age.

Poorer performance on a variety of "cerebellar" motor tasks were reported in dyslexia [33]. Cerebellar dysfunction is an underlying cause of developmental dyslexia, which is diagnosed when there is an unexpected discrepancy between a child's reading ability and their cognitive skills. Cerebellar dysfunction leading to a procedural learning deficit could be an explanation of deficiency in acquiring literacy skills [33]. Also, the magnetic resonance imaging (MRI) studies of cerebellar differences in dyslexic children confirmed reduced grey matter in right lobule VI and reduced grey matter in left VI. It was found that the fluency component of dyslexia is associated with abnormal activation in the right lobule VI [33].

One of longitudinal studies examined how the development of speech and motor skills at the age of about the second year of life determined the ability of learning how to read [34]. The author found that the development of motor and speech skills determine reading ability at school age, but it was insufficiently at this age to make a diagnosis, classification, or to indicate a potential risk for not adopting reading. Two facts that arise from this study confirmed the results of our research. Firstly, the motor and speech skills determine reading skills. The neuromotor maturity assessment includes the evaluation of motor skills and visual-linguistic recognition. Secondly, between the second year and school age, there are more years during which the child is actively developing. However, we believe that, when it comes to the typical population, influences of motor and speech skills should not be considered separately, but as a whole, along with other aspects of neuromotor maturity.

Difficulties in reading are also a broad term and may include difficulties of verbal expression, recognition and comprehension of symbols and remembering reading text.

Researches of residual reflexes support our results. When there is a residual ATNR, it prevents proper tracking, and eye tracking forward and backward (saccades), which is absolutely necessary to read. Crossing the midline, can be impaired, and the child tracks line by whole his head instead by view. The presence of ATNR in school age may prevent eyes coordination function which induces blurred vision and diplopia. Also, its presence means that adequate connection between the brain hemispheres (*corpus callosum*) do not develop and the dominance of the brain functions do not develop properly. These links mature naturally at the age of 6.5 to 7.5 years and there are often mirrored letters to that period, but not after being 8. Inadequate development of *corpus collosum* restrains preference of skills for which the right side of the brain should be responsible the left side contributing to the difficulties of children with dyslexia. There are often present difficulties in the remembering, spelling, learning, sense of direction. Without the developing the dominance of hemispheres, the lateralization and development of a sense of direction are prevented. Centers for decoding language are in the left hemisphere of the brain, thus ATNR can inhibit the development of language skills such as reading and writing. ATNR is stimulated by the vestibular system, which means that this system would be less developed, resulting in problems of balance and coordination. Many previous studies confirm that the use of cerebral-vestibular tests in combination can, to some extent, detect learning disabilities such as dyslexia and attention deficit disorder (ADD) [35, 36]. Levinson [36] even concluded that dyslexia and ADD are a reflection of deeper cerebral-vestibular determinants. When tonic labyrinthine reflex (TLR) is restrained, it often affects the problem of the spatial orientation and especially confusion on distance of things, what is in front and what is behind. In reading, for example skipping lines may occur.

There are studies that explored the potential impacts of postural control on reading skills. Loras et al. [37] state that there are opposing views on whether postural control affect the quality of reading. The studies that confirm this influence, Loras et al. [37] state, do not deal with the nature of this relationship nor explain it. Loras et al. [37] find in his research that there is no statistically confirmed link between the abilities of balance and reading results on the cognitive tests or tests of attention. It should be noted that the sample consisted of 100 people aged above 20 years.

This study affirms that not all aspects of neuromotor maturity affect the reading skills in children, but the vast majority do. Our results confirm that neuromotor immaturity of children poses a risk to the acquisition of reading in children. The review of studies that deal with the relationship of aspects of neuromotor immaturity and reading, largely affirm the results.

Neuromotor maturity and numeracy skills

The research showed that a number of pupils have difficulty in numeracy. In the group of pupils who were neuromotor mature, 92.52% of them had no difficulties in numeracy, while in the group of pupils with neuromotor immaturity only 52.38% of them had no difficulties in numeracy. Since we used tasks from the test designed for screening dyscalculia to detect difficulties in numeracy, we would compare the obtained result with the results of other studies in the field of developmental dyscalculia. The prevalence of developmental dyscalculia is 3%–6% [38]. In our study, it was found that there were problems of numeracy in 7.48% of children in the group of neuromotor mature children. Possible reasons for a slightly higher percentage than that reported in the literature can be found in the fact that the cause of dyscalculia can often be explained by the presence of dyslexia. Also, the difficulties in numeracy were much more common in the children from rural areas as compared to those from urban areas. Our sample consisted of children mostly from rural areas.

In the children with neuromotor immaturity, the difficulties in numeracy were present in a large percentage, and therefore, the neuromotor immaturity represents a risk for the acquisition of numeracy skills. The question is whether the risk is direct or indirect. The acquisition of mathematical operations and numbers is very complex. Mathematical operations are diverse and involve a whole range of skills that are required for their performance. It is believed that the performance of arithmetic operations requires primarily cognitive and much less motor skills. In this sense, we can consider that reduced cognitive abilities can be the most important direct causes for difficulties in performing arithmetic operations. We would try to eleborate the results we got and establish a potential connection between the neuromotor immaturity and presence of difficulties in numeracy.

In 1970, Ladislav Kosc [39] defined developmental dyscalculia as a structural disorder of mathematical skills which origin stemmed from genetic or congenital disorders of those parts of the brain that were direct anatomical-physiological substrates of maturation of mathematical abilities in accordance with age, without concurrent disorders of general mental function [39]. Kosc actually suggested that causes of difficulties in numeracy could be twofold, whether as a result of underdeveloped mental functions, or as a result of structural brain disorders.

It is known that a dysfunction in any hemisphere of the brain can lead to a reduced ability of acquisition of numeracy skills. The difficulties are more pronounced if the left hemisphere is compromised. It was found that the left hemisphere is in conjunction with constructive dyspraxia, poor auditory and visual discrimination and motor coordination. Within neuromotor maturity, using the Tansley standard visual figures test and the Bender test, we examined, among other things, a visual discrimination. The Tandem walk and Fog walk test require a motor coordination during the execution of the tasks. Within the assessment of neuromotor immaturity, we examined the ability of auditory discrimination. In case of our study, we do not assume structural changes in the form of brain damage, but we talk about immaturity of structures to take over functions completely and partially.

Dysfunctions of the right hemisphere in the group of children who do not show signs of structural abnormalities the MRI and computed tomography (CT) were manifested as defects in the domains of graphomotor skills, slow cognitive and motor performance, although the reading skills are preserved. Dysfunctions of right hemisphere involve various difficulties including difficulties in spatial perception. Many of the symptoms that are associated with dysfunction of the right hemisphere may also occur as a result of dysfunction of the vestibular system and associated pathways that support the processes of visual perception in the right hemisphere [9]. Risey and Briner [40] examined the relationship of the presence of central vertigo and dyscalculia and found that patients with vertigo had difficulties to count backwards and even when they were aware of making a mistake, they continued to repeat the process. Hence, the difficulties of balance may affect the acquisition of certain operations with numbers. The patients in this research also had difficulties with the mental arithmetic and central auditory processing. As part of our research, we evaluated the balance, and within the assessment of acquired mathematical operations there were tasks to repeat numbers backwards. Therefore, there is a possibility that the immaturity of vestibular function leads to a dysfunction in the field of visual and auditory processing and maybe to the difficulties in the process of mental sequencing.

Regarding the relation of persistence of residual reflexes and reporting difficulties in numeracy, we did not find in the literature that any author indicates a direct connection of these phenomena. Some of the known facts could be a link between these two phenomena. The knowledge of own body parts, especially hands and fingers is very important for learning the concept of number. The child firstly meets his/her body. Acquisition of numbers to 5 is closely related to counting the fingers of the hand. Later, the counting of physical objects comes. The speed of development of hand and grasp may have an indirect connection with the acquisition of numbers. When assessing the reflexes, the balance has a major impact on the performance of tasks and evaluation whether the residual reflex is present, or not. We have already mentioned the example of research that linked the central vertigo and dyscalculia.

Neuromotor maturity and acquisition of arithmetic operations are very complex. The obtained results suggest that there is a risk that the neuromotor immaturity bears for the acquisition of basic academic skills and acquisition of mathematical operations. We listed some of researches that support the results and indicate the nature of the risk. Such researches are scarce and very much desirable in the future.

Conclusion

There are studies referring to the verified neurodevelopmental delay and special learning disabilities such as dyslexia, dysgraphia and dyscalculia. On the other hand, research that relates to the impact of soft neurological signs and neuromotor immaturity on the possibility of the acquisition of reading, writing and numeracy are very rare. Our research gives a complete picture of the risks of neuromotor immaturity for the acquisition of these skills. This study clearly indicates that the risk of difficulties in reading, writing and numeracy is significantly higher in neuromotor immature children compared to those school children without delays. We hope that this research will support the emergence of new forms of treatments and rehabilitation procedures within the system of education. The results indicate that the neurological and motor characteristics must be considered on an equal footing with cognitive capacities in school settings because they determine the quality of basic academic skills of the child that are necessary and represent a prerequisite for learning process and achieving educational goals.

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