GRAMOTNOST, PREGRAMOTNOST
A VZDĚLÁVÁNÍ, 7, 3, 55–86

Predictors for the Development of Arithmetic Skills in Pupils of Younger School Age

Kateřina Skalová Pražáková, Klára Špačková, Anna Kucharská

Abstract: This study aims to map the predictors for the development of arithmetic skills in young school-age pupils. Specifically, the research investigation focused on comparing differences in performance between pupils with mathematical learning difficulties and a control group of pupils. The respondents performed tasks focusing on executive functions, spatial abilities, as well as estimation and symbolisation of quantities.
The performance of pupils with MLD (mathematical learning difficulties) differed from that of children without identified difficulties, particularly on tests focusing on matching number symbols and on numeracy skills alone. Significant, albeit smaller, differences between groups were also evident in non-symbolic quantity comparison and spatial skills (mental rotation). In terms of accuracy, we did not find statistically significant differences between the groups in any of the areas studied. The results indicate a close correlation between the speed of quantity symbolisation and the level of arithmetic skills.

Key words: mathematics, mathematical skills, arithmetic skills, younger school age, dyscalculia, mathematical learning difficulties

Introduction

The aim of the present study is to identify the risk factors for difficulties in the acquisition of numeracy skills among primary school pupils. We focus mainly on those indicators of difficulties in arithmetic that cannot be explained solely by the low intelligence of the individual, inappropriate teaching methods at school, or inadequate home preparation. Initially, we intended to deal with a specific numeracy disorder, i.e. **Developmental Dyscalculia (DD)**. However, due to inconsistencies in the way it is defined by different authors, we have decided not to adhere to this term strictly. Instead, we have started to use the more general

 DOI: 10.14712/25337890.4532

term ***mathematical learning difficulties* (MLD)**. Nevertheless, in selecting the respondents for our study, we have tried to at least approximate the common criteria for diagnosing dyscalculia and have focused only on pupils with intellectual abilities within the norm. Despite their preference for the MLD designation, authors Bartelet, Ansari, Vaessen, and Blomert (2014) also followed a similar approach, suggesting that the terms be treated as synonyms in their study. This study is also inspired by, among other things, research on dyscalculia. We consider it likely that some of the respondents with MLD from our study would meet the criteria for a DD diagnosis with a more detailed diagnostic procedure. We chose the MLD designation because we did not conduct a more detailed diagnosis for the purposes of this study.

Learning disabilities in mathematics (or dyscalculia), as reported by some authors (Butterworth, Varma, & Laurillard, 2011; Hannell, 2013; Kuhn, 2015; Pražáková & Špačková, 2018), have generally received less attention than, for example, difficulties in language areas and thus remain neglected in terms of research and funding. At the same time, some (Butterworth et al., 2011; Kuhn, 2015) point out that improving the level of an individual's mathematical skills would help to improve not only their quality of life but also their country's GDP. Thus, our aim is to look for ways to identify potential risks of numeracy skills acquisition problems as early as possible and to address them in a timely manner.

We believe that identifying the causes of difficulties in mathematics in individual children will help us recognise whether they are due to a lack of aptitude on the part of the pupil, or to other causes, such as inadequate teaching methods. In particular, the results of studies (Locuniak & Jordan, 2008; Stock, Desoete, & Roeyers, 2009; Presentación, Siegenthaler, Pinto, Mercader, & Miranda, 2015) conducted with preschool children before the respondents encountered formal mathematics instruction, or at the beginning of the first year of primary school (Passolunghi, Vercelloni, & Schadee, 2007), and which were later compared with their mathematics skill levels, suggest to us that the relationship between some skills and subsequent mathematics achievement may be largely causal and therefore not likely to be a simple association. Nevertheless, even in studies focusing on primary school pupils, the authors sought to compare the mathematical skills of respondents with their performance on tasks in which performance was to be least affected by school instruction. In these tasks, children were asked, for example, to compare groups of objects (e.g. dots) based on their number (numerosity) or two numbers based on their numerical value. **It is assumed that even children with specific numeracy impairments can**

manage most of these tasks correctly, but they need more time to complete them compared to children without difficulties in mathematics (e.g., Butterworth, 2003; Landerl, Bevan, & Butterworth, 2004; Landerl, Fussenegger, Moll, & Willburger, 2009; Szucs, Devine, Nobes, Gabriel, & Soltesz, 2013; Pražáková, 2017; Šamajová & Cígler, 2020). Other domains receiving attention in this context include working memory (Landerl et al., 2004, 2009; Passolunghi et al., 2007; Presentación et al., 2015), spatial ability (Locuniak & Jordan, 2008; Vágnerová & Klégrová, 2008; Stock et al, 2009; McCaskey, von Aster, O'Gorman Tuura, & Kucian, 2017) inhibition (Presentación et al., 2015; Wang, Tasi, & Yang, 2012) and logic (Stock et al., 2009; Presentación et al., 2015; Morsanyi, Devine, Nobes, & Szűcs, 2013).

In some studies (Landerl et al., 2004, 2009; Bartelet et al., 2014; Szucs, Devine, Nobes, Gabriel, & Soltesz, 2013; Pražáková, 2017; Šamajová & Cígler, 2020), computer-administered tools were used to help pupils perform the tasks. Their advantage lies in the possibility of measuring the reaction time for each item separately, in addition to the number of errors, with greater accuracy than if the administrator measured the time manually using a stopwatch. They also allow for group assignments and immediate evaluation of results.

In the following paragraphs, the research investigation into possible indicators of difficulties in mathematics will be presented in more detail. Our aim was to investigate the above-mentioned indicators of difficulties in mathematics in the Czech school environment. Furthermore, we decided to use **tablet-administered methods** for this purpose**.** In contrast to methods using computer administration, our respondents can choose an answer directly on the touch screen and do not have to divide their attention between the monitor and another part of the device (keyboard or mouse). Moreover, in contrast to research (e.g., Landerl et al., 2004, 2009; Bartelet et al., 2014; Szucs et al., 2013; Pražáková, 2017; Šamajová & Cígler, 2020) in which respondents had to choose an answer from two options when non-symbolically comparing quantities or when comparing numerical symbols, we designed some tasks so that they had to choose from three options. Our hypothesis was that this would increase the difficulty of the tasks and thus increase the differences in performance between children with and without mathematical difficulties. **In the future, we want to contribute to expanding the possibilities of diagnosing difficulties in mathematics**. Finally, potential further research is discussed.

Mathematical Abilities and Skills

The term ability can generally be understood as the potential or aptitude for a particular activity, be it sport, playing a musical instrument, etc. (Říčan, 2010). At the same time, however, it is also used to refer to the level of knowledge and skills that we have already attained and that enable us to perform various activities (Atkinson, 2003; Říčan, 2010).

Experts and researchers (cf. Landerl, Bevana, & Butterworth, 2004; Vágnerová & Klégrová, 2008; Zelinková, 2009; Jordan, 2010; Hannell, 2013; Bednářová & Šmardová, 2015) agree that multiple sub-skills are involved in solving mathematical problems and that there is no single holistic mathematical ability or skill. At the same time, we can encounter multiple ways to categorise these abilities. In the Czech Republic, the following categorisation is often used (Vágnerová & Klégrová, 2008), which also corresponds to the concept in the Diagnostic and Statistical *Manual of Mental Disorders* (5th ed.; DSM-5; American Psychiatric Association, 2013):

- understanding the nature of numbers – understanding the symbolism of numbers, the meaning of number order and inclusion (the fact that a larger number includes a smaller one),
- memory for numbers and other numeric characters,
- numeracy skills - the ability to handle numbers and apply general rules to the relationships between them,
- mathematical reasoning - specific abstract thinking that no longer depends only on concrete numbers, including the manipulation of more general concepts such as algebraic signs.

By suggesting that a number of different predictors are involved in mathematical skills, Jordan (2010) suggests a possible explanation for why **some individuals may perform relatively well in certain areas of mathematics while performing less well in others.**

In addition to cognitive predictors, a number of other factors influence the mathematical results we achieve. These include motivation (Presentación et al., 2015; Mercader, Miranda, Presentación, Siegenthaler, & Rosel et al., 2018), the socio-emotional development of the individual (Novák, 2004; von Aster & Shalev, 2007) and the influence of the family environment, among others, but these can be difficult to control (Locuniak & Jordan, 2008; Presentación et al., 2015). In this article, we focus primarily on cognitive predictors for the development of numeracy skills.

Predictors for the Development of Mathematical Skills

Some studies have sought to identify predictors for the development of numeracy skills that cannot be fully explained by inappropriate teaching styles at school or inadequate home preparation.

An important study in this respect is the investigation conducted by Landerl et al. (2004), in which the authors looked for possible causes of difficulties in mathematics in pupils with dyscalculia, dyslexia and a combination of both learning disabilities. They examined skills such as executive function, visuomotor coordination, reading and writing numbers, and estimating quantities. For some tasks, a voice recording was made to determine the exact reaction time – the time it took pupils to complete the task. The authors concluded that the main cause of dyscalculia is impaired understanding of basic number concepts, especially the idea of numerosity. This was particularly evident in the set of tasks where pupils were presented with a group of dots and were asked to quickly determine their number, but also when comparing numbers according to their numerical value. That study contributed to the development of a standardised method, the *Dyscalculia Screener* (Butterworth, 2003), aimed at screening for dyscalculia (see below).

Not all experts, however, agree with this notion of dyscalculia. For example, Osmon et al. (2006) concluded, on the basis of cluster analysis, that dyscalculia can be classified according to the causes of the difficulties as deficits in executive functions, in spatial abilities, or dual (mixed) deficits in spatial and executive functions. Bartelet et al. (2014) also performed a factor analysis in children with MLD, which yielded several groups of different sizes, divided according to impairments in different domains. These included a subtype of MLD with the so-called weak mental number line subtype, which was manifested in the placement of digits on a number axis, a group with impairment in the approximate number system (weak ANS subtype), which was manifested, for example, in the area of numerosity, a spatial difficulties subtype, which also showed impairment in the approximate number system (ANS)[1], the access deficit subtype, with difficulties in, for example, comparing numbers according to numerical value, and finally, the no numerical cognitive deficit subtype, which showed no impairment in the areas studied and, on the contrary, children from this group showed good results in verbal working memory, as did the garden-variety subtype, which showed only relatively lower nonverbal IQ.

Research on early predictors of subsequent numeracy skills has also yielded important findings. For example, Stock et al. (2009) found seriation

[1] ANS provides a fuzzy representation of numerosities. It resides in the intraparietal sulcus- IPS (Szucs et al., 2013; Plassová, Stuchlíková, & Vavrečka, M, 2017).

ability (see below) to be the strongest ever predictor in the preschool period, thereby highlighting another important area – that of logic.

It is evident that the researchers focused on a range of abilities that could be considered predictors for the development of numeracy skills. The following paragraphs provide a closer look at those areas that were most frequently encountered in our study of the available research. We have already addressed risk factors in the development of numeracy skills in preschool children in a review study (Pražáková & Kucharská, 2019). Here, we focus more on those predictors in the context of school years. Although the following predictors are divided into categories, **these categories may overlap** (e.g. spatial and memory abilities tend to be considered components of intelligence).

General Intelligence

Intelligence or intellectual ability can be defined as "*the ability to learn from experience, to reason in abstract terms, and to deal purposefully with one's environment*" (Atkinson, 2003, p. 692). According to some authors (Vágnerová & Klégrová, 2008; Zelinková, 2009), mathematical ability can also be understood as one of the components of the structure of intelligence. At the same time, however, the level of reasoning ability does not clearly predict how an individual will master mathematics (Zelinková, 2009). As for the predictive value of intelligence in relation to school performance, according to Vágnerová (2005), the correlation coefficient is between 0.5 and 0.7, so it is a relatively high value.

Each of the subcomponents of intelligence may have a different effect on the development of mathematical skills. For example, great importance is attributed to memory skills (Locuniak & Jordan, 2008; Vágnerová & Klégrová, 2008) and spatial skills (Vágnerová & Klégrová, 2008; Landerl et al., 2009). In contrast, the level of vocabulary or even the ability to solve Matrix-type[2] problems in relation to numeracy skills appears to be less important (Landerl et al., 2004; Locuniak & Jordan, 2008).

Numerosity

According to a number of authors (Butterworth, 2003; von Aster & Shalev, 2007; Iuculano, Tang, Hall, & Butterworth, 2008; Babite & Emerson, 2018), humans have an innate implicit understanding of quantity. This allows us, for example, to compare two groups of objects according to their quantity. The same ability has been observed in human infants and even

[2] Among other skills, these tasks test nonverbal fluid intelligence and the ability to understand the relationships between the parts and the whole of a pattern (Maccow, 2011).

in some species of animals (Butterworth, 2003; Furman & Rubinsten, 2012). We can also encounter the term ***number sense***, which includes the ability to understand and work with quantity (Babite & Emerson, 2018) or the ability to represent numerical magnitude nonverbally on a number axis (Aster & Shalev, 2007).

Numerosity has been investigated in relation to numeracy skills in a number of studies, but the results do not appear to be entirely consistent. This link seems to be increasingly less conclusive compared to the ability to symbolise quantity using numbers (Furman & Rubinsten, 2012), which is the focus of the next section of this chapter. This is confirmed by the results of a pilot study conducted in the Czech Republic (Pražáková, 2017; Pražáková & Špačková, 2018). Another study conducted in the Czech Republic (Šamajová, 2018; Šamajová & Cígler, 2020) also failed to reliably demonstrate a significant association of this ability with numeracy impairment. In another study (Stock et al., 2009) conducted with preschool children, non-symbolic quantity comparison was found to be a relatively significant predictor of subsequent difficulties in mathematics but was not among the strongest predictors.

Symbolic Number Processing

Research results show that both **accuracy and fluency** in working with number symbols play a very important role in numeracy skills. In tasks aimed at matching numbers according to their numerical value, as well as in tasks aimed at matching a numerical symbol to a group of the corresponding number of objects (e.g., dots), respondents with specific learning disabilities in mathematics repeatedly perform worse than respondents from control groups (Landerl et al., 2004, 2009; Szucs et al., 2013; Pražáková, 2017; Pražáková & Špačková, 2018).

Logic

In Czech (Novák, 2004; Traspe & Skalková, 2013) and international (Stock et al., 2009; Presentación et al., 2015) literature, one can find the classification of intellectual development stages according to Piaget's theory, which serve as fundamental predictors for the acquisition of primary mathematical skills. In this context, the following abilities – which are also referred to as logical abilities by some authors (Stock et al., 2009; Presentación et al., 2015) – are often mentioned:

- **Classification** – sorting elements according to a certain criterion or similarity. Children first learn to sort by physical properties, then by purpose and finally by quantity (Novák, 2004). Some authors (Stock et al., 2009; Presentación et al., 2015) also introduce the concept of inclusion, which they refer to as the highest form of classification and by which they mean the understanding that a number can contain other numbers.

- **Seriation** – perception of differences between elements and the ability to sort them according to size, number, etc. Stock et al. (2009) found this ability in preschool children to be the strongest predictor of later arithmetic skills (relative to already acquired numeracy, quantity comparison and other logical skills).
- **Conservation** - understanding the principle of preserving the quantity of elements even when changing their spatial arrangement (understanding that nothing is added or lost during this change).

Further insights into logic in relation to mathematics are provided by Morsanyi, Devine, Nobes and Szűcs (2013), who examined it in school-age children using syllogisms[3]. Compared to the control group, children with dyscalculia performed poorly on those tasks where implausible premises appeared. The authors thus concluded that children with dyscalculia have weaker reasoning skills. Yet they themselves discuss whether it may have been more of a failure of inhibition skills. The latter is usually classed with executive functions.

Executive Functions

Executive functions are used to control, manage and regulate cognitive processes. They are particularly important in new or more demanding situations requiring rapid and flexible adaptation, but also, for example, where it is necessary to resist distractions (Vágnerová 2012). Of the executive functions, **working memory and inhibition** in particular were investigated in relation to mathematical abilities and skills. They are discussed in more detail below.

Inhibition

Vágnerová (2012) describes inhibition as the ability to control and suppress what is not needed in a given situation or that which is disturbing. Several studies have confirmed the link between this ability and mathematics performance. Wang, Tasi, and Yang (2012) examined different types of inhibition in school-age children and found that children with specific difficulties in mathematics failed primarily in number inhibition, where they were asked to verbally indicate the number (quantity) of digits presented that did not correspond to their numerical value. They also performed poorly in graph inhi-

[3] The children solved problems like *„Insects are smaller than mice. Mice are smaller than rabbits. Are rabbits smaller than insects?"* In some of the problems presented, plausible statements were replaced with implausible ones, e.g., *„Mice are bigger than elephants."* The children were instructed to imagine that the given premises were correct.

bition, where they had to label the less distinctive of two shapes. On the other hand, dyslexic children performed worse in the word inhibition, where they had to name the colour in which different words were printed and suppress the tendency to read the word.

Memory

Performance in mathematics can also be influenced by memory, which facilitates recall of mathematical facts (e.g., that 2 + 3 = 5), procedures, mnemonic devices, etc. (Mazzocco, 2007). One of the most frequently cited types of memory in relation to mathematical skills is verbal working memory. For example, Locuniak and Jordan (2008) administered digit span backward repetition tasks to preschool children and this skill emerged as a significant predictor of later numeracy fluency, whereas simple digit span forward repetition did not show significant predictive power. Presentación et al. (2015), who observed executive functions in preschool children, **found working memory to be the overwhelmingly strongest predictor of numeracy skills.** Similarly, Passolunghi et al. (2007) also tested children at the beginning and end of their first year of school, and in addition to numeracy skills, working memory was also found to be the strongest predictor of later mathematics performance. The authors **suggest both of these abilities be a part of a simple screening for later difficulties in mathematics.**

Visuospatial Ability

Mathematics is also associated with spatial or visuospatial abilities. According to some authors, they are important for the mastery of geometry (Locuniak & Jordan, 2008; Vágnerová & Klégrová, 2008; Stock et al., 2009). Other possible consequences of deficits in this area are losing the order of digits, difficulties in working with the decimal point, deflection of digits from columns, etc. (Stock et al., 2009).

At the same time, McCaskey et al. (2017) point out that individuals with dyscalculia do not have a general deficit in spatial abilities but in some subcomponents. According to their study, respondents with dyscalculia performed statistically significantly worse, for example, in the area of so-called mental rotation, where they were asked to identify a particular shape (e.g. a square) if it was rotated in a different way from the template. On the other hand, they did not differ from the control group in tasks where they had to compare objects according to size, which was also shown in our earlier study (Pražáková, 2017; Pražáková & Špačková, 2018).

Language Abilities

Some authors have also linked mathematics to language skills (e.g., Locuniak & Jordan, 2008; Mazzocco, 2007). As Mazzocco notes, words can describe, for example, quantity (e.g., one, two, or three), categories of quantities (many, few), relative quantities (more, less), or relationships between quantities (twice as many). Even the memorisation of mathematical facts (e.g., 2 + 3 = 5) can be considered a linguistic as well as mathematical matter in this respect.

Didactical Aspects of Success in Mathematics

Mathematical knowledge and skills can also be impaired by inappropriate or insufficient stimulation from the school or family, e.g. as a result of forms of teaching that do not match the child's personality type or cognitive learning styles, however appropriate his or her intellectual and mathematical predispositions may otherwise be (Novák, 2004).[4]

Dilemmas about what to pay more attention to in mathematics education include drill on the one hand and comprehension on the other (Resnick & Ford, 2008; Rendl & Páchová, 2013). Proponents of the drill approach stress the need for repetition, i.e., automation of acquired knowledge. It turns out that this approach is also supported by many Czech teachers, while according to its critics, it leads only to mechanical acquisition of the material (see Rendl & Páchová, 2013). Didacticians drawing on constructivism, for example, oppose the drill approach. Among the best-known proponents of didactic constructivism in the Czech Republic is Hejný (see, e.g., Hejný & Kuřina, 2015), and his methodology of teaching mathematics is already widespread in many Czech schools.

Research by McConnell (in Resnick & Ford, 2008) has shown that while strict drilling leads to greater accuracy and speed in solving examples, a comprehension-focused approach, in contrast, promotes greater success with less familiar types of numerical problems. With regard to the so-called Hejný method specifically, the results are not entirely clear-cut. For example, in research by Chytrý, Říčan and Živná (2019), pupils taught using the classical method performed significantly worse in a didactic mathematics test. However, the limitations of this study include a relatively small number of respondents. Conversely, the Czech School Inspectorate (2017) found a slight difference between schools in favour of teaching according to Hejný, although these results did not reach statistical significance.

Developmental Dyscalculia

Developmental dyscalculia (DD) is generally understood to be a specific learning

[4] Novák uses the term didactogenic calculastenia for this phenomenon.

disorder with deficits in calculation (or arithmetic) skills that is not primarily caused by low intellectual ability or inadequate education (Butterworth et al., 2011; Novák, 2004; Vágnerová, 2008; Kaufmann & von Aster, 2012). In ICD-11 for Mortality and Morbidity Statistics, it is defined as follows: „*Developmental learning disorder with impairment in mathematics is characterised by significant and persistent difficulties in learning academic skills related to mathematics or arithmetic, such as number sense, memorization of number facts, accurate calculation, fluent calculation, and accurate mathematical reasoning.*" It also states that it leads to a significant reduction in academic or vocational competences.

An earlier version (ICD-10) described DD primarily as a deficit manifesting itself in arithmetic skills rather than in more abstract calculation tasks, which include algebra, geometry and others. Thus, in the newer version, there has been some expansion of this definition. However, neither of these versions explicitly uses the term dyscalculia anymore. Butterworth et al. (2011), who suggest that dyscalculia manifests itself primarily in arithmetic, state that even individuals with severe dyscalculia can excel in geometry, use statistical files and master computer programming at a high level. The authors differ on how to define, limit and classify it.

In the literature, we can also encounter the term ***mathematical learning difficulties* (MLD)**. Although, according to some authors (Bartelet et al., 2014), it can be used as a synonym for dyscalculia in certain contexts, it is often used as a more general term for difficulties in mathematics. According to other authors (Kaufmann & von Aster, 2012), the term MLD, unlike the term dyscalculia, does not take intellectual ability into account. They see the importance of distinguishing these terms only for research purposes; the labels should not affect the planning of interventions in practice. According to Karagiannakis et al. (2014), MLD also encompasses a wide range of deficits in mathematical skills. They consider the concept of dyscalculia too one-dimensional and therefore propose a multidimensional classification model that takes into account several subtypes of MLD according to causes and possible manifestations. These authors, on the other hand, consider it important to distinguish between the different subtypes and to use them in interventions.

Diagnosing Difficulties in Mathematics

The assessment of an individual's mathematical abilities and skills is quite complex. As stated by Novák (2004), in addition to the recognition of mathematical skills, it includes the collection of anamnestic data, the diagnosis of general intellectual abilities, personality traits and possibly medical aspects.

In the Czech Republic, we still encounter the so-called discrepancy criterion, the purpose of which is to determine whether a specific learning disability or a more general cognitive deficit is present. Vágnerová and Klégrová (2008) consider a difference of at least 15-20 points, i.e. 1-1.25 standard deviations, between IQ and performance in didactic mathematical tests to be diagnostically necessary. However, inconsistency in the definition of dyscalculia is also evident in terms of diagnostic criteria based on the severity of difficulties in mathematics assessed by standardised tests, ranging from performance below the 3rd percentile to performance below the 25th percentile, i.e. 2 to 0.68 standard deviations below the mean (Devine, Soltesz, Nobes, Goswami & Szucs, 2013). Kaufmann and von Aster (2012) and Kuhn (2015) also note that in the *Diagnostic and Statistical Manual of Mental Disorders* (5th ed.; DSM-5; American Psychiatric Association, 2013), the requirement for a discrepancy criterion is also not strictly stated, given the heterogeneity of these disorders and comorbidities with others. Rather, Kaufmann and von Aster recommend examining discrepancies within individual subtests of multidimensional intelligence tests.

One of the most common and multidimensional intelligence tests used in the Czech Republic is the third edition of the Wechsler Intelligence Scale for Children – WISC-III (Krejčířová, Boschek, & Dan, 2002). The Wechsler tests reflect, for example, verbal comprehension, perceptual-spatial abilities, memory, work rate, etc. Children with learning disabilities in mathematics can be expected to score lower on some of these subtests (especially the numeracy skills subtest) (cf. Landerl et al. 2004, 2009; von Aster & Shalev, 2007; Locuniak & Jordan, 2008; Vágnerová & Klégrová, 2008; Presentación et al. 2015; Peters et al. 2018). This may reduce the overall score.

Kaufmann and von Aster (2012) divide tests of mathematical abilities and skills into curricular (performance) tests, which cover the school curriculum and assessment of mathematical skills, and neuropsychological orientation tests, which focus more on the causes of possible difficulties in this area. The *Dyscalculia Screener* (Butterworth, 2003), aimed at screening for dyscalculia, is probably an example of the second type of test. The method screens not only for numeracy skills attained but also for numerosity and the ability to symbolise quantities, which Butterworth considers to be key predictors for the development of arithmetic skills. The author further assumes here that even **children with dyscalculia can solve most of the problems correctly and that they differ from others mainly in their speed of solution.** He also draws on the finding that **pupils with specific difficulties in mathematics perform worse than their neurotypi-**

cal peers only on time-limited tasks and, conversely, do not differ significantly from the control group on tasks without a time limit (e.g. Jordan & Montani, 1997). Thanks to computer administration, reaction time is measured in milliseconds. The method also includes a control subtest that focuses on reaction time when working with non-numerical stimuli.

To our knowledge, there is no standardised diagnostic tool currently available in the Czech Republic that uses computer administration and allows such sensitive measurement of reaction time. One of the most recent test methods used here is the *Diagnostic of Mathematical Abilities and Skills* (Bednářová et al., 2015). This battery is used to determine the current level of the sub-skills needed for mathematics as well as the achieved skills. It focuses on the area of numbering (e.g. reading and writing numbers), basic number operations and the application of basic number operations (e.g. adding the characters of operations).

Aim of the Study

The main aim of the research was to map the possible causes of difficulties in mathematics among younger pupils (1st stage) in Czech primary schools. We were looking for indicators that could not be explained only by low intelligence, insufficient home preparation or inappropriate teaching methods at school.

Methods

Respondents

The participants were pupils in the 3rd year of primary school in the Czech Republic. The data collection took place between 2020 and 2022; the data collection period was extended due to measures taken in the light of the COVID-19 pandemic. The experimental group (21 pupils with MLD) and the control group (35 pupils) were formed from an original sample of 150 pupils attending a total of 5 schools in or near Prague. Of these, 99 children were taught using the classical method, while the rest were taught using the constructivist method, namely the so-called Hejný method (see e.g. Hejný & Kuřina, 2015).

The **experimental group** consisted of students with MLD who scored a standard score of 85-115 on a test of nonverbal intellectual abilities, while their scores were at or below the 25th percentile on at least two subtests testing mathematical abilities and skills. According to the comparison by Devine et al. (2013), most studies use more stringent criteria (lower percentile scores) for inclusion in the MLD or DD groups. We opted for this step in order to increase the number of respondents. The group consisted of a total of 21 students, 7 boys and 14 girls. The average age was 109.73 months.

The **control group** consisted of pupils who achieved a standard score of 85-115 on a test of nonverbal intellectual abilities. At the same time, they had to meet the condition that their results on the mathematical abilities and skills test corresponded to at least the 40th percentile in at least two subtests. In total, there were 35 pupils, 24 boys and 11 girls. The average age was 108.29 months.

The groups were designed to be statistically significantly different in terms of mathematics performance but not in terms of nonverbal intellectual ability (see the Standardised Methods section for more details). Thus, as in some previous studies (Landerl et al., 2009; Bartelet et al., 2014; Szucs et al., 2013), all selected respondents had standard scores (IQ) on a nonverbal intelligence test in the average range. The selected students were then presented with the experimental tasks.

Comparisons of the research groups on the standardised tests are shown in Table 1. For most tasks, the data did not show a normal distribution, therefore a Mann Whitney U test was run to determine whether there were differences in achievement scores. The table shows that the groups were not statistically significantly different in terms of nonverbal intellectual ability ($p = 0.180$), and the effect size did not reach very high values. On the contrary, the results reached statistical significance ($p < 0.05$) in all the areas of mathematical abilities studied; moreover, the differences between the groups can be considered large. The method of statistical processing is described in more detail in the Results section.

There were no statistically significant differences between the groups in terms of age. However, the groups could not be aligned in terms of gender composition. While the experimental group is dominated by girls, the control group shows a predominance of boys.

In the course of administering the standardised methods, it was brought to our attention by some teachers who teach mathematics using a constructivist approach that their students were not used to working under a time limit as required by the chosen standardised tools. We therefore decided to check whether there would be differences in our sample between students taught in the classical manner and students taught in the constructivist manner within the standardised methods. No significant differences were found in most of the areas monitored by the standardised methods. Only in the *Basic Numerical Operations* test (Bednářová et al., 2015) did the respondents taught in a constructivist manner perform worse. Although this is inconsistent with previous research (Chytrý et al., 2019; Czech School Inspectorate, 2017), it may represent a limitation of the research, which is addressed in the final discussion.

Table 1. Descriptive statistics and results for the Comparison of the Experimental and Control Groups in standard tasks

	Group	N	Mean	Median	SD	Statistic	P value	Effect Size
Cattel	C	35	102.6	104	9.08	288	0.180	0.216
	MLD	21	99.3	101	9.19			
No. missing	C	35	86.9	95.3	19.27	105.5	< 0.001	0.713
	MLD	21	40.2	33.9	32.30			
Operations	C	35	67.3	66.0	16.52	1.0	< 0.001	0.997
	MLD	21	16.8	14.0	10.01			
Characters		35	74.9	78.5	17.76	4.0	< 0.001	0.989
		21	14.6	14.2	12.81			

Note: MLD – mathematical learning difficulties, C – control, N – sample size, SD – standard deviation, p – p value

Standardised Methods

Standardised methods were used in this study to select appropriate respondents for the subsequent part of the research in which experimental methods were administered. The purpose of the standardised tests was thus to identify students with and without difficulties in mathematics.

Mathematical abilities and skills were assessed using three subtests selected from the *Diagnostic of Mathematical Abilities and Skills* test battery (Bednářová et al., 2015). The subtests were chosen to at least partially cover all areas of mathematics targeted by the method. Specifically, the subtests were *Filling in the missing numbers* (area of numeration), which contains ascending or descending number series in which some numbers are missing and the pupil is asked to fill them in; *Basic number operations,* which contains numerical examples focusing on addition, subtraction, multiplication and division, where the child is asked to write the result; *Completion of operations* (application of basic numerical operations), which contains the same types of examples as *Basic number operations*, but instead of a result, pupils are asked to complete the sign of the operation, i.e. plus, minus, times or divide. Pupils get one point for each correct answer. All subtests are timed and the raw scores of each subtest are converted to percentiles.

Nonverbal intellectual abilities were assessed using the first part of the *Cattel*

Fluid Intelligence Test – CFT 20 R (Fajmon, Hönigová, Urbánek, & Širůček, 2015). It is a nonverbal method; all subtests are figural in nature[5] and solved in pencil-and-paper form. All tasks are time-limited. The test also allows for group administration. Gross scores are converted to IQ scores.

Experimental Methods

In order to map possible cognitive predictors for the development of numeracy skills, we decided to use a non-standardised test battery administered via tablets. The administration was done in groups of up to 10 students. At the beginning of each subtest, pupils were instructed how to solve the task, while at the same time, the instructions were displayed to them via the app. This was followed by three test items. If a pupil made a mistake, the app automatically alerted them to the error and prompted them with the correct answer. The test items were not scored or timed. Before the actual subtest was given, pupils had the opportunity to ask the administrators questions. After completing all the subtest items, after the time limit had expired, or after a pupil had answered three consecutive items incorrectly, respondents were instructed to wait for further instructions from the administrator.

The test battery was created for the purposes of this study and was also partially used in a collaborative project (Stiernakova, 2022).

In composing the test items, we assumed, as did (Butterworth, 2003), that **most students can complete most items correctly** and that students with DD or MLD can usually correctly determine, for example, which of the two numbers presented represents the larger value. Based on the results of previous studies (e.g., Jordan & Montani, 1997; Landerl et al., 2004; Pražáková, 2017), we expected that students with MLD would differ from neurotypical students **mainly in the speed with which they solve these relatively easy tasks** (except for the control *Ordinary Reaction Time* subtest, where, on the contrary, we did not expect differences).

The following subtests were given.

Normal Reaction Time. This is a control subtest. Its purpose was to see if the groups differed in solving tasks that we assumed to be unrelated to mathematics. Respondents were sequentially presented with two, three or four boxes, one of which contained a picture and the others were blank. Students were asked

[5] It includes 4 subtests: Series – determining which of the five images best completes the series; Classification – determining the image that does not belong with the others; Matrix – determining the image that best completes the matrix; Topology – selecting the image that most closely matches the rules in the template.

to click on the box containing the picture as quickly as possible. A total of 30 items were administered within a time limit of two minutes. The control subtest in the standardised *Dyscalculia Screener* (Butterworth, 2003) method works on a similar principle, where students are asked to press a computer button when a black dot appears on the monitor.

Classification. As mentioned above, classification is often considered a logical skill (Novák, 2004; Stock et al., 2009). This skill has been investigated, for example, by Stock et al. (2009) in preschool children, and in their research, the respondents were asked to work with numbers. In this task, students were instructed to choose the picture out of four that was least similar to the others. For example, three pictures showing fruit and one showing a pastry could be presented at the same time. In total, 15 items were administered within a time limit of three minutes.

Mental Rotation. This task was chosen to measure spatial ability. According to McCaskey et al. (2017), mental rotation is one of the spatial abilities where students with DD differ more from neurotypical students. Respondents were shown a picture of a cube with three sides at the top of the screen and two others at the bottom. Pupils were informed that one of the cubes at the bottom was the same as the one at the top, but was rotated differently. They were asked to identify which of the two cubes at the bottom corresponded to the one at the top. Thus, the task was designed to assess the level of spatial imagination and required a mental rotation for successful completion. Fifteen items were administered within a time limit of three minutes. A similar task from the standardised I-S-T 2000 R: Structure of Intelligence Test (Plháková, 2005), which is administered in a pencil-and-paper format, was also used in our earlier study (Pražáková, 2017) with adult respondents with DD, where they achieved slightly lower scores compared to the standardisation sample. However, that was a very small research sample.

Inhibition. At the top of the screen there was a box containing two shapes, one of which was always larger and more prominent. At the bottom were two more boxes, each containing one shape. Respondents were asked to indicate which of the shapes on the bottom corresponded in shape to the smaller of the shapes shown above. Twenty items were administered within a time limit of two minutes. This test was inspired by the *Graph Inhibition* task by Wang, Tasi, and Yang (2012), which also deals with geometric shapes. We chose this form of the task here because it can be easily measured using tablets.

Comparing Two Fields of Dots. Pupils were asked to compare two fields according to the number of dots and to mark the more numerous of the two, regardless of the size of the dots. Twenty items were

Table 2. Descriptive statistics and results for the Comparison of the Experimental and Control Groups in the Normal Reaction Time subtest

	Group	N	Mean	Median	SD	Statistic	P value	Effect Size
Speed	C	35	27.281	24.865	10.905	342	0.672	0.0694
	MLD	21	26.700	24.698	5.835			
Correctness	C	35	29.286	30.000	2.926	346	0.578	0.0585
	MLD	21	27.952	30.000	5.277			
Median	C	35	0.725	0.707	0.147	300	0.257	0.1837
	MLD	21	0.760	0.724	0.138			

Note: MLD – mathematical learning difficulties, C – control, N – sample size, SD – standard deviation, p – p value

administered within a time limit of two minutes. As mentioned above, similar tasks have been administered in multiple studies (Landerl et al., 2004, 2009; Bartelet et al., 2014; Szucs et al., 2013; Pražáková, 2017; Pražáková & Špačková, 2018; Šamajová, 2018; Šamajová & Cígler, 2020; Stock et al., 2009), but without using tablets.

Comparing Three Fields of Dots. Unlike the previous task, here the students were asked to compare three fields containing dots. This time they had to mark the box that contained neither the most nor the least dots. Thus, if the simultaneously displayed fields contained, for example, 2, 4 and 7 dots, respondents should click on the field with 4 dots. There were 15 items administered within a time limit of three minutes.

Comparing Two Numbers. Students were asked to compare two boxes of numbers by clicking on the one that indicated the larger number, regardless of the size of each digit. Twenty items were administered within a time limit of two minutes. A similar type of task has been used in a number of previous studies (Landerl et al., 2004, 2009; Szucs et al., 2013; Pražáková, 2017; Pražáková & Špačková, 2018) as well as the standardised method, the Dyscalculia Screener (Butterworth, 2003), but none of them used tablets for administration.

Comparing Three Numbers. Students were asked to compare three boxes containing numbers. Again, the criterion was the quantity that the numbers denoted. Respondents were asked to click on the number that indicated neither the largest nor the smallest number. Thus, if they had to decide between the numbers 2, 4 and 7, they should click on the box containing the number 4 as instructed.

Table 3. Descriptive statistics and results for the Comparison of the Experimental and Control Groups in the Classification subtest

	Group	N	Mean	Median	SD	Statistic (df)	p	Effect Size
Speed	C	35	78.82	80.45	36.86	-1.362 (54)	0.179	-0.3759
	MLD	21	93.95	88.33	45.42			
Correctness	C	35	8.83	10.00	3.66	348	0,738	0,0544
	MLD	21	9.52	10.00	2.42			
Median	C	35	4.07	3.90	1.28	0.357 (53)	0.723	0.0991
	MLD	21	3.94	3.73	1.36			

Note: MLD – mathematical learning difficulties, C – control, N – sample size, SD – standard deviation, p – p value

There were 15 items administered within a time limit of three minutes.

Arithmetic. Respondents were shown an arithmetic problem at the top of the screen. At the bottom, they were presented with two possible results. Students were instructed to mark the number corresponding to the correct result. Twenty problems were administered with a time limit of three minutes. In our earlier study (Pražáková, 2017; Pražáková & Špačková, 2018), respondents with DD differed more from the control group in a similar task than in the other areas studied. A similar subtest is also included in *Dyscalculia Screener* (Butterworth, 2003).

According to the original plan, we had also prepared a test for verbal **working memory,** namely the backward repetition of a series of numbers and letters. Based on previous research (Locuniak & Jordan, 2008; Presentación et al., 2015; Passolunghi et al., 2007), we considered it to be one of the most important predictors of the development of numeracy skills. However, this task was designed for individual administration. Due to the complex and rapidly changing pandemic situation, we finally decided to exclude it from the study areas.

Results

We first determined whether the individual test results reached a normal distribution. In order to assess if the differences between the compared groups reached statistical significance in each test method, we used the T-test for two independent sets in the case of a normal distribution and the non-parametric Mann-Whitney U-test if the data did not fit a normal distribution. We set a 5% significance level ($p<0.05$) as the criterion

Table 4. Descriptive statistics and results for the Comparison of the Experimental and Control Groups in the Mental Rotation subtest

	Group	N	Mean	Median	SD	Statistic	p	Effect Size
Speed	C	35	79.62	74.20	53.50	306	0.302	0.167
	MLD	21	99.18	101.88	60.80			
Correctness	C	35	8.03	10.00	4.15	299	0.243	0.188
	MLD	21	7.19	9.00	4.09			
Median	C	34	4.60	3.99	2.70	209	0.035	0.353
	MLD	19	6.16	5.86	2.44			

Note: MLD - mathematical learning difficulties, C- control, N- sample size, SD – standard deviation, p – p value

for confirming statistically significant differences between groups.

Next, the effect size was calculated so that we could determine the differences between them more accurately. Thus, the results obtained using the T-test were supplemented with the *d* statistic (Cohen's d), where differences between sets are considered small for values of *d* around 0.2, medium for values around 0.5 and large for *d* around 0.8 (Cohen, 1988). Sawilowsky (2009) further describes the values as very large for *d* around 1.2 and huge for *d* around 2. The results of the U-test were complemented by calculations for the correlation coefficient r, where differences between sets are considered small for values of r = 0.1, medium for r = 0.3, and large for r = 0.5 (Cohen, 1988).

To look for differences between the groups, we analysed the total time taken to solve each problem (speed), the average number of correct answers (correctness) and the median time for each group (median).

Normal Reaction Time. In the control subtest monitoring reaction time when working with non-numerical stimuli, the differences between groups did not reach statistical significance, nor were they very large in terms of effect size (Table 2).

Classification. When classifying the images, the differences between the groups did not reach statistical significance. Also, the effect size reaches very low values (see Table 3).

Mental Rotation. In this test, children with MLD performed statistically worse than the control group in terms of median speed of correct responses (see Table 4). The effect size reached moderate values.

Table 5. Descriptive statistics and results for the Comparison of the Experimental and Control Groups in the Inhibition subtest

	Group	N	Mean	Median	SD	Statistic (df)	p	Effect Size
Speed	C	35	41.21	41.49	20.430	-1,035 (54)	0.305	-0,286
	MLD	21	46.47	43.99	14.403			
Correctness	C	35	16.63	18.00	4.466	323	0.715	0.122
	MLD	21	17.10	19.00	4.836			
Median	C	35	1.98	1.96	0.815	291	0.195	0.210
	MLD	21	2.34	2.14	0.830			

Note: MLD – mathematical learning difficulties, C – control, N – sample size, SD – standard deviation, p – p value

Inhibition. Although the MLD students were slower than the control group, the differences between the groups did not reach statistical significance (see Table 5).

Comparing Two Fields of Dots. Here too, the MLD students achieved lower scores, both in terms of speed and accuracy. However, the differences between the groups did not prove to be statistically significant (see Table 6).

Comparing Three Fields of Dots. When comparing the three fields of dots, statistically significant differences in terms of the median correct response rate were found in favour of the control group, and the differences between the groups can be considered to be moderate (see Table 7).

Comparing Two Numbers. When determining the larger of the two numbers, the differences between the groups reached statistical significance in terms of both speed and median speed of correct answers in favour of pupils without identified difficulties in mathematics. The effect size also reached high values (see Table 8).

Comparing Three Numbers. When comparing three numbers, the students with MLD were statistically significantly worse in terms of speed of responses compared to the control group (see Table 9). The differences can be considered to be approximately moderately high.

Arithmetic. When solving the arithmetic problems, the differences between groups reached statistical significance in terms of both speed and median speed of correct answers in favour of pupils without identified difficulties in mathematics (see Table 10). Moreover, the effect size reaches very high values.

Table 6. Descriptive statistics and results for the Comparison of the Experimental and Control Groups in the Comparing Two Fields of Dots subtest

	Group	N	Mean	Median	SD	Statistic	p	Effect Size
Speed	C	35	76.72	57.39	59.69	267	0.807	0,273
	MLD	21	106.98	116.27	67.34			
Correctness	C	35	5.77	5	4.65	253	0.052	0.312
	MLD	21	6.33	8	4.21			
Median	C	30	5.71	5.31	2.86	284	0.158	0.229
	MLD	19	7.84	8.12	3.48			

Note: MLD - mathematical learning difficulties, C- control, N- sample size, SD – standard deviation, p – p value

Conclusion and Discussion

In this study, we built on previous research examining possible causes of difficulties in mathematics. In contrast to those studies, we used tablets to administer the tasks, which, to our knowledge, have never been used for this purpose in the Czech Republic.

The experimental group of pupils with MLD and the control group were composed so that the pupils differed as much as possible in the mathematical areas of interest but not in their nonverbal intellectual abilities. We tried to follow similar, albeit simplified, criteria as in the diagnosis of dyscalculia, while no longer strictly adhering to this term. Apart from the lack of a clear definition, another reason was that both mathematical and intellectual abilities were assessed only tentatively, not comprehensively, with the inclusion of multiple components of both intellect and mathematics. The disparity criterion of at least one standard deviation difference between the results of the intelligence test and the test of mathematical abilities and skills, which is still commonly considered in the Czech Republic in diagnosing DD, was also not met. In order to recruit as many respondents as possible into the experimental group, we chose a relatively modest criterion, namely, scores below the 26th percentile in two of the three subtests administered in the standardised mathematics diagnostic tool. We believe that with a larger number of respondents, it would have been ideal to choose more stringent criteria, but it was important for us to achieve signifi-

Table 7. Descriptive statistics and results for the Comparison of the Experimental and Control Groups in the Comparing Three Fields of Dots subtest

	Group	N	Mean	Median	SD	Statistic	p	Effect Size
Speed	C	35	67.67	60.83	32.48	267	0.088	0.274
	MLD	21	84.86	93.73	38.35			
Correctness	C	35	15.34	16.00	2.92	343	0.683	0.067
	MLD	21	14.05	14.00	2.84			
Median	C	35	2.69	2.16	1.38	171	0.019	0.402
	MLD	21	3.82	3.16	2.27			

Note: MLD – mathematical learning difficulties, C – control, N – sample size, SD – standard deviation, p – p value

cant differences between the comparison groups.

The results obtained using experimental methods are largely consistent with previous research (Butterworth, 2003; Landerl et al., 2004, 2009; Szucs et al., 2013; McCaskey et al., 2017; Pražáková, 2017; Šamajová & Cígler, 2020). **The performance of pupils with MLD differed from that of children without identified difficulties on the experimental tasks, particularly on tests focused on matching number symbols and on numeracy skills alone.** Significant, albeit smaller, differences between the groups were also evident in **non-symbolic quantity comparison and in spatial skills** (mental rotation). However, in terms of accuracy, we found no statistically significant differences between the groups in any of the areas examined. Where the groups did differ significantly from each other, it was invariably only in terms of task-solving speed. This means that MLD pupils were slower at solving some experimental tasks compared to children without identified difficulties, but this did not significantly affect the accuracy of the solutions. As mentioned above, such findings are not very surprising to us. A British standardised instrument, the *Dyscalculia Screener* (Butterworth, 2003), was constructed on the basis of a similar hypothesis. In this instrument, the test items were designed so that most pupils could solve most of the tasks correctly. Children with difficulties in mathematics (or DD) are to be identified mainly by their need for more time to solve items with numerical stimuli. The exception here is also a control subtest with non-numerical stimuli, focusing on simple reaction time, which is intended to distinguish whether pupils are slower

Table 8. Descriptive statistics and results for the Comparison of the Experimental and Control Groups in the Comparing Two Numbers subtest

	Group	N	Mean	Median	SD	Statistic	p	**Effect Size**
Speed	C	35	32.33	31.67	9.402	170	<.001	0.537
	MLD	21	39.83	40.78	7.596			
Correctness	C	35	18.66	20.00	3.360	322	0.400	0.124
	MLD	21	19.14	19.00	0.910			
Median	C	35	1.53	1.44	0.297	170	<.001	0.537
	MLD	21	1.83	1.81	0.362			

Note: MLD - mathematical learning difficulties, C- control, N- sample size, SD – standard deviation, p – p value

to respond to all stimuli in general or specifically in tasks more closely related to mathematics. Butterworth also draws on findings (e.g., Jordan & Montani, 1997) indicating that **although students with DD tend to be slower than neurotypical students on numerical tasks, they might perform similarly on tasks without a time limit.**

It follows that because the research groups in this study were compared with each other in time-limited tasks, not only in the experimental but also in the standardised tasks, we cannot conclude that they would have differed in tests that had no time limit. Even so, it should be kept in mind that the MLD group was not significantly slower in all tasks -- not even in the standardised methods. The groups were designed to differ only on the maths skills test but not on the nonverbal intellectual ability test, which also has a set time limit. It therefore seems likely that, even within the non-standardised methods, pupils with MLD performed worse, particularly on those tasks that were genuinely related to mathematics rather than general work pace or intelligence. Thus, it also appears that, in the context of school-based support measures, increasing the time limit for pupils with MLD (or DD) serves a purpose.

The assumption that students with MLD perform significantly worse on inhibition was not supported in this study. Further research would be needed to determine whether this was due to the composition of the research population (grouping criteria, sample size, etc.) or the nature of the test material. Significant group differences did not show up in the control subtest focusing on simple reaction time, which we did not expect

Table 9. Descriptive statistics and results for the Comparison of the Experimental and Control Groups in the Comparing Three Numbers Test

	Group	N	Mean	Median	SD	Statistic	p	Effect Size
Speed	C	35	68.63	63.86	33.61	-2.271(54)	0.031	-0.612
	MLD	21	89.47	84.03	34.80			
Correctness	C	35	10.34	12.00	4.36	363	0.939	0.014
	MLD	21	10.48	11.00	4.13			
Median	C	34	4.69	4.27	1.95	211	0.012	0.409
	MLD	21	5.76	5.25	1.54			

Note: MLD – mathematical learning difficulties, C – control, N – sample size, SD – standard deviation, p – p value

given its purpose, nor in the subtest on item classification (logic). In the latter subtest, we also did not anticipate large differences between the groups because, as we have already mentioned, the groups did not differ significantly in terms of nonverbal intellectual abilities. In some respects, this task resembles the CFT 20 R method, especially its *Classification* subtest, although in our experimental test, unlike the CFT 20 R, students worked with concrete patterns. This hypothesis would need to be confirmed or refuted by further research.

Compared to the studies (e.g., Landerl et al., 2004, 2009; Bartelet et al., 2014; Szucs et al., 2013; Pražáková, 2017; Šamajová & Cígler, 2020) that we drew on here, we also added tasks comparing three fields with objects or three fields with numbers. This was to test our hypothesis that this might increase the differences in performance between pupils with MLD and pupils without difficulties in mathematics, especially in the case of non-symbolic quantity comparisons, where differences between groups are usually not very large. We were only able to confirm this assumption partially here. Although the students with MLD performed worse, they were statistically significantly different from the control group only in terms of median speeds for the Compare Three Fields with Objects task. In contrast, when comparing numerical symbols, the groups differed less from each other when working with three fields than when comparing only two fields. Although the MLD pupils performed statistically significantly worse than the control group even when working with three fields, in terms of identifying possible difficulties in mathematics in the early years of schooling, compar-

Table 10. Descriptive statistics and results for the Comparison of the Experimental and Control Groups in the Arithmetic subtest

	Group	N	Mean	Median	SD	Statistic	p	Effect Size
Speed	C	35	94.33	90.89	29.572	136	<.001	0.630
	MLD	21	138.74	147.46	42.76			
Correctness	C	35	18.03	18.00	1.790	336	0.586	0.087
	MLD	21	18.33	18.00	3.07			
Median	C	35	3.32	3.43	0.949	135	<.001	0.633
	MLD	21	4.77	4.70	1.61			

Note: MLD – mathematical learning difficulties, C – control, N – sample size, SD – standard deviation, p – p value

ing two fields with numbers seems to be more effective thus far.

As also mentioned, the study involved not only schools that teach mathematics in the classical manner, but also schools that teach the so-called Hejný method, which is based on constructivism. In order to determine whether pupils taught according to different methods achieve comparable results in standardised tests, we compared the results in these tests according to the method of teaching. In one of the subtests of the standardised test of mathematical abilities and skills (Bednářová et al., 2015), pupils taught using constructivist methods achieved statistically significantly worse results in the part focusing on numerical operations than pupils taught in the classical way. This result may represent a limitation of this study, although it contrasts with, for example, the results of the Czech School Inspectorate (2017). A possible explanation for why pupils taught using this method performed worse is the time limit set in standardised methods, which, according to some teachers from the participating schools who teach in a constructivist manner, their pupils are not used to working with. Unfortunately, we did not have a standardised tool with standards specifically designed for the Hejný method, and therefore had no way of identifying possible difficulties in pupils taught in this manner. It should also be noted that we are dealing with a small research population sample here, and so any differences cannot yet be overgeneralised. In the future, we recommend that these findings be verified on a larger sample and that standards also be developed for the Hejný method. Similarly, we consider it worthwhile to check whether similar differences are also present in our experimental methods.

It is important to keep in mind that data collection was severely disrupted by the COVID-19 pandemic and did not proceed as planned due to relatively strict and prolonged measures, including repeated school closures. Although schools from other regions were included in the original sample, we only made this comparison for respondents from Prague or the surrounding area because none of the schools from other regions ultimately participated in data collection through experimental methods.

For the reasons mentioned above, we were forced to spread the data collection over a much longer period of time than anticipated, and even then fewer students took part. Due to the overall complexity of the situation following the pandemic outbreak, we also abandoned the intention to investigate verbal working memory, the importance of which might be interesting to explore alongside the other areas of interest. Based on previous research (Locuniak & Jordan, 2008; Presentación et al., 2015; Passolunghi et al., 2007), we considered this ability to be an important aspect for predictors of arithmetic skill development and originally intended to administer it individually, unlike the other experimental tasks, but we only managed to do so with 11 respondents. We were not able to prepare the option of assessing it using tablets in time, a solution conceived later, due to the rapidly deteriorating COVID-19 situation and the tightening of pandemic measures. In the end, we decided not to complicate an already difficult situation in schools with further testing. **In the future, however, it might still be interesting to add a working memory subtest to our battery,** or at least to test respondents' working memory orally in individual sessions. It would thus be useful to replicate the research on a larger research sample of children from more regions of the country, possibly including first or second grade students.

The Czech Republic currently **lacks a simple screening system** focused on mathematical skills that could identify pupils at risk of difficulties in the early years of education who deserve special attention. This could include, for example, a number matching test, given that these types of tasks appear to be highly relevant in relation to mathematics, as mentioned above. It should also be noted that this type of test is already used with computer administration in a standardised screening tool abroad (Butterworth, 2003). If the hypothesis that working memory is also a significant indicator of mathematics difficulties is confirmed, it could be included in a possible screening tool, as suggested by Passolunghi et al. (2007). However, as there are arguably multiple predictors for the development of numeracy skills, an overly simple screening with, e.g., only two skills (such as number matching and working memory) might not detect all children at risk of difficulties, such as children with impaired spatial skills.

Possible indicators of difficulties in mathematics **should also be investigated causally,** preferably already in preschool children (i.e. preschoolers' abilities in relation to later numeracy skills). As evidenced by international research conducted with kindergarten pupils, apart from the ability to solve certain types of arithmetical problems, the levels of which can vary from country to country (Locuniak & Jordan, 2008; Stock et al., 2009), it is precisely working memory (Locuniak & Jordan, 2008; Presentación et al., 2015) and the ability to serialise (Stock et al., 2009) that emerge as strong predictors of numeracy skills in the early years of school. These, or others, could thus become part of future screening for difficulties in mathematics as early as preschool age, as we also suggested in a previously published review study (Pražáková & Kucharská, 2019).

It should also be kept in mind that there are probably multiple subtypes of difficulties in mathematics, depending on the underlying causes but also in terms of how they manifest. Thus, because individuals with MLD may not have impairments in all predictors, not all areas of mathematics are affected.

These subtypes should also be examined more closely in the Czech context. At the same time, there is still no consensus among the professional community on how to classify the different types of difficulties in mathematics. Therefore, our proposal is to **approach** both the diagnosis and the remediation of possible difficulties in mathematics **individually**, regardless of the extent to which they fit specific diagnostic "labels."

References

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.).

Bartelet, D. Ansari, D. Vaessen, A. Blomert, L. (2014) Cognitive subtypes of mathematics learning difficulties in primary education. *Research in Developmental Disabilities*, 35, 657–670.

Bednářová, J. at al. (2015). *Diagnostika matematických schopností a dovedností: varianta pro školská poradenská zařízení 3. a 4. ročník*. Brno: Pedagogicko-psychologická poradna Brno.

Bednářová, J., & Šmardová, V. (2015). *Diagnostika školní připravenosti, varianta pro školská poradenská zařízení*. Brno: Pedagogicko psychologická poradna Brno.

Butterworth, B. (2003). *Dyscalculia Screener*. London: nferNelson.

Butterworth, B. Varma, S. Laurillard, D. (2011). Dyscalculia: From Brain to Education. *Science*, 332(6033), 1049–1053.

Cohen, J. *Statistical Power Analysis for the Social Sciences*. Hillsdale, NY: Lawrence Erlbaum, 1988.

Česká školní inspekce. (2017). Výběrová z jištění výsledků žáků na úrovni 5. a 9. ročníků základních škol ve školním roce 2016/2017 – závěrečná z práva. [online]. [cit. 2021-08-02]. Dostupné z: https://www.csicr.cz/getattachment/17f8e265-b04f-4459-a106-3aecbf735ca0/Vyberove-zjistovani-vysledku-zaku-na-urovni-5-a-9-rocniku-ZS-zaverecna-zprava.pdf.

Devine, A. Soltesz, F. Nobes, A. Goswami, U. Szucs, D. (2013). Gender differences in developmental dyscalculia depend on diagnostic criteria. *Learning and Instruction*, 27, 31–39.

Fajmonová, V., Hönigová, S., Urbánek, T., & Širůček, J. (2015). *CFT 20-R – Cattellův test fluidní inteligence*. Praha: Hogrefe – Testcentrum.

Furman, T., & Rubinsten, O. (2012). Symbolic and non symbolic numerical representation in adults with and without developmental dyscalculia. *Behavioral and Brain Functions*, 8, 55–69.

Hannel, G. (2013). *Dyscalculia. Action plans for successful learning in mathematics*. New York: Routledge.

Hejný, M., & Kuřina, F. (2015). *Dítě, škola a matematika: konstruktivistické přístupy k vyučování* (3. vydání). Praha: Portál.

Chytrý, V, Říčan, J, & Živná, D. (2019). Matematická výkonnost a metakognice žáků základních škol běžných, základních škol Montessori a žáků vyučovaných podle Hejného metody. *Studia paedagogica* 24(1), 107-133.

ICD-10 [online]. [cit. 2023-09-20]. Dostupné z: https://icd.who.int/browse10/2010/en#F81.2.

ICD-11 [online]. [cit. 2023-08-19]. Dostupné z: https://icd.who.int/browse11/l-m/en#/http://id.who.int/icd/entity/771231188 .

Iuculano, T., Tang, J., Hall, Ch. W., & B. Butterworth, B. (2008). Core information processing deficits in developmental dyscalculia and low numeracy. *Developmental Science* 11(5), 669–680.

Jordan (2010). Early Predictors of Mathematics Achievement and Mathematics Learning Difficulties. [online]. [cit. 2023-09-11]. Dostupné z: https://www.child-encyclopedia.com/numeracy/according-experts/early-predictors-mathematics-achievement-and-mathematics-learning.

Karagiannakis, G. Baccaglini-Frank, A. Papadatos, Y. (2014) Mathematical learning difficulties subtypes classification. *Frontiers in Human Neuroscience*, 8(57), 1–5.

Kaufmann, L., & von Aster, M. (2012). The diagnosis and management of dyscalculia. *Dtsch Arztebl Int*, 109(45), 767–78. DOI: 10.3238/arztebl.2012.0767.

Košč, L. (1972). *Psychológia matematických schopností*. Bratislava: Slovenské pedagogické nakladateľstvo.

Krejčířová, D., Boschek, P., & Dan, J. (2002). *WISC-III: Wechslerova inteligenční škála pro děti*. Praha: Testcentrum.

Kuhn, J. Developmental Dyscalculia: Neurobiological, Cognitive, and Developmental Perspectives. (2015). *Zeitschrift für Psychologie*. 223(2), 69–82.

Landerl, K., Bevan, A., & Butterworth, B. (2004). Developmental dyscalculia and basic numerical capacities: a study of 8–9-year-old students. *Cognition* 93(2), 99–125.

Landerl, K. Fussenegger, B. Moll, & K. Willburger, E. (2009). Dyslexia and dyscalculia: Two learning disorders with different cognitive profiles. *Journal of Experimental Child Psychology*, 103(3), 309–324.

Locuniak, M. N., & Jordan, N. (2008). Using Kindergarten Number Sense to Predict Calculation Fluency in Second Grade. *Journal of Learning Disabilities,* 41(5), 451–459.

Mazzocco, M. M. (2007). Early predictors of mathematical learning difficulties: Variations in children's diffi culties with math. *Exchange*, 151, 51–54

Mercader, J., Miranda, A., Presentación, J. M., Siegenthaler, R., & Rosel, J. F. (2018). Contributions of Motivation, Early Numeracy Skills, and Executive Functioning to Mathematical Performance. A Longitudinal Study. *Frontiers in Psychology*. [online]. [cit. 2023-09-11]. Dostupné z: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5775518/.

McCaskey, U., von Aster, M., O'Gorman Tuura, R., & Kucian, K. (2017). Adolescents with Developmental Dyscalculia Do Not Have a Generalized Magnitude Deficit – Processing of Discrete and Continuous Magnitudes. *Frontiers in Human Neuroscience*, 11, 1–19.

Morsanyi, K., Devine, A., Nobes, A., & Szűcs, D. (2013). The link between logic, mathematics and imagination: Evidence from children with developmental dyscalculia and mathematically gifted children. *Developmental Science*, 16(4), 542–553.

Novák, J. (2004). *Dyskalkulie: specifické poruchy počítání: metodika rozvíjení základních početních dovedností*. Havlíčkův Brod: Tobiáš.

Osmon, D. C., Smerz, J. M., Braun, M. M., & Plambeck, E. (2006). Processing Abilities Associated with Math Skills in Adult Learning Disability. *Journal of Clinical and Experimental Neuropsychology*, 28(1), 84–95.

Passolunghi, M. Ch., Vercelloni, B., & Schadee, H. (2007). The precursors of mathematics learning: Working memory, phonological ability and numerical competence. *Cognitive Development*, 22, 165–184.

Peters, L., Bulthé, J., Daniels, N., Op de Beeck, H., & De Smedt, B. (2018). Dyscalculia and dyslexia: Different behavioral, yet similar brain activity profiles during arithmetic. *NeuroImage: Clinical* 18 (2018), 663–674.

Plassová, M., Stuchlíková, I., & Vavrečka, M. (2017). Úvod do aproximálního numerického systému. *Pedagogika*, 67(2), 161–176.

Plháková, A. (2005). *I-S-T 2000 R: Test struktury inteligence.* Hogrefe – Testcentrum.

Pražáková, K. (2017). *Přesnost a rychlost ve vnímání množství u jedinců s dyskalkulií* (Diplomová práce). Praha: PedF UK.

Pražáková, K., & Špačková, K. (2018). Přesnost a rychlost ve vnímání množství u jedinců s dyskalkulií. *Gramotnost, pregramotnost a vzdělávání*, 2 (2), 69–90.

Pražáková, K., & Kucharská, A. (2019). Riziko dyskalkulie a dalších obtíží v matematice u dětí předškolního věku. *Gramotnost, Pregramotnost A Vzdělávání*, 3(2), 143–165.

Presentación, M. J., Siegenthaler, R., Pinto, V., Mercader, J., & Miranda, A. (2015), Math Skills and Executive Functioning in Preschool: Clinical and Ecological Evaluation. *Revista de Psicodidáctica*, 20(1), 65–82.

Rendl, M., & Páchová, A. (2013). Procesy učení v diskurzu učitelů matematiky na 2. stupni základní školy. *Kritická místa matematiky na základní škole očima učitelů*. Praha: Univerzita Karlova v Praze. 127-182.

Resnick, L. B., & Ford, W. W. (2008). *Psychology of Mathematics for Instruction*. New York: Routledge.

Stieranková, M. (2022). *Vybrané kognitivní předpoklady a metakognice ve vztahu k obtížím v aritmetických dovednostech u žáků mladšího školního věku* (Diplomová práce). Praha: PedF UK.

Stock, P. Desoete, A., & Roeyers, H. (2009). Screening for mathematical disabilities in kindergarten. *Developmental Neurorehabilitation*, 12(6), 389–396.

Szucs, D., Devine, A., Nobes, A., Gabriel, F., & Soltesz, F. (2013). Developmental dyscalculia is related to visuo-spatial memory and inhibition impairment. *Cortex*, 49 (10), 2674-2688.

Traspe, P., & Skalková, I. (2013). *Dismas: Diagnostika struktury matematických schopností*. Praha: Národní ústav pro vzdělávání.

Vágnerová, M. (2005). *Školní poradenská psychologie pro pedagogy*. Praha: Karolinum.

Vágnerová, M., & Klégrová, J. (2008). *Poradenská psychologická diagnostika dětí a dospívajících*. Praha: Karolinum.

Von Aster, M. G., & Shalev, R. S. (2007). Number development and developmental dyscalculia. *Developmental Medicine & Child Neurology*, 49, 868–873.

Von Aster, M. G. (2000). Developmental cognitive neuropsychology of number processing and calculation: gervarieties of developmental dyscalculia. *European Child & Adolescent Psychiatry*, 9, 41–57.

Wang, L.–C., Tasi, H.–J., & Yang, H.–M. (2012). Cognitive inhibition in students with and without dyslexia and dyscalculia. *Research in Developmental Disabilities*, 33(5), 1453–1461.

Mgr. Kateřina Skalová Pražáková
PhDr. Klára Špačková, Ph.D.
doc. PaedDr. PhDr. Anna Kucharská, Ph.D.
The Department of Psychology of the Education Faculty
Charles University
katerina.prazakova@mensa.cz
klara.spackova@pedf.cuni.cz
anna.kucharska@pedf.cuni.cz