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Learning Disabilities: A Contemporary Journal (LDCJ), *a refereed professional journal, is a forum for research, practice and opinion papers in the area of learning disabilities (LD) and related disorders. The mission of the journal is to provide the most up-to-date information on diagnosis and identification, assessment, interventions, policy, and other related issues on LD. The journal intends to inform and challenge researchers, practitioners, and individuals who are involved with learning disabilities.*

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Electronic submission may be sent via email to either Richard T. Boon, Ph.D., or to Teresa Citro at tacitro@aol.com. The editors reserve the right to make final editorial changes to the manuscripts (without, however, altering the content of the original submission).

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Numerical and Calculation Abilities in Children with ADHD

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The aim of this study was to investigate the specific numerical and calculation abilities of 28 children with ADHD without comorbid mathematical learning disabilities (LD), ranging from the 1st to the 5th grade of primary school, and to examine the stability or the development of the arithmetic profile. Our results showed that a high percentage of children with ADHD have severe difficulties on numerical and calculation tasks, particularly with counting and arithmetical facts, and these percentages increase with age. Whereas younger children show more problems with lexical processes, for older children, mental calculation and counting processes are particularly difficult. The older students had a statistically worse performance than the younger students on the two measures of time (i.e., mental calculation time and counting time), indicating automatization deficits. This study underlines the importance for teachers to taking the individual arithmetic profiles of children with ADHD into account and of identifying the processes which should be enhanced through education and teaching interventions.

Keywords: Numerical and calculation abilities, ADHD, primary school, and automatization deficits.

Introduction

Attention deficit hyperactivity disorder (ADHD) is a developmental condition characterized by the presence of severe and pervasive symptoms of inattention, hyperactivity and impulsivity. Furthermore, individuals with this disorder are at a high risk for developing a wide range of impairments affecting multiple domains of life, such as interpersonal, school, and family functioning (Harpin, 2005).

The main theoretical explanation for the ADHD symptomatology is related to executive function (EF) deficits, with important weaknesses found in planning, working memory, response inhibition and vigilance (Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Along with EF deficits, individuals with ADHD have difficulties in many general cognitive abilities, such as memory, visuo-motor competencies, behavioral control, and social skills (Crawford, Kaplan, & Dewey, 2006; Seidman, Biederman, Monuteaux, Doyle, & Faraone, 2001).

One area of impairment that is especially important in childhood is academic performance. The literature shows that school-aged children with ADHD experience numerous academic and educational problems (Daley & Birchwood, 2010).

Loe and Feldman (2007) reviewed the literature on the academic and educational outcomes of children with ADHD, concluding that it is associated with poor grades and poor reading, as well as poor math standardized test scores. The meta-analysis carried out by Frazier, Youngstrom, Glutting, and Watkins (2007) indicated a moderate to large discrepancy in academic achievement between individuals with ADHD and their typically achieving peers, thus substantiating the significant impact of ADHD symptoms on academic performance.

The low performance of children with ADHD could be due to the high comorbidity that this disorder presents with learning disabilities (LD), ranging from 25 to 65% (Mayes, Calhoun, & Crowell, 2000; Mayes & Calhoun, 2006). In a recent publication by DuPaul, Gormley, and Laracy (2013), a total of 17 studies (2001-2011) that examined ADHD-LD comorbidity were reviewed, revealing a mean comorbidity rate of 45.1%. However, even when children with ADHD do not present comorbid LD, it has been demonstrated that they present a significantly lower development as compared to their peers on academic performance. Barry, Lyman, and Klinger (2002) found that children with ADHD (with average intellectual abilities) obtained significantly lower scores in reading, writing, and mathematics skills. In addition, they demonstrated a greater discrepancy between actual and predicted achievement than a group of children without ADHD. Moreover, ADHD behaviors predicted academic underachievement, even when the participants with comorbid ADHD and LD were excluded. The authors conclude that the greater the severity of the behavioral symptomatology in children with ADHD, the greater the negative impact on their school performance.

Most of the research on academic performance and ADHD has focused on reading disorders in children with ADHD, rather than difficulties in mathematics (Capano, Minden, Chen, Schachar, & Ickowicz, 2008); in fact, research on the calculation skills of children with ADHD is limited (see Lucangeli & Cabrele, 2006). Studies on ADHD and mathematical achievement have basically used global measures of arithmetic that confirm a general poor performance (Barry et al., 2002; Biederman et al., 2004). However, very few studies have attempted to investigate the specific numerical and calculation deficits associated with ADHD (Kauffman & Nuerk, 2008).

Numerical and calculation abilities comprise different subcomponents that are relatively independent. The basic mechanisms of numerical ability are lexical, semantic, and syntactic processes (Lucangeli, Tressoldi, & Fiore, 1998). Semantic processes involve the ability to understand the meaning of the number, and they are related to operations of quantity discrimination and number ordering with Arabic numbers. Syntactic processes involve the spatial relationships between the digits of the number, they require knowing the number's value based on its position, and they are the "grammar" of the number. Finally, lexical processes refer to the ability to name the numbers, and they are related to telling the sequence of numbers or knowing how to read and write them. These numerical knowledge processes are basic to learning other complex mechanisms like calculation (Lucangeli, Iannitti, & Vettore, 2007).

Zentall and colleagues have studied the specific relationship between ADHD and mathematics. Zentall, Smith, Lee, and Wieczorek (1994) compared 121 boys with typical development and 107 boys with ADHD, aged 7.4 to 14.5 years, on timed arithmetic word problem-solving and mental calculation tasks. They found that the boys with ADHD demonstrated not only significantly lower problem-solving ability and conceptual understanding, but they were also significantly slower on computation. However, one of the conclusions of Zentall's group research is that, by the middle school years, accuracy is no longer a sensitive measure of ADHD, and only fluency continues to differentiate students with ADHD from comparison participants (Zentall, 2007).

In a more recent article, Zentall, Tom-Wright, and Lee (2012) conducted a comprehensive examination of the literature on the academic deficits in mathematics and reading of children with ADHD -with and without co-occurring LD- and the effects of psychostimulant and sensory stimulation. In this review, Zentall and her collaborators summarized the deficits observed in math calculations of children with ADHD without LD. Findings showed less mature math procedures involving finger counting (Rubinsten, Bedard, & Tannock, 2008); slower retrieval speed and greater variability across grade levels (Dykman & Ackerman, 1991; Zentall & Smith, 1993); reduced accuracy of calculations up to middle school, especially regarding time on task and on multiplication facts and addition and subtraction facts with negative numbers and borrowing (Bennett, Zentall, French, & Giorgetti-Borucki, 2006; Zentall & Smith, 1993).

Kaufmann and Nuerk (2008) studied the specific mathematical processes where children with ADHD fail. These authors compared 16 children with ADHD-combined type (ADHD-C) and 16 children without ADHD, from 9 to 12 years old, on a wide range of number processing and calculation tasks. Their aim was to investigate which specific components of these skills might be impaired in children with ADHD without concomitant dyscalculia and/or dyslexia. The tasks used by Kaufmann and Nuerk were simple and complex mental calculations, written calculations, and core numerical processing tasks: two involving non-verbal magnitude representations (i.e., thermometer task and number comparison) and three involving verbal representations (i.e., counting sequences –forward and backward-, transcoding -dictation-, and dots enumeration). They found that children with ADHD-C did not perform worse than children without ADHD on simple and complex calculation tasks and on most of the number processing tasks, except for those related to non-verbal number magnitude representation.

Specifically, children with ADHD made more errors on the number comparison task for all distances, and they showed a typical numerical distance effect; that is, the greater likelihood of errors interacted with number magnitude, causing them to make more errors, particularly in adjacent number pairs. Although the authors did not find significant group differences on calculation tasks or reaction time, children with ADHD tended to be slower and more variable, and they performed quantitatively lower on all the calculation tasks, so that in some cases null group differences might be moderated by power or ceiling effects. Moreover, both groups displayed comparable scores on executive functioning and working memory tasks, so that the observed group differences were not due to differences in more general neuropsychological functioning. These authors interpret their results in terms of a semantic verbal processing deficit in children with ADHD.

These results could be linked to those found in a recent study on estimation calculation (Sella, Re, Lucangeli, Cornoldi, & Lemaire, 2012). In this study, the authors found that children with ADHD and controls were able to correctly execute a selected strategy on more than 97% of the problems; however, children with ADHD selected the best strategy for each problem less often than the children in the control condition, and they took more time to estimate sums of two-digit addition problems, especially with adjacent number pairs.

Miranda, Melia, and Marco (2009) set out to investigate the deficits of children with ADHD and mathematical LD compared to children with ADHD, children with mathematical LD, and children in the control condition on cognitive and metacognitive calculation abilities, as well as on EF. They used a computerized test to evaluate mathematical cognitive processes in 86 six- to eleven-year-old children. The test consisted of eight tasks grouped in three factorial scales: numerical knowledge (reading units and tens, operation symbol comprehension, and numerical production and comprehension), calculation procedures (arithmetical procedures and mental calculation), and arithmetic problem solving. The ADHD and mathematical LD group performed significantly worse than all the other groups and was associated with more severe EF impairments. Specifically, children with ADHD and mathematical LD performed worse than the control group on almost all of the numerical knowledge tasks (operation symbol comprehension, numerical production and comprehension) and on the calculation procedure tasks. In contrast, children with ADHD without mathematical LD did not differ from the control group on any of the numerical knowledge and calculation procedure tasks. However, except for one task (reading units and tens), the mean scores of the children with ADHD were consistently lower than the control group's scores, and this was particularly noticeable in mental calculation.

In summary, the results from the review of the existing literature on specific mathematics problems in children with ADHD are contradictory. Some studies found that children with ADHD without comorbid mathematical LD presented accuracy and speed calculation problems, specifically on arithmetic facts, whereas other studies did not find a worse performance on calculation or number processing tasks. One possible explanation for these differences would be that problems in mathematical abilities may be different depending on the age of the children; that is, there could be a change or development in the mathematical abilities of children with ADHD over time.

Moreover, a recent meta-analysis about the effectiveness of drug treatments in improving the academic achievement of children with ADHD in the classroom concluded that, although drug treatment benefited children in the amount of school work they completed, it less consistently improved children's accuracy on specific assignments such as arithmetic (Prasad et al., 2013). These results, together with the essential role of mathematics in daily life, justify studying specific mathematical deficits in children with ADHD in order to design effective interventions.

Addressing these issues, the present study proposed to investigate the numerical and calculation abilities of children with ADHD without comorbid mathematical LD in order to detect their specific difficulties. The second objective of this study was to examine the stability or development of this profile during school age. The strengths of the present research are that we had a specific individual profile of the mathematical abilities of children with ADHD, and we could individualize the strengths and weaknesses of the children with ADHD in the field of calculation. Moreover, we collected data from the first to the fifth grade of primary school, which will allow us to determine the stability of any difficulties found over time.

Method

Participants

Twenty-eight primary school children with ADHD, assessed at the Center for Education and Learning Difficulties (Padova, Italy), participated in this study. Primary school in Italy lasts five years and is divided into two cycles: the first cycle (first and second grades) and the second cycle (third, fourth, and fifth grades). We categorized the children in two groups according to the cycle they were attending.

For all students involved in this investigation, we received appropriate approval from parents and the school. All the students were Caucasian, had no physical, sensory, or neurological impairments, and spoke Italian as their first language. According to their teachers, each of the participants had grown up in an adequate socio-cultural environment. Demographic information about the age, gender, and ADHD subtype is summarized in Table 1.

In order to identify ADHD-specific underlying numerical and calculation deficits, children with comorbid dyscalculia were excluded from the study. According to the Italian official guidelines (AID-AIRIPA, 2012), the diagnostic criteria for dyscalculia are the following:

1. According to standardized calculation tasks, children must have a performance below the 5th percentile (or -2 SD) on almost 50% of the tasks on a specific battery for the assessment of calculation (e.g. for Italy, AC-MT, Cornoldi et al., 2002);
2. Persistence of problems during the child's academic history;
3. Resistance to treatment: children with dyscalculia do not improve significantly after a period of specific treatment on calculation;
4. The disorder must have important consequences in the child's daily school life;
5. General criteria for LD have to be respected.

Each child's mathematical learning was assessed in a quiet room by a psychologist specialized in LD.

Table 1. ***Demographic characteristics of the subjects***

	ADHD (Total) $N = 28$	ADHD (Cycle 1) $N = 9$	ADHD (Cycle 2) $N = 19$
Age in months (*SD*)	101.04 (14.48)	82.89 (4.56)	109.63 (7.91)
Male (%)	60.7	66.7	57.9
ADHD subtype			
Inattentive (%)	60.7	66.7	57.9
Combined (%)	39.3	33.3	42.1

Measures

The most widely-used Italian test battery, the AC-MT (Cornoldi, Lucangeli, & Bellina, 2002), was used to assess the students' mathematical skills. The AC-MT is a standardized battery for assessing calculation ability; it is a paper and pencil tool used for screening in schools and clinical settings. Test-retest reliability of the AC-MT is r =.65 (mean for all subtests). The calculation assessment measures taken into account were:

Mental calculation: Children are asked to compute some calculations in their heads (6 operations, 3 additions and 3 subtractions). For each operation, the time is measured from the moment the operator finishes saying the numbers in the operation aloud, to the moment when the child answers. The time limit for each calculation is 30 seconds. The operator asks the children what strategies they used and records their responses. Two parameters are considered for this task, i.e. number of errors and time (total time for correct and incorrect responses).

Written calculation: This task aims to examine the child's application of the procedures needed to complete written computational operations and the automatism involved. Children in the first and second grades are asked to solve four operations (additions and subtractions), while children in the third, fourth, and fifth grades are asked to solve eight operations (additions, subtractions, multiplications, and divisions). The parameter considered is the number of correct responses.

Counting: Children are asked to count aloud as quickly as possible. This task changes for different grades: first-grade children have to count forward from 1 to 20; second-grade children have to count forwards from 1 to 50; and for the other grades, children are asked to count backward from 100 to 50. This task is used to investigate whether children have learned the sequence of numbers as a memorized sequence, and if they have understood the role of each number in the counting. The parameter considered is the number of errors (number of times the solution of continuity is interrupted).

Number dictation: Children are asked to write down some numbers in a verbal dictation (numbers range from one to six digits depending on the children's age). This test provides information about syntactic and lexical mechanisms of number production. The parameter considered is the number of errors.

Arithmetical facts: This task is used to investigate how children have stored some combinations of numbers, and whether they are able to access them without having to perform controlled calculation procedures. The operations include additions, subtractions, and multiplications, presented verbally and with 5 seconds allowed to answer each operation (there are 12 operations). Examples of arithmetic facts are simple operations such as multiplication tables, or 8 + 2 or 10 - 5. Here again, the number of errors is considered.

Numerical knowledge is a multiple task including the following subtasks (and the parameter considered is the sum of correct answers on all the subtasks).

Number comparison: Six pairs of numbers are presented, and children are asked to circle the largest number in each pair; e.g. 856 versus 428, "Which number is larger?" This task requires an understanding of the semantics of numbers and the ability to read numbers (lexical level).

Transcoding in digits: This task assesses the children's ability to elaborate the syntactic structure of numbers that governs the relationship between the digits the numbers contain. Children are shown six series of verbally-described numbers, and they have to transform them into a final number; e.g; "we have 3 tens, 8 units and 2 hundreds," and the child has to transform them into the number 238.

Number ordering (from the greatest to the least, and vice versa): This task is used to assess the semantic representation of numbers by means of quantity comparisons. To answer correctly, the child must be able to recognize single quantities, compare them, and place them in the right order. Five series of 4 numbers were presented; e.g. 36, 15, 576, 154, and the child had to arrange them in the right order.

Data Analysis

To facilitate comparisons between the different age groups, *z-scores* for all the individual measures were calculated using normative data. Then, children were categorized in three groups according to their level of proficiency on each of the subtests: "without difficulties" (children who were above - 1 SD), "moderate difficulties" (children between - 1 and - 2 SD) and "severe difficulties" (children who were lower than - 2 SD). The percentages of the 28 children placed in each of these groups were calculated.

Next, the sample was divided according to the primary school cycle, and the percentages were recalculated. Then, the *z-scores* for the cycle 1 and cycle 2 groups were compared on each subtest, using *t-tests* for independent samples, in order to test the development of the ADHD arithmetic profile during their primary school years.

Results

General Arithmetic Profile of Children with ADHD

Table 2 shows the percentage of children with ADHD who present moderate or severe difficulties on each subtest of the AC-MT. The most impaired measures were mental calculation times and the two counting measures (errors and time), where more than 25% of children fall into the "severe difficulties" category. There were high percentages of children in the "moderate difficulties group" on written calculation and arithmetic facts, while numerical knowledge, number dictation and mental calculation errors seem to have the highest percentages of children with good performance, up to 75%.

Table 2. ***Percentages (%) of children with ADHD distributed according to their performance on the AC-MT subtest***

AC-MT subscales	No difficulties (z > - 1 SD)	Moderate difficulties (-1 < z < -2 SD)	Severe difficulties (z < - 2SD)
Mental calculation (errors)	75	7.1	17.9
Mental calculation (time)	71.4	3.6	25
Written calculation	68	20	12
Counting (errors)	57.1	7.2	35.7
Counting (time)	64.3	7.1	28.6
Number dictation	82.1	-	17.9
Arithmetic facts	57.7	30.8	11.5
Numerical knowledge	92.6	3.7	3.7

Developmental Arithmetic Profile of Children with ADHD

In order to see whether the arithmetic profile is stable over time or changes with age, we divided the sample according to the primary school cycle. Table 3 shows the percentages of children categorized by their performance on the AC-MT subtests according to the cycle they were attending.

When children were divided into the two groups by age, the difficulties showed different patterns. Children with ADHD who attend first and second grades have more difficulties with counting (errors) and number dictation, where more than 30% fall into the "severe difficulties" category. The other two subtests on which an important percentage of children score in the "moderate difficulties" category are written calculation and arithmetical facts. However, all or almost all of the children were within the parameters of normal performance on mental calculation (errors and time), counting (time) and numerical knowledge.

Children who attend third, fourth, and fifth grades generally showed more difficulties on the AC-MT subtests. Specifically, more than 20% of these children presented "severe difficulties" with mental calculation (both errors and time) and counting (both errors and time). A high percentage of children showed "moderate difficulties" on arithmetic facts, and most of the children seemed to fall inside the normal parameters only on number dictation and numerical knowledge.

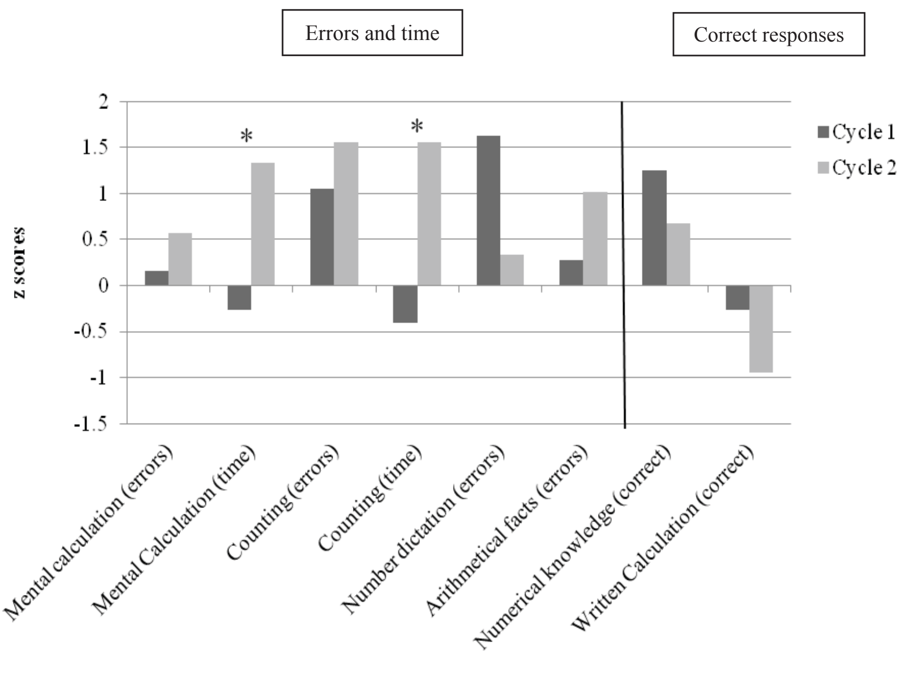
Table 3. ***Percentages (%) of children with ADHD categorized by cycle and distributed according to their performance on the AC-MT subtest***

	First cycle (1st , 2nd)		Second cycle (3rd, 4th, 5th)			
AC-MT subscales	**No difficulties (z > - 1SD)**	**Moderate difficulties (-1 < z < -2 SD)**	**No difficulties (z > - 1SD)**	**Severe difficulties (z <- 2SD)**	**Moderate difficulties (-1 < z < -2 SD)**	**Severe difficulties (z <- 2SD)**
Mental calculation (errors)	88.9	-	68.4	11.1	10.5	21.1
Mental calculation (time)	100	-	57.9	-	5.3	36.8
Written calculation	75	25	64.6	-	17.7	17.7
Counting (errors)	66.7	-	52.6	33.3	10.5	36.9
Counting (time)	100	-	47.4	-	10.5	42.1
Number dictation	66.7	-	89.5	33.3	-	10.5
Arithmetic facts	71.4	28.6	52.6	-	31.6	15.8
Numerical knowledge	88.9	-	94.4	11.1	5.6	-

Differences in Numerical and Calculation Abilities Between Cycle 1 and Cycle 2 of Children with ADHD

The *z-scores* of the cycle 1 and cycle 2 groups, calculated from normative data, were compared on each subtest using *t-tests* for independent samples. Results of independent-sample *t-tests* showed statistically significant differences between the *z-scores* of the first and second cycle groups on mental calculation time ($t(26) = -3.39$, $p = .002$) and counting time ($t(26) = -3.97$, $p = .001$). Specifically, the second cycle group was significantly slower on the mental calculation task (cycle 1: $M = -0.26$, $SD = 0.61$ vs. cycle 2: $M = 1.33$, $SD = 1.84$) and on the counting tasks (cycle 1: $M = -0.41$, $SD = 0.77$ vs. cycle 2: $M = 1.55$, $SD = 1.85$). Arithmetic facts and written calculation were near significance ($p < .10$), with the oldest group showing worse performance. The only subtests on where cycle 1 performed worse than cycle 2 were number dictation and numerical knowledge (see Figure 1).

Figure 1. **Comparison between Cycle 1 and Cycle 2 students on ACMT performance**



Discussion

This study aimed to better understand the mathematical abilities of children with ADHD by examining their performance on different numerical and calculation tasks.

First, our results showed that a high percentage of children with ADHD reported severe difficulties on numerical and calculation abilities, greater than what would be expected in the general population, even when these children with ADHD did not have a diagnosis of dyscalculia. Specifically, counting and arithmetic facts were the most affected processes in the school-age children with ADHD in our sample, probably because these processes require a certain degree of automaticity. However, this profile seems to change with age, at least within the primary school population. In general, the percentages of children presenting severe and moderate difficulties increase with age. In the first cycle, there was a high percentage of children without difficulties, even reaching 100% on some of the measures (mental calculation time and counting time). The main difficulties in these children were found on counting errors and number dictation, classified as lexical processes involving the ability to name numbers. In contrast, a high percentage of children in the second cycle encountered difficulties on almost all the measures of numerical and calculation abilities. Specifically, these children had greater problems with mental calculation and counting, considering both errors and time. This result indicates that the errors are not due to impulsivity, or responding quickly, a characteristic that sometimes characterizes children with ADHD; despite being slower and needing more time, they continue to commit errors. These data seem to show that both mental calculation and counting processes are particularly difficult for children with ADHD in the second cycle of primary school.

It is worth noticing that in both cycles numerical knowledge appears to be intact, as none of the children reported problems in this task. Thus, they do not show difficulties with basic calculation processes, such as lexical or syntactical ones processes, but they do have problems in learning procedural knowledge. The difficulty does not lie in the conceptual knowledge of the number, but rather in its application to automated tasks. Another aspect that can explain these results is the educational style of the teachers. For example, a recent study (Re, Pedron, Tressoldi, & Lucangeli, in press) found that after specific training in calculation abilities, children with difficulties in these areas showed very meaningful improvements, even reaching normality in some cases. This data supports the idea that specific teaching that takes the specific learning profiles of the children into account can produce good results and avoid learning problems.

One limitation of the present study is the small sample size, which could affect the generalization of the findings and the power of the statistical analysis. Nevertheless, in spite of the small number of participants, we found significant differences in some variables between children attending cycles 1 and 2. When the two cycles were compared, statistically significant differences emerged in times to perform mental calculation and counting; moreover, differences in arithmetic facts were very close to significance. These three tests are related to automatization deficits, and on all three tests, children in the second cycle had greater problems than children in the first cycle. These results support those found by Zentall's group, namely, that by the middle school years, fluency is the process that differentiates students with ADHD from comparison participants (Zentall, 2007). Due to automatization deficits, these children may encounter major problems on other tasks that require the use of calculation, such as solving arithmetic problems.

However, we must take into account that the counting task was different for the two cycles. While children attending first and second grades had to count forward from 1 to 20 and from 1 to 50, respectively, in the other grades children were asked to count backward from 100 to 50. This latter task also involves working memory. Therefore, these specific results on counting might be due to deficits in working memory, a cognitive ability that has been shown to be deficient in children with ADHD (Martinussen & Tannock, 2006). This explanation is supported by several research outcomes that have studied the relationship between mathematical LD and EF in children with ADHD, finding a relationship with working memory (Biederman et al., 2004). In fact, some researchers attribute the significant mathematical delays in children with ADHD to attentional, working memory and EF impairments, and these skills are necessary for calculations.

In summary, even if absence of a comorbidity with dyscalculia, children with ADHD show difficulties with some aspects of calculation. It appears that children with ADHD have difficulties in learning mathematics, and these difficulties vary with age. In the first years of primary school, the more severe difficulties were observed in the lexical processes, while in older children, the deficits were concentrated in the automatization and procedural processes. These findings seem to indicate that difficulties in some aspects of the calculation of children with ADHD (without mathematical LD) do not appear from the first years of life, but instead are acquired over time, as, at least in primary school, the older children have more severe problems. Some persistent errors in counting were found; however, the changes observed from the first and the second cycle of primary school may be attributable to instruction. In fact, several explanations could be found for these difficulties. On the one hand, the impairments may be directly related to ADHD symptoms and deficits in executive functioning that characterize children with ADHD, as some authors have shown. For example, a review by Daley and Birchwood (2010) suggests that deficits in executive functioning could be at the heart of ADHD-related academic underperformance, and that there is a possible inattention-EF impairment pathway to academic problems in individuals with ADHD. Thus, a plausible explanation is that the objectives of the mathematics curriculum progressively make more EF demands on working memory, planning or monitoring. Therefore, future studies should explore the role of EF in the specific mathematical difficulties of children with ADHD.

Another possible explanation could be the deficiencies of the school system itself, especially in adapting the teaching-learning process to the peculiarities of students with ADHD. In the population of children in general, the development of mathematical skills at school starts late, teachers do not know how to enhance these skills very well, and teaching methodologies are often dysfunctional (Re et al., in press). These factors could affect children with ADHD more severely, especially when school tasks increase in difficulty, and more mental resources are needed to cope with them.

Mathematical abilities are important not only for academic success but also for their impact on daily life. Our results show that calculation and numerical abilities are impaired in children with ADHD, even if they do not present mathematical LD. For this reason, the present study has important practical implications. First, it demonstrates the need for a comprehensive evaluation of specific mathematical aspects, even though the children do not present mathematical LD, paying particular attention to number sequencing and arithmetical facts. Secondly, the specific assessments should be continued throughout the academic years, since the areas where we will have to intervene will be different depending on the age. When children are younger, the planning of programs with specific contents should focus especially on lexical aspects, while in older children greater attention should be paid to the learning of procedural knowledge and the application of automated tasks.

Because these difficulties increase with age, it is also important to consider the role of motivation. Specifically in the case of mathematics, motivation has been found to have a role in predicting mathematical performance in children with ADHD that could be even greater than the role played by the executive functions. Therefore, the teacher must not only attend to transmitting contents, but he or she must also foster motivation toward learning (Miranda, Colomer, Fernandez, & Presentancion, 2012). Finally, our data underline the importance for educators/teachers of taking individual calculation profiles into account. Individual profiles identify which processes should be enhanced through education in order to ensure the development of all the components of an individual's pattern.

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Mathematics Instruction: Do Classrooms Matter?

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Counting abilities have been described as determinative precursors for a good development of later mathematical abilities. However, an important part of variance in mathematical achievement has also been associated with differences between instruction methods given in schools. In this study counting and instruction as predictors for mathematical skills were studied in 423 children. Our data revealed that the mastery of the counting principles in kindergarten was predictive for the risk of mathematical (dis)abilities in grade 1. Moreover, children sharing a common instructional background tended to have more similar scores on mathematical tests, yet, the importance of mastery of the counting principles in the prediction of later mathematical achievement was the same for all classrooms.

Keywords: Mathematical abilities, risk for math disability, counting, procedural calculation, fact retrieval, kindergarten predictors, classroom, and instruction.

Introduction

Mathematics is inherently present in everyday life. Although mathematical problems have serious educational consequences, this area has received little attention in research until recently (Engle, Grantham-McGregor, Black, Walker, & Wachs, 2007; Landerl, Bevan, & Butterworth, 2004). However, Dowker (2005) indicated that the impact of poor mathematical skills is greater than the influence of poor reading skills. Differences in mathematical abilities between and within individuals are normal. Teachers are expected to cope with learning differences and to adjust their teaching style to the needs of all students. But in some cases, these differences appear to be so severe or resistant that they can be considered as characteristics of 'problems' or even 'disabilities' (Grégoire & Desoete, 2009). Most practitioners and researchers currently report a prevalence of mathematical learning disabilities (MLD) between 2 and 14% of children (Barbaresi, Katuskic, Colligan, Weaver, & Jacobsen, 2005; Desoete, Roeyers, & De Clercq, 2004; Shalev, Manor, & Gross-Tsur, 2005). The prevalence of MLD in siblings even ranges from 40 to 64% (Desoete, Praet, & Ceulemans, 2013; Shalev et al., 2001).

The term MLD refers to a significant degree of impairment in the mathematical skills (with substantially below mathematical performances). In addition, children with MLD do not profit enough from (good) help. This is also referred to as a lack of responsiveness to intervention. Finally, the problems in MLD cannot be totally explained by impairments in general intelligence or external factors that could provide sufficient evidence for scholastic failure. The challenges that people with MLD face (see e.g. Desoete, Van Hees, Tops, & Brysbaert, 2012; Vanmeirhaeghe

& VanHees, 2012) become evident through a statement made by Kristel, a Master in education: “Why was elementary school like hell? Because I felt a huge pressure on me. Open your manual on page 68. There we go again! Where is page 68? Other pupils already had taken down the title, while I was still looking for page 68. It was a constant feeling of needing to exert myself. I had to concentrate very hard in order to follow what was going on. That is what made it so difficult for me. Everyone was faster than I was.“

A child with MLD needs extra support to enable him or her to follow a lesson according to his or her own intellectual level. MLD goes namely far beyond (mental) arithmetic. Even remembering definitions takes more efforts, as becomes evident through a statement by Sara, a Bachelor in journalism: “I need three times more time than an average student to learn the same subjects.”

While early literacy is stimulated by almost all parents, early numeracy and counting gets less universal attention, although also the development of mathematical (dis)abilities begins before formal schooling starts (Ceulemans, Loeys, Warreyn, Hoppenbrouwers, & Desoete, 2012; Sophian, Wood, & Vong, 1995). It is therefore not surprising that children start with a quite heterogeneous baggage of counting skills at the school-desk. In addition, Opdenakker and Van Damme (2006) found that an important part of the variance in mathematical abilities in first grade were associated with differences between schools.

This study focused on counting abilities (Aunola et al., 2004; Gersten, Jordan, & Flojo, 2005; Le Fevre et al., 2006) in combination with mathematical instruction (Opdenakker & Van Damme, 2006) as a predictor of mathematical (dis)abilities in a large sample of children with a wide range of mathematical competencies.

Counting can be considered as a key ability for the development of age adequate mathematical skills. By means of counting, number facts are stored in long-term memory (Geary, 2011). In addition, counting activities lead to better strategies for addition and subtraction (Le Fevre et al., 2006) and multiplication (Blöte, Lieffering, & Ouwehand, 2006).

The mastery of the essential counting principles has been described as an essential feature for the development of counting (Geary, 2004; Gelman & Meck, 1983; Wynn, 1992). Children have to master the stable order, the one-to-one correspondence and the cardinality principle in kindergarten. The stable order principle implies that the order of number words must be invariant across counted sets. The one-to-one correspondence principle holds that every number word can only be attributed to one counted object. Once the cardinality principle is acquired, children know that the value of the last number word represents the quantity of the counted objects. Knowledge of the stable-order principle is reliable first of all, followed by the one-to-one correspondence principle, while mastery of the cardinality principle was found to develop the slowest (Butterworth, 2004; Fuson, 1988).

Mathematical instruction might differ in the adopted instructional paradigm (Case, 1998; Daniels & Shumow, 2003; De Corte, 2004; Ellis & Berry, 2005). The adoption of a traditional approach (e.g., emphasis on rules, memorizing, and rehearsing), a structuralist approach (e.g., stressing abstract conceptualizations of mathematical content) or a constructivistic view towards learning (e.g., teaching mathematics presenting problems within a familiar context in order to give meaning), will affect the design of learning materials and the instructional strategies suggested in textbooks (Carnine, Dixon, & Silbert, 1998; Van de Walle, 2007). This has been researched in an extensive way in relation to mathematics (Cooper, 1993; Nathan, Long, & Alibali, 2002). Moreover, differences between the instructional interventions and curricula are found in the timing and the stage at which the conceptions are presented to children as well as in the kinds of learning opportunities provided and in its organizing and sequencing (Schmidt, McKnight, Valverde, & Houang, 1997). As such, a large variation of teaching practices is adopted to teach mathematics in primary education. Depending on the curriculum, the textbooks used in the classroom, and the preferences and beliefs of each individual teacher, instruction can strongly differ across classrooms (Remillard, 1999). However, Slavin and Lake (2008) revealed that there is a lack of evidence supporting a differential effect of mathematics curricula on students' mathematicals performance results.

Although some authors stressed the importance of instruction and curricula (e.g., Chval, Chávez, Reys, & Tarr, 2009; Van Steenbrugge, Valcke, & Desoete, 2010; Zhao, Valcke, Desoete, Verhaeghe, & Xu, 2011) there is inconclusive evidence (Slavin & Lake, 2008) on the influence of instruction on children's mathematical skills in grade 1.

In this study the relationship between mastery of the counting principles in kindergarten (child factors) on the one hand and instruction (classroom factors) on the other hand on (dis) mathematical abilities will be analyzed.

Method

Participants

This study was carried out with 423 children (223 girls) in kindergarten. Of this sample, 369 children were tested in grade 1. All participants were Caucasian native Dutch-speaking boys and girls living in the Flemish part of Belgium. The children in this study had a mean age of 70.02 months (*SD* = 4.01 months) and attended on average 7.42 months (*SD* = 1.03 months) of school in the last kindergarten class when tested the first time.

Subjects were retrospectively classified as at-risk for a math learning disability (MLD) if they had scored < -1.5 on the *z*-score of one of the mathematical ability tests in grade 1 ($n = 48$). Children who scored *z*-scores above -1.5 on both mathematical tests in grade 1 were classified as typical achievers ($n = 321$), not at-risk for a math disability.

Materials

All counting abilities were tested in kindergarten with the TEDI-MATH (Grégoire, Noel, & Van Nieuwenhoven, 2004). The TEDI-MATH has proven to be a well validated and reliable instrument. Children had to judge the counting of linear and random patterns of drawings and counters. To assess the abstraction principle, children had to count different kinds of objects that were presented in a heap. Furthermore, a child who counted a set of objects was asked 'how many objects are there in total?', or 'how many objects are there if you start counting with the leftmost object in the array?'. When children had to count again to answer, they did not gain any points, as this was considered to represent good procedural knowledge but a lack of understanding of the counting principles. One point was given for a correct answer with a correct motivation. A sum score was constructed (maximum: 13 points). Cronbach's alpha was .85.

In order to obtain a complete overview of the mathematical abilities of children and to test for procedural calculation and semantic memory abilities (Pieters et al., 2013), the following mathematical tests were used: the Arithmetic Number Fact Test (Tempo Test Rekenen [TTR]; De Vos, 1992) and the Kortrijk Arithmetic Test Revision (Kortrijkse Rekentest-Revisie [KRT-R]; Baudonck et al., 2006).

The Arithmetic Number Fact Test (Tempo Test Rekenen [TTR]; De Vos, 1992) is a test consisting of number fact problems (e.g., 2 + 5 = ... ; 9 - 2 = ...). Children have to solve as many additions and subtractions as possible within 2 minutes. The psychometric value of the test has been demonstrated on a sample of 10,059 children.

The Kortrijk Arithmetic Test Revision (Kortrijkse Rekentest-Revisie [KRT-R]; Baudonck et al., 2006) is an untimed standardized test on procedural calculation from grade 1 until 6. The KRT-R requires that children solve calculations in a number-problem format (e.g., 16 - 12 = …) or in a word-problem format (e.g., 1 more than 3 is …). The psychometric value of the test has been demonstrated on a sample of 3,246 children and is frequently used in Flemish education and diagnostic assessment.

Procedure

The children were recruited in 25 randomly selected schools, 9 schools were located in a city while 16 of them were located rurally. All parents received a letter with the explanation of the research and could submit informed consent in order to participate.

Children were tested during school time in a separate and quiet room. Toddlers were tested individually. The test leaders all received training in the assessment and interpretation of the tests. After completion of the test procedure, all the parents of the children received individual feedback on the results of their children.

Results

In this sample, only 44.2% of the children mastered the three counting principles by the end of kindergarten (see also Stock, Desoete, & Roeyers, 2009). In addition, a MANOVA with procedural and conceptual counting skills as a dependent variable and group (children at-risk for MLD, children not at-risk for MLD) as a group was significant on the multivariate level ($F(2, 366) = 37.241$; $p <.001$, = partial $\eta^2 = .169$). There were significant differences on the univariate level for procedural ($F(1, 367) = 49.288$; $p <.001$, = partial $\eta^2 = .118$) and for conceptual counting ($F(1, 367) = 48.832$; $p <.001$, = partial $\eta^2 = .117$) with children at-risk for a math disability having lower developed procedural ($M = 41.31$; $SD = 22.89$) and conceptual ($M = 34.27$; $SD = 28.29$) counting abilities compared to their peers not at-risk for math disabilities (procedural counting $M = 69.25$; $SD = 26.10$; conceptual counting $M = 64.35$; $SD = 27.74$).

Since the children in this study were clustered in classrooms and thus not sampled randomly and independently, intra-class correlations were computed for both dependent mathematical ability variables (the procedural calculation and fact retrieval skills of children in grade 1). The intra-class correlation was calculated as the proportion of the between-group variance relative to the sum of the between- and within-group variance.

Table 1. ***Mixed Model Analysis: Null Model of mathematical abilities***

Parameter	Procedural calculation		Numerical Facility	
	Estimate	*SE*	Estimate	*SE*
Level 1 Intercept	.56*	.04	.63*	.05
Level 2 Intercept	.57*	.18	.42*	.14
Intra-class correlation	.50		.40	

Note. * $p < .001$

The intra-class indices (see Table 1) indicated that between 40 and 50% of the variance in the mathematical abilities of children could be explained by getting the same instruction. The individual level intercept variance was .56 for procedural calculation and .63 for numerical facility. The classroom level intercept variance was .57 for procedural calculation and .42 for numerical facility.

In order to take into account this data structure, multilevel analyses were performed with counting skills as the independent predictor, the scores on the mathematical tests as Level 1 and classrooms (or instruction) as Level 2. The results of the analyses are shown in Table 2.

Table 2. ***Mixed Model Analyses: Model including counting and mathematical instruction as factors***

Parameter	Procedural calculation		Numerical Facility	
	Estimate	*SE*	Estimate	*SE*
Fixed				
Intercept	-.13	.13	-.05	.13
Counting skills	.33*	.06	.21*	.05
Random				
Level 2 Intercept	.41*	.13	.36*	.12
Level 2 Instruction	.03	.02	.00	.02

Note. * $p < .001$

The fixed part of the model revealed that counting skills play a significant role in the prediction of both procedural calculation and numerical facility. Children with better counting skills in kindergarten tended to perform better on arithmetic tests in first grade. The random part of the model revealed that there was significant intercept variance between the classrooms for both arithmetic tests, indicating that classrooms differ in their mean performances. Yet, no significant slope variance was found for the scores on the arithmetic tests between the different classrooms.

Discussion

The goal of the current research was to gain more insight into the importance of mastering the counting principles in kindergarten versus the variance between classrooms or the role of instruction on mathematical abilities and the risk for math disability in Grade 1.

In this study, more than half of the children did not master the three counting principles by the end of kindergarten. Large differences in the mastery of the essential counting principles in toddlers existed, so teachers may need to pay a lot of attention to the different baggage children bring with them when entering first grade.

In addition, counting abilities in toddlers and their procedural calculation and fact retrieval abilities one year later in first grade were assessed in a large sample that included children with a wide range of mathematical abilities. Our findings revealed that it was possible to differentiate between children at-risk and not at-risk for mathematical disabilities in elementary schools based on the procedural and conceptual knowledge of counting in kindergarten.

Furthermore, it was supposed that children who performed better on the items of the counting principles as a whole in kindergarten, had better scores on mathematical tests in first grade one year later than children who had lower scores on the counting items. Since high values were found for the intra-class correlations, it was necessary to take into account the clustered structure of the data and to use multilevel analyses. The expected hypothesis could be confirmed. The better children performed on the counting items in the last kindergarten class, the better they performed on the two mathematical tests in first grade. These results confirm the role of counting abilities in the development of proficient arithmetic strategies (Stock et al., 2009, Stock, Desoete, & Roeyers, 2007; Van De Rijt & Van Luit, 1999).

The results pointed out that a large part of the variance in mathematical achievement in first grade can be associated with differences between schools. By using multilevel analyses it was possible to allow for similarities in the performances of children in the same classroom, but no explanatory factors could be found. We found significant random variation for the mean class achievement indicating that the level of performances was quite different between schools and those children sharing a common educational background tended to have more similar scores on mathematical tests when compared with children in other schools. Yet there was no random slope variation, meaning that the importance of mastery of the counting principles in the prediction of later arithmetic achievement was the same for all classrooms. There was no differential influence of the school context on the children's basic counting knowledge.

Yet, the study had a few limitations. In this study the TEDI-MATH items (Grégoire et al., 2004) were used. We thus still` have to be careful with our conclusions since MLD might not be a homogeneous disability (Pieters et al., 2013) and the choice of the used task can have an important impact on the results. Furthermore, the conclusions of this study have to be interpreted carefully since a large proportion of the variance remained unexplained. A lot of other possible powerful predictors besides the counting abilities such as language (Praet, Titeca, Ceulemans, & Desoete, 2013; Vukovic & Lesaux, 2013) and magnitude estimation skills (Stock, Desoete, & Roeyers, 2010) were not taken into account in this research. For example, contextual variables such as home environment and parental involvement (e.g., Reusser, 2000) should be included in future studies. These limitations indicate that only a part of the picture is investigated so the results of the study have to be interpreted with care. Yet the large group of children that was assessed in this study strengthens the generalizability of the results.

In conclusion, our results revealed a relationship between mastery of the counting principles in kindergarten (child factors) on the one hand and instruction (classroom factors) on the other hand, on mathematical abilities and the risk for a math disability. It was possible to explain significant proportions of scores on mathematical tests in first grade based on the counting scores in kindergarten. In addition, there were important differences between schools. Taking into account the large differences in baggage in terms of counting skills children took with them when starting basic schooling and the fact that scores on counting tasks were good predictors for later arithmetic abilities, it is important that teachers in first grade pay enough attention to the instruction of counting skills.

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Can Executive Functions Help to Understand Children with Mathematical Learning Disorders and to Improve Instruction?

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Working memory, inhibition and naming speed was assessed in 22 children with mathematical learning disorders (MD), 17 children with a reading learning disorder (RD), and 45 children without any learning problems between 8 and 12 years old. All subjects with learning disorders performed poorly on working memory tasks, providing evidence that they have a deficiency related to simultaneously storage and processing of verbal and/or visuospatial information. In addition, children with MD+RD suffered from problems with quantity naming speed compared to children without MD. Our data revealed the importance to manage working memory loads and give more time to complete homework, exercises, and examinations.

Keywords: Executive functions, working memory, mathematical learning disorders, and math instruction.

Introduction

Specific learning disorders (LD) are common in childhood (Beghi, Cornaggia, Frigeni, & Beghi, 2006; Dirks, Spyer, van Lieshout, & de Sonneville, 2008). The DSM-5 differentiates LD with impairment in reading, written expression, and mathematics. Mathematical disorders (MD) are defined as specific disorders with impairments in math abilities at a level that is significantly below expected given the age and effective teaching. Moreover, the mathematical impairments in MD are not explained by extraneous factors, such as sensory deficits (Landerl et al., 2004; Passolunghi, Vercelloni, & Schadee, 2007), and have to be persistent (Fletcher et al., 2005). In order to be sure of the persistence of MD, it is important to consider consistency in performance over time (Fletcher et al., 2005; Mazzocco & Myers, 2003). Most researchers currently report prevalence of MD in between 3 and 14% of children (Barbaresi, Katusic, Colligan, Weaver, & Jacobsen, 2005; Rubinsten & Henik, 2009; Shalev, Manor, & Gross-Tsur, 2005). Recently, Geary (2011) estimated a prevalence of approximately 7% of all school aged students. Several hypotheses have been studied to identify the origins of MD in children (e.g., Butterworth, 1999; Wolf & Bowers, 1999). A deficit in working memory, inhibition, or naming speed has been proposed to explain the problems in the underlying cognitive system of boys and girls who suffer from MD (Bull & Scerif, 2001; Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007; Passolunghi & Siegel, 2004) and or a combined reading disorders (RD) and MD (RD+MD; Pauly et al., 2011; van der Sluis, de Jong, & van der Leij, 2004; Willburger, Fussenegger, Moll, Wood, & Landerl, 2008). However, there are studies not supporting the hypothesis of such deficits (e.g., Censabella & Noel, 2005; Kibby, Marks, Morgan, & Long, 2004; Landerl, Bevan, & Butterworth, 2004). Thus, the empirical pattern is far from straightforward.

RD are defined as impairments in reading and/or written expression (spelling abilities). These impairments are at a level that is significantly below expected given the age and the teaching that the children have received (Ziegler et al., 2008). The prevalence of RD in school-aged children is approximately between 5 and 12% (Schumacher, Hoffmann, Schmal, Schulte-Korne, & Nothen, 2007). However, since language and orthography play an important role in reading, prevalence of RD may differ across countries (Callens, Tops, & Brysbaert, 2012). Clear differences are marked between regular and more irregular orthographies and it is assumed that different problems are manifested in RD in languages that embed regular grapheme-phoneme correspondence than in languages with a less transparent orthography and grapheme-phoneme mapping (Bergmann & Wimmer, 2008; Callens, Tops, & Brysbaert, 2012). There are several hypotheses concerning the causes of this phenomenon. Deficits in phonologically related processes are often considered one of the key factors for developing RD (e.g., Peterson & Pennington, 2012; Vellutino et al., 2004), but there is also the double-deficit hypothesis by Wolf and Bowers (1999). This theory focuses both on phonological processing and naming speed. In addition, Stein and Walsh (1997) revealed a general magnocellular deficit in children with RD, meaning that children with RD were unable to correctly process fast incoming visual and auditory information (Stein & Walsh, 1997). Finally, research has found evidence that deficits in working memory are associated with RD (e.g. Savage et al., 2007). In addition, the role of inhibition in the reading process has been stressed (Schmid, Labuhn, & Hasselhorn, 2011). Failures to inhibit improper (though more dominant) pronunciations might impair word recognition performance in a more profound manner (Chiappe, Hasher, & Siegel, 2000).

Executive functioning can be described as the general purpose control mechanisms that coordinate, regulate, and control cognitive processes during the operation of cognitive tasks (Miyake et al., 2000) and are localized in the central executive control system of working memory. According to Baddeley (1986), working memory has to be seen as an active system that regulates complex cognitive behavior. His multi-component model consists of a central executive component, a phonological loop and a visuospatial sketchpad. In this model, the central executive is an attentional control system, which executes the processing aspects of a task. The central executive strongly interacts with one multi-dimensional and two domain-specific storage systems. The phonological loop is responsible for the storage and maintenance of verbal information; the visuospatial sketchpad has similar responsibilities for visual and spatial information. The multi-component model of Baddeley (1986) is used by the main part of LD studies investigating working memory (e.g., Passolunghi & Siegel, 2004; van der Sluis, van der Leij, & de Jong, 2005). And it will also be used in this study. Forward recall tasks can be considered as measures of the phonological loop and the visuospatial sketchpad, while backward recall and dual span tasks are used as measures of the central executive.

In his heuristic taxonomy, Nigg (2000) separates executive inhibition from motivational and automatic inhibition. The former might be considered part of executive functioning. Executive or effortful inhibition is categorized in interference control, behavioral, oculomotor, and cognitive inhibition. Interference control refers to the ability to maintain response performance and suppress competing, distracting, or interfering stimuli that evoke a competing motor response. It is often measured by Stroop (Stroop, 1935) and Flanker (Eriksen & Eriksen, 1974) tasks. In addition, behavioral inhibition is seen as the capacity to suppress a prepotent or dominant response and entails the deliberate control of a primary motor response in compliance with changing context cues. The Go/no-go is a frequently conducted measure of behavioral inhibition (e.g., Friedman & Miyake, 2004; Purvis & Tannock, 2000) and hence will be used in this study.

Naming speed can be defined as those processes that underlie the rapid recognition and retrieval of visually presented linguistic stimuli (Wolf & Bowers, 1999) or as the ability to quickly recognize and name a restricted set of serially presented high frequency symbols, objects, or colors (Heikkila, Narhi, Aro, & Ahonen, 2009; McGrath et al., 2011), and is often measured by a task based on the Rapid Automatized Naming paradigm of Denckla and Rudel (1974). Savage et al. (2005) found that number naming speed discriminated children with RD from those in a control condition. Both groups were between 7 and 10 years old. In addition, D'Amico and Passolunghi (2009) found slower naming speed on both numbers and letters in 9 year old children with MD in comparison with age-matched children in a control condition. Hence, it is also unclear if naming speed problems are related to a deficit in letter or numerosity processing or if the problems are more general.

Although the comorbidity between MD and RD is higher than would be expected by chance, little is known about the question if children with MD, RD, or RD+MD perform poorly on all working memory, inhibition, and naming speed tasks, or if they have a domain-specific deficit related to tasks requiring simultaneous storage and processing of verbal or numerical information. The principal objective of this study was therefore to gain more insight into the (modality-specific or domain-general) cognitive processes underlying MD with and without RD, and into the relationship between learning disorders themselves.

Method

Participants

The participants were 112 children (45 control, 22 MD, 28 RD+MD, and 17 RD) between 8 and 12 years old. The characteristics of the participants are described in Table 1.

Table 1. Subject Characteristics of the Sample

Characteristic	Control	RD	MD	MD+RD
	M *(SD)*	M *(SD)*	M *(SD)*	M *(SD)*
Age in months	120.91 (10.37)	119.53 (13.41)	117.55 (9.01)	122.29 (12.43)
Male : female	19:26	10:7	6:16	9:11
IQ	108.42 (9.86)[a]	105.18 (8.47)[ab]	94.82 (9.21)[c]	99.57 (11.45)[bc]
Z-score TTR	0.94 (0.62)[a]	-0.27 (0.61)[b]	-0.27 (0.82)[b]	-0.87 (0.71)[c]
Z-score KRT-R	0.80 (0.39)[a]	0.50 (0.52)[a]	-1.02 (0.64)[b]	-0.92 (0.69)[b]
Z-score PI	0.91 (0.41)[a]	-0.90 (0.57)[c]	0.49 (0.51)[b]	-0.90 (0.49)[c]
Z-score EMT	0.90 (0.65)[a]	-0.78 (0.42)[c]	0.41 (0.70)[b]	-0.79 (0.60)[c]
Z-score Klepel	0.84 (0.63)[a]	-0.81 (0.42)[b]	0.47 (0.84)[a]	-0.89 (0.50)[b]

Note. RD = reading disorders; MD = mathematical disorders; RD+MD = reading and mathematical disorders; TTR = Arithmetic Number Facts Test (fact retrieval skills); KRT-R = Kortrijk Arithmetic Test Revision (procedural mathematical skills); PI = Paedological Institute-dictation (spelling); EMT = One Minute Reading Test (word reading speed).
[a,b,c] posthoc indices at $p < .05$.

Children in the control condition came from regular elementary schools and children diagnosed with MD, RD or RD+MD were referred by paraprofessionals with a clinical diagnosis of a learning disorder. All children were tested on math, reading, and spelling measures to ensure that the relevant criteria were met. Control children had to achieve a score above the 25th percentile on all tests. In congruence with Geary (2011), children with MD had to score ≤ the 10th percentile on at least one of the frequently used standardized math tests, measuring mental arithmetic and number knowledge (procedural skills) and fact retrieval. Children with RD had to achieve a score ≤ the 10th percentile on a spelling and reading tests, measuring word reading speed and pseudo-word reading. Children with RD+MD had to score ≤ the 10th percentile on at least one math test and ≤ the 10th percentile on at least one spelling or reading test (Dirks, Spyer, van Lieshout, & de Sonneville, 2008; Murphy, Mazzocco, Hanich, & Early, 2007).

Instruments and Procedures

Working Memory Measures

Digit and word list recall forward was used to measure the phonological loop. Block recall was used as a measure for the visuospatial sketchpad. In backward digit recall, backward word list recall, and backward block recall, children are required to recall sequences of digits, words or squares in the reverse order as a measure of the central executive component of working memory. In addition, two dual tasks were used to test this construct. In listening recall, children had to verify sentences by stating 'true' or 'false' and memorize the final word for each sentence. In the second dual task, children had to identify whether the shape on the right side was the same or opposite of the shape on the left. In addition, they had to recall the location of a red dot (see De Weerdt, Roeyers, & Desoete, 2013a). Composite scores for the phonological loop, the visuospatial sketchpad and the central executive component were calculated by merging the sum of the raw scores of each working memory component to z-scores.

A Go/no-go paradigm was used to assess behavioral inhibition of non-symbolic and symbolic stimuli. The frequency of go trials was 75%. Moreover, inter-trial interval was kept constant at 2250 ms. The task consisted of two formats (symbolic and non-symbolic) and three conditions, measuring a picture (non-symbolic), a letter (symbolic), or a digit modality (symbolic). Each condition consisted of 45 go trials (the picture of a bird in the first condition, letter 'a' in the second, and number '1' in the third) and 15 no-go trials (a butterfly, 'm' and '6', respectively, see also De Weerdt, Roeyers, & Desoete, 2013b). Mean reaction time of the correct go trials (MRT) and commission errors were used as dependent measures.

Naming Speed Measures

Each task contained 30, pseudo-randomly ordered trials and used four different stimuli. In the first naming speed task, people were asked to read color names written in black ink, as a rough indication of reading ability. During the second naming speed task, naming speed of colors was measured by visualized colored rectangles. For the word and color naming speed tasks, the stimuli were red, green, blue and yellow. In the third naming speed task, the students were asked to read the digits that appeared in the middle of the screen. Finally, the last naming speed task concerned the naming of the quantity of rectangles. For the naming speed tasks concerning numbers and quantities, the stimuli ranged from one to four. A voice key was used to measure reaction time (RT). Since accuracy was very high on all tasks, errors were not analyzed.

Results

ANOVAs were conducted to compare the divergent aspects of working memory.

As shown in Table 2, analyses revealed significant results for the composite score of the phonological loop ($p < .001$), the visuospatial sketchpad ($p < .001$) and the central executive ($p < .001$). Moreover, significant results were found for MRT on the naming speed task of quantities ($p = .014$), the naming speed task of words ($p = .002$) and on the letter ($p = .011$), and digit modality ($p = .015$) of the Go/no-go task.

Based on the results presented in Table 2, Cohen's d was calculated pairwise between the groups and for each variable (see Table 3). Significant differences were found between the control group and the clinical groups.

Finally, logistic regression analyses were conducted in order to clarify to what extent working memory, behavioral inhibition, and naming speed predicted the probability of MD, and RD+MD. They were also supposed to clarify, which of these cognitive skills were the most influential. Results are presented in Table 4.

Table 2. ***Means and Standard Deviations of Working Memory Composite Scores, and Behavioral Inhibition and Naming Speed tasks***

	Control	RD	MD	MD+RD	
Measures	M *(SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*F*(3,108)
Working memory tasks					
Composite scores					
Phonological loop	0.62 (0.76)[a]	-0.21 (1.12)[b]	.00 (0.66)[b]	-0.23 (0.81)[b]	8.29***
Visuospatial sketchpad	0.33 (0.63)[a]	-0.46 (1.14)[b]	-0.25 (0.76)[b]	-0.29 (0.69)[b]	6.64***
Central executive	0.65 (0.82)[a]	-0.29 (0.83)[b]	-0.22 (0.83)[b]	-0.70 (0.87)[b]	16.76***
Go/no-go task					
Commissions					
Pictures	4.87 (2.98)	4.35 (2.45)	5.23 (3.13)	4.50 (2.84)	0.40
Letters	5.49 (2.81)	7.00 (3.12)	5.82 (3.61)	5.65 (3.17)	1.01
Digits	4.80 (3.41)	6.76 (3.61)	5.14 (2.87)	4.36 (2.67)	2.20
Mean reaction time					
Pictures	365.80 (42.45)	403.26 (73.64)	370.73 (53.82)	382.17 (51.49)	2.29
Letters	371.05 (53.22)[a]	419.38 (86.10)[ab]	397.12 (55.68)[ab]	417.36 (74.77)[b]	3.92*
Digits	373.80 (61.05)[a]	417.43 (87.55)[ab]	394.24 (60.81)[ab]	425.71 (81.21)[bc]	3.62*
Naming speed tasks					
Mean reaction time					
Numbers	602.40 (128.91)	664.70 (128.73)	615.20 (113.98)	693.54 (198.14)	2.49
Quantities	663.58 (105.47)[a]	752.30 (119.14)[ab]	719.00 (119.06)[ab]	771.35 (211.69)[b]	3.69*
Words	584.53 (115.47)[a]	693.54 (146.22)[b]	549.28 (71.94)[a]	613.50 (131.41)[ab]	5.48**
Colors	740.33 (137.62)	837.21 (212.25)	723.12 (145.31)	760.69 (154.50)	1.87

Note. RD = reading disorders; MD = mathematical disorders; RD+MD = reading- and mathematical disorders.
* $p < .05$; ** $p < .01$; *** $p < .001$
[a,b] post hoc indices at $p < .05$.

Table 3. ***Effect Sizes of Working Memory Composite Scores, and Behavioral Inhibition and Naming Speed Tasks***

	Cohen's d					
Measures	RD vs. Control	MD vs. Control	MD+RD vs. Control	MD vs RD	MD+RD vs. RD	MD+RD vs. MD
Working memory tasks						
Composite scores						
Phonological loop	-0.97**	-0.86*	-1.11***	0.24	-0.02	-0.31
Visuospatial Sketchpad	-1.01**	-0.87*	-.96**	0.23	0.20	-0.06
Central executive	-1.16***	-1.07***	-1.63***	0.08	-0.49	-0.57
Go/no-go task						
Commissions						
Pictures	-0.19	0.12	-0.12	0.32	0.06	-0.25
Letters	0.53	0.11	0.05	-0.36	-0.44	-0.05
Digits	0.58	0.11	-0.14	-0.52	-0.80	-0.29
Mean reaction time						
Pictures	0.07	0.11	0.36	-0.53	-0.36	0.22
Letters	0.77	0.49	0.75*	-0.32	-0.03	0.31
Digits	0.64	0.34	0.76*	-0.32	0.10	0.44
Naming speed tasks						
Mean reaction time						
Numbers	0.64	0.13	0.63	-0.51	0.10	0.49
Quantities	0.73	0.44	0.58*	-0.29	0	-0.22
Words	0.86**	-0.27	0.24	-1.24	-0.57	0.52
Colors	0.64	-0.13	0.13	-0.65	-0.44	0.23

Note. RD = reading disorders; MD = mathematical disorders; RD+MD = reading- and mathematical disorders.
* $p < .05$; ** $p < .01$; *** $p < .001$

Table 4. ***Multinomial Logistic Regression Model for Predicting Learning Disorders based on Working Memory Composite Scores, and Behavioral Inhibition and Naming Speed Tasks, in Control of Gender, Age and Intelligence***

			95% CI for OR		
Group comparison	Model	OR	Lower	Upper	Wald *(df)*
RD vs. Control[a]	Gender[d]	1.52	0.39	6.00	0.36
	Age	1.05	0.98	1.12	1.58
	IQ	0.97	0.90	1.04	0.67
	NS Quant	1.00	1.00	1.01	2.01
	NS Words	1.01	1.00	1.01	0.79
	Acc CE	0.24	0.10	0.57	10.23***
MD vs. Control	Gender	0.61	0.15	2.48	0.47
	Age	1.03	0.96	1.10	0.61
	IQ	0.88	0.82	0.95	12.24***
	NS Quant	1.01	1.00	1.02	5.00*
	NS Words	0.99	0.98	1.00	4.44*
	Acc CE	0.19	0.07	0.52	10.47***
MD+RD vs. Control	Gender	0.43	0.11	1.70	1.45
	Age	1.09	1.02	1.16	5.94*
	IQ	0.92	0.86	0.99	5.20*
	NS Quant	1.01	1.00	1.02	6.11*
	NS Words	1.00	0.99	1.00	0.82
	Acc CE	0.10	0.04	0.25	22.77***
MD vs. RD[b]	Gender	0.40	0.08	1.94	1.29
	Age	0.98	0.91	1.06	0.20
	IQ	0.91	0.84	0.98	5.88*
	NS Quant	1.00	1.00	1.01	0.76
	NS Words	0.99	0.98	1.00	8.17**
	Acc CE	0.82	0.31	2.14	0.17
MD+RD vs. RD	Gender	0.28	0.07	1.21	2.91
	Age	1.04	0.97	1.02	1.36
	IQ	0.95	0.89	1.11	1.77
	NS Quant	1.00	1.00	1.01	1.29
	NS Words	0.99	0.99	1.00	4.30*
	Acc CE	0.40	0.17	0.94	4.39*
MD+RD vs. MD[c]	Gender	0.70	0.17	2.85	0.24
	Age	1.06	1.00	1.12	3.32
	IQ	1.05	0.99	1.12	2.34
	NS Quant	1.00	1.00	1.01	0.08
	NS Words	1.01	1.00	1.02	2.55
	Acc CE	0.49	0.22	1.11	2.94

Note. OR = odds ratio; CI = confidence interval; MD = mathematical disorders; RD = reading disorders; MD+RD = mathematical and reading disorders; NS = naming speed; quant = quantities; Acc CE = accuracy central executive.
[a] control group as reference category; [b] reading disorders group as reference category; [c] mathematical disorders group as reference category; [d] girls as reference category.
* $p < .05$; ** $p < .01$; *** $p < .001$

The best model consisted of naming speed of words, naming speed of quantities, and the composite score of the central executive. Model fit was significant, χ^2 (18, N = 112) = 97.06, p < .001, and Nagelkerke R^2= .62. Log-likelihood-tests showed significant results for naming speed of words (χ^2 (3, N = 112) = 12.10, p = .007), of quantities (χ^2 (3, N = 112) = 7.89, p = .048), and for the composite score of the central executive (χ^2 (3, N = 112) = 39.40, p < .001).

Discussion

All children were tested with (backward) digit-, word list-, block-, and listening-recall, spatial span, backward word list recall, and backward block recall. Large effect sizes were found between the control group and all clinical groups on all working memory components. As shown in Table 3, none of the other cognitive skills had such large effect sizes. Moreover, the logistic regression analysis with predictors of the working memory, behavioral inhibition, and naming speed tasks revealed that the composite score of the central executive appeared to be the most crucial cognitive predictor (see Table 4). Although naming speed of words and quantities were found to be significant predictors as well, their odds ratios were near to 1.00 and hence they only added value to the model to a very limited degree (see Table 2).

In line with previous studies (Passolunghi & Siegel, 2004; Siegel & Ryan, 1989; Swanson, Zheng, & Jerman, 2009), we can conclude that working memory, and central executive functioning in particular, is of importance in specific learning disorders and may to a certain extent prevent children with learning disorders from developing age-adequate skills in reading and mathematics. The central executive overruled the importance of for instance behavioral inhibition.

Inhibition has to be seen as one of the most crucial executive functions (Miyake et al., 2000). Behavioral inhibition - the capacity to suppress a prepotent or dominant response (Nigg, 2000) - was measured with a Go/no-go task. The analyses showed that children with MD did not experience any behavioral inhibition or interference control deficits compared to peers with age-adequate mathematical abilities.

These findings are in congruence with e.g, Censabella and Noel (2008). These authors investigated both interference control and behavioral inhibition in 10 year old children (20 children with MD and 20 in the control condition). They did not find any differences between both groups and concluded that children with MD do not seem to suffer from inhibition deficits (Censabella & Noël, 2008). However, these results are contrary to several other studies reporting inhibition problems in children with MD. For instance, Zhang and Wu (2011) described problems in children with MD on both a color-word and a numerical Stroop. Moreover, a study by Bull and Scerif (2001) emphasized a significant correlation between mathematical performance and the level of interference control on the quantity Stroop task (the lower the mathematics ability, the higher the interference).

Naming speed can be defined as those processes that underlie the rapid recognition and retrieval of visually presented linguistic stimuli (Wolf & Bowers, 1999) or as the ability to quickly recognize and name a restricted set of serially presented high frequency symbols, objects, or colors (Heikkilä et al., 2009; McGrath et al., 2011). To draw conclusions regarding which aspect of naming speed is impaired in children with learning disorders, four naming speed tasks have been employed with a rapid automatic naming paradigm.

Children with MD+RD performed slower on the quantity naming speed task than children without MD, so naming speed tasks differentiated between MD+RD vs. controls, but not between MD vs. controls. These findings made us propose, in line with e.g., Willburger et al. (2008) and Landerl et al. (2004) that deficits in naming speed are domain-specific in children with MD+RD.

Conclusion

This study provided information into working memory, inhibition, and naming speed in children with LD. All children with LD performed poorly on working memory tasks, providing evidence that they have a deficiency related to simultaneously storage and processing of verbal and/or visuospatial information. In addition, children with MD+RD suffered from problems with quantity naming speed compared to children without learning disorders.

In addition, the differences between children with isolated MD (impairment in mathematics), and combined MD+RD (impairment in mathematics and/or impairments in reading or written expression) were analyzed. In this study, it seems that the two profiles (MD and MD+RD) were not so different. Both groups of children differed from controls on working memory tasks. However, children with MD+RD differed also from controls on inhibition (using letters and digits) and on naming speed tasks (with quantities), whereas children with MD did not differ from controls on this respect. In addition, the most significant differences and the largest effect sizes were found between the RD+MD group and the control condition, pointing to the fact that the profile of children with MD+RD might be seen as the additive combination of problems due to RD and MD.

Since working memory components revealed the largest effect sizes, it may in particular be relevant, in line with Gathercole et al. (2006), to manage working memory loads in structured learning activities in the classroom or at home. Due to problems with retrieval and processing of information, children with MD or RD+MD may need more time to complete homework, exercises, and examinations compared to peers without learning disorders.

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Number Line Estimation in Children with Developmental Dyscalculia

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In the number to position task, several studies have shown that typically developing children shift from a biased (logarithmic) to an accurate (linear) mapping of symbolic digits onto a spatial position on a line. The initial pattern of overestimation of small numbers and the underestimation of larger numbers is compensated by means of age and education. Children with mathematical disability seem to show less accuracy in placing numbers on the line and their mapping tends to be more biased than linear. Here we evaluate to what extent this hypothesis holds for a sample of Italian children who have received a formal diagnosis of developmental dyscalculia (DD). Ten children with DD (M age-months = 123, SD = 25) and ten typically developing (TD) children (M age-months = 121, SD = 23), matched for age and gender, completed two number to position tasks (intervals: 0-100, 0-1000). For the interval 0-100, children with DD obtained a mapping in an intermediate stage between logarithmic and linear whereas the TD group reached a linear mapping. For the interval 0-1000, children with DD exhibited a logarithmic mapping whereas TD children had a linear mapping. These results highlight the presence of basic numerical deficit in children with DD.

Keywords: Developmental dyscalculia, number line estimation, and number to position task.

Introduction

Successful mathematical achievement can be considered as the by-product of several cognitive, educational, and motivational factors, which can differently interact across a lifetime. Various reasons could be responsible for weak mathematical achievement in children who perform at the lower end on standardized mathematical tests. Beyond educational and motivational aspects, children with math difficulties may present relatively different cognitive profiles thus composing a rather heterogeneous group (Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007). Therefore, it is important to identify which cognitive subcomponent is impaired in children with math learning difficulties and understand at which level the cognitive process fails. Several studies have highlighted that children with developmental dyscalculia (DD) have a specific impairment in basic numerical processing (Landerl, Bevan, & Butterworth, 2004; Mazzocco, Feigenson, & Halberda, 2011; Moeller, Neuburger, Kaufmann, Landerl, & Nuerk, 2009a; Piazza et al., 2010). Therefore, it is important to investigate whether children with math disability are able to estimate numerical quantities relatively to typically developing peers.

Two mechanisms have been individuated as fundamental for fast quantification processes: the Object Tracking System (OTS) and the Approximate Number System (ANS; Feigenson, Dehaene, & Spelke, 2004; Piazza, 2010). The former allows identifying quickly and accurately the numerical quantity of small sets of objects (i.e., up to 3-4 items; Mandler & Shebo, 1982) without the use of counting strategies; the second, the Approximate Number System (ANS), allows approximating the numerical quantity of larger sets. Recent findings have highlighted that both quantification systems are impaired in children with DD. In the subitizing range, they tend to adopt serial counting to determine the numerosity of small sets resulting in longer reaction times (Schleifer & Landerl, 2010; Moeller et al., 2009a; Landerl, Bevan, & Butterworth, 2004). For larger quantities (beyond 4), children with DD show lower efficiency and need a larger numerical difference between two sets of items to be able to precisely identify the one with the larger/smaller numerical quantity (Piazza et al., 2010; Mazzocco, Feigenson, & Halberda, 2011). In Piazza and colleagues' study (2010), performance of 10 year-old children with DD to compare sets based on the numerical quantity (number acuity) was similar to the performance of 5-year younger typically developing children. The low performance shown by children with DD on non-symbolic numerical tasks suggests that their poor math achievement stems from an impaired basic numerical representation.

Beyond the approximate representation, numerical quantities may be represented in an exact way by means of numerical symbols. Zorzi and Butterworth's model (1999) postulates that numerate children and adults are able to linearly map Arabic digits to the corresponding numerical internal magnitude (also see Verguts, Fias, & Stevenson, 2005). In a seminal study, Siegler and Opfer (2003) have used the number to position task (NP-task) to show that children shift from an intuitive to an exact representation of numbers with age and greater numerical skill. Participants from grades two and six were required to place Arabic numbers (i.e., 25) onto a black horizontal bounded line going from 0 to 100. This task entails transcoding a numerical value into a spatial position on a visual line. Performance of younger children was characterized by an overestimation of small numbers and an underestimation of larger numbers, yielding a logarithmic pattern. Because smaller numbers are over-represented on the mental number line, according to the ANS, it suggests that younger children facing an unfamiliar numerical range rely on an intuitive and logarithmic mapping to solve the task. Nevertheless, other theoretical perspectives suggested different interpretations regarding the pattern of biased estimates in younger children. According to the Familiarity model, the pattern of estimates is more consistent with a bilinear fit separating familiar and non-familiar numbers (Ebersbach, Luwel, Frick, Onghena, & Verschaffel, 2008; Moeller, Pixner, Kaufmann, & Nuerk, 2009b). Other authors, instead, interpreted the positioning of a number as a consequence of a proportional judgment (Barth & Palladino, 2011).

Despite this theoretical issue, with increasing age and numerical proficiency, children shift from an immature mapping to a formal and linear one by placing numbers in correspondence of the correct position. Interestingly, at a same developmental time point, a child may use both mappings depending on the scale of the line interval:

Preschoolers show a linear mapping for small intervals such as 1-10, whereas their mapping is still logarithmic for a larger scale such as 0-100 (Berteletti, Lucangeli, Piazza, Dehaene, & Zorzi, 2010); during the first two years of elementary school, the linear mapping is progressively acquired for the 0-100 interval (Siegler & Booth, 2004), whereas linearity is mastered around the 4th grade for the 0-1000 interval (Booth & Siegler, 2006) and around the 6th grade for the 0-10000 interval (Thompson & Opfer, 2010). With increasing numeracy, a child will position numbers linearly on progressively larger intervals. It is critical to report that being perfectly able to name and recite the entire sequence of an interval does not grant linearity (Berteletti, Lucangeli, & Zorzi, 2012). Thus, children's logarithmic mapping is not merely an artifact of the task itself or poor knowledge of the items in the interval presented but it entails a specific maturation of the understanding of numerical quantities. Finally, supporting the diagnostic importance of the NP-task, studies have shown that performance correlates with other estimation tasks (Booth & Siegler, 2006), memory for small versus large numbers (Thompson & Siegler, 2010) and future mathematical achievement (Booth & Siegler, 2008).

Geary, Hoard, Nugent, and Byrd-Craven (2008), using standardized mathematical achievement tests, classified 1st and 2nd grade children into mathematical learning disability (below the 11th percentile), low math achievement (between 11th and 25th percentile), and typical achievement groups. In the number line task with the interval 0-100, grade 1 pupils with math disability displayed a logarithmic representation compared to the other groups, who showed a linear mapping. Only by grade 2, children with math disability displayed a representation at an intermediate stage between the logarithmic and the linear mapping. In a subsequent study, Landerl, Fussenegger, Moll, and Willburger (2009) analyzed performance in the NP-task of typically developing, dyscalculic, dyslexic, and dyslexic-dyscalculic children between 8- and 10-years of age. Children categorized as dyslexic had a score below 1 standard deviation (SD) in a reading fluency test and an adequate score in the arithmetic test. Conversely, children with dyscalculia had a score below 1 SD in the arithmetic test but had an adequate score in the reading test. Children with performance below 1 SD in both, the reading and the arithmetic tests, were categorized as dyslexic-dyscalculics. In the 0-100 interval, only the control group had a reliable linear positioning and the dyslexia and dyscalculia groups approximated a linear mapping whereas the dyslexia-dyscalculia showed no difference in precision between the two fits. In the 0-1000 interval, only the control group was close to a linear fit whereas for all the other groups the logarithmic model provided a better explanation of the data. The difference in favor of a logarithmic model was reliable only for the dyslexia-dyscalculia group.

In the present study, we replicate and extend results of the previous studies by investigating the ability to translate numbers into a spatial position in Italian children with DD. Because the NP-task has the potential for becoming a diagnostic tool for low math achievement, it is important to test its reliability with several groups from different cultural and educational systems. Moreover, its simplicity makes it a task administrable to children prior to formal schooling (Berteletti et al., 2010) and therefore a tool for an early diagnosis of low achievement. To this aim, the estimates of children with DD in two NP-tasks (intervals: 0-100, 0-1000) were compared to those of a typical developing (TD) group. We expect children with DD to show a less accurate mapping as compared to the TD group and to show longer reaction times (RT) for placing numbers. Lower precision and longer RT confirm a reduced basic numerical knowledge in children with DD.

Method

Participants

Ten children between 8- and 13-years of age with DD (2 boys; *M* age-months = 123, *SD* = 25, range: 96 - 163) were recruited from the Regional Center for Research in Learning Disabilities (Padova, Italy). They all received a formal diagnosis of DD by an expert clinician with a specific specialization in learning disabilities and scored in the normal range for IQ (>85), had neither sensory deficits nor comorbidity with Attention Deficit Hyperactivity Disorder. Ten TD children from middle-socioeconomic schools in Northern Italy were matched in age and gender to the DD group (2 boys; *M* age-months = 121, *SD* = 23 months, range 98 - 158). Children in the TD group were free from learning or attentional disabilities. The DD and TD group did not differ in terms of age ($p = .83$).

Task and Procedure

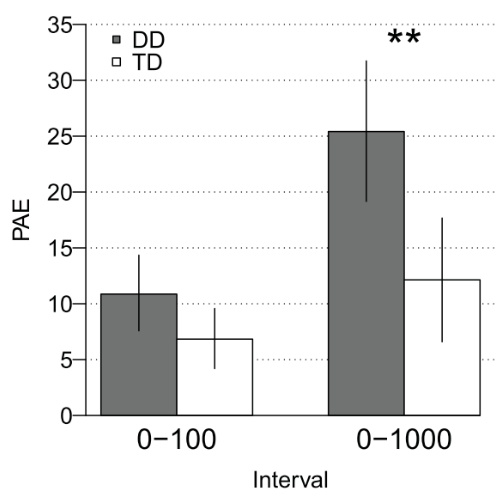
Children were met individually, in a quiet room, and completed the two computerized versions of the NP-task (Siegler & Opfer, 2003). Tasks were presented as games, no time limit was given and items or questions could be repeated if necessary but neither feedback nor hints were given to the child. Students were free to stop at any time. The Number-to-Position task (NP-task) was a computer adaptation from Siegler and Opfer's (2003). An approximately 17 cm black line was presented in the center of the screen with a mild yellow background. In the 0-100 interval, the left end was labeled 0 and the right end was labeled 100. Children were required to estimate the position on the line of ten numbers (2, 3, 4, 6, 18, 25, 42, 67, 71, 86; set A and B from Siegler & Opfer, 2003). In the interval 0-1000, the left end was labeled 0 and the right end was labeled 1000 and there were twenty-two numbers to estimate (2, 5, 18, 34, 56, 78, 100, 122, 147, 150, 163, 179, 246, 366, 486, 606, 722, 725, 738, 754, 818, 938; sets A and B from Opfer & Siegler, 2007). Answers were given by clicking on the line using the mouse; however, the range of movement of the cursor was constrained to the area covering the line as to avoid collecting unreliable responses. For each trial, the number to position was presented in the upper left corner of the screen. Children first completed the 0-100 interval task and then the 0-1000 interval task. At the beginning of the experiment, children were asked to place the numbers 0, 100 and 50 in the interval 0-100 and 0, 1000 and 500 in the interval 0-1000. This ensured that children understood the task and the interval range, and that they were capable of using the mouse to respond. Moreover, when a response was given, a small red circle appeared in the selected position as visual feedback. After the practice phase, the other numbers were presented randomly. Both estimates and reaction times were recorded.

Results

We removed responses under 200 ms (less than 0.002% of all trials) and above 2 standard deviations (less than 0.01% of all trials) across groups. Analyses followed the method recommended by Siegler and colleagues (Siegler & Booth, 2004; Siegler & Opfer, 2003) and Bonferroni's correction was applied to all post-hoc comparisons. Estimation accuracy was assessed using the percentage of absolute error of estimation (PAE = |estimate - target number|/ interval*100) for each participant in each condition. We analyzed the PAE in a mixed ANOVA with Group as the between-subject factor (TD and DD) and Interval size as the within-subject factor (0-100 and 0-1000). Mean PAEs in the 0-100 interval were 7% for TD children and 11% for children with DD. In the 0-1000 interval, the mean PAEs were 12% for TD children and 25% for children with DD (see Figure 1). Both main effects were significant ($F(1, 18) = 51.28$, $p < .001$ and $F(1, 18) = 11.12$, $p = .004$, for Interval and Group, respectively). Because the interaction was also significant ($F(1, 18) = 11.2$, $p = .003$), we performed separate t-tests to compare groups' performance in each interval. In the 0-100 interval, the two groups did not differ significantly ($t(18) = 2.1$, $p = .05$); whereas in the 0-1000 interval, DD showed lower accuracy in placing the number compared to the TD control group ($t(18) = 3.58$, $p = 0.002$). Mean RT were also analyzed in a mixed ANOVA with Group as the between-subject factor (TD and DD) and Interval as the within-subject factor (0-100 and 0-1000). Mean RTs in the 0-100 interval were 5.9 s ($SD = 2.4$ s) and 4.7 s ($SD = 1.8$ s) for TD and children with DD, respectively. In the 0-1000 interval, mean RTs were 5.3 s ($SD = 2.5$ s) and 5.3 s ($SD = 2.8$ s) for TD and children with DD, respectively. The main effects of the Group and of the Interval as well as the interaction Group x Interval did not reach significance ($p = .58$, $p = .98$, and $p = .13$, respectively).

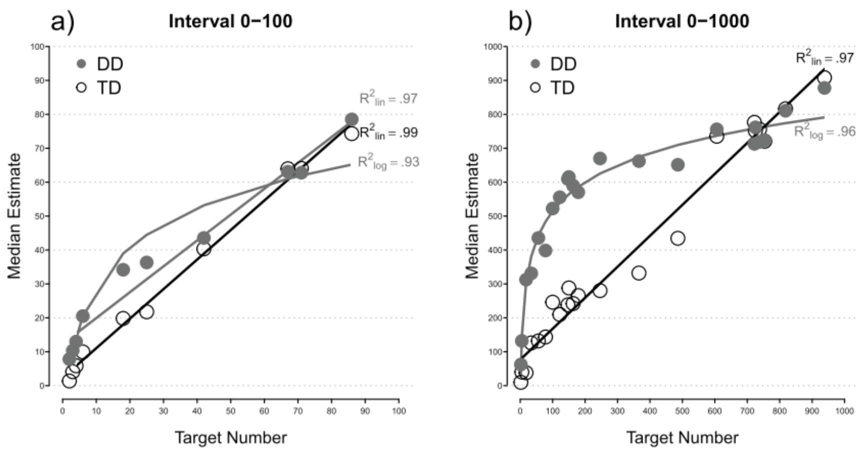
In order to understand the pattern of estimates, we fitted the linear and the logarithmic functions first on group medians and subsequently individually for each child (Siegler & Opfer, 2003).

Figure 1. **Percentage of absolute error (PAE) in TD and children with DD for the two NP-tasks. Children with DD showed lower accuracy in placing numbers in the 0-1000 interval as compared to the TD group. Error bars correspond to 95% CI. ** *p* < .01**



Median estimates and the best fitting models are reported separately for each group in Figure 3. The difference between linear and logarithmic models was tested with paired-sample t-tests on absolute distances between children's median estimate for each number and the predicted values according to the linear model and the logarithmic model. If the t-test was significant, the best fitting model was attributed to the group (Figure 2). In the 0-100 interval, the linear model had the highest R^2 for both groups and was significantly different from the logarithmic model for the TD group ($t(9) = 4.34$, $p = .002$, R^2 lin = 99%, vs. R^2 log = 87%) but not for the DD group ($t(9) < 1$, R^2 lin = 97% vs. R^2 log = 93%). In the 0-1000 interval, the linear model had the highest R^2 and was significantly different from the logarithmic model only for the TD group ($t(21) = 7.18$, $p < .001$, R^2 lin = 97% vs. R^2 log = 73%) whereas for the DD group the logarithmic model had the highest R^2 and was significantly different from the linear model ($t(21) = 3.13$, $p = .005$, R^2 lin = 67% vs. R^2 log = 96%).

Figure 2. **Children estimates and best fitting models for the DD and TD group separately in (a) the 0-100 interval and (b) the 0-1000 interval. The TD group obtained a linear representation in both NP tasks, whereas the DD group showed an intermediate stage, between logarithmic and linear mapping, in the 0-100 interval and a logarithmic mapping in the 0-1000 interval.**



We ran linear and logarithmic regression analyses also on individual data, the child was assigned to a linear or logarithmic category based on the highest R^2. Whenever both models were not significant, the child was considered unable to perform the task properly and classified as not having a numerical mapping (Table 1).

Table 1. ***Cell values represent number of children (no children were classified as showing a non-numerical mapping)***

	Type of Mapping	
Interval	Logarithmic	Linear
0-100 Interval		
TD $_{(N = 10)}$	2	8
DD $_{(N = 10)}$	5	5
0-1000 Interval		
TD $_{(N = 10)}$	2	8
DD $_{(N = 10)}$	8	2

Individual analysis confirmed the group analysis results. In the 0-100 interval, TD children mostly displayed a linear mapping, whereas half of children with DD were classified as linear and the other half as logarithmic. In the 0-1000 interval, the individual analysis confirmed a predominant linear mapping for the TD group, whereas most of the children with DD displayed a logarithmic mapping. These results therefore reinforce the developmental delay of children with DD to properly estimate the position of numbers on the NP-task. Finally, no child, in both intervals, was categorized as having a non-numerical mapping, thus suggesting that all participants possessed sufficient knowledge of numbers to properly accomplish the tasks.

Discussion

Several studies have demonstrated that children, from as early as preschool, progressively shift from a logarithmic to linear mapping in the NP-task (Berteletti et al., 2010; Siegler & Opfer, 2003). The logarithmic mapping is considered a direct evidence that children assign more space on the mental number line to small numerosities than to larger numerosities, following a logarithmically compression that is a signature of the ANS (Siegler & Booth, 2003; for different accounts, see Barth & Palladino, 2011; Eberbasch et al., 2008; Moeller et al., 2009b). With education, children learn to linearly translate numbers into the correct spatial position. Such fine mapping correlates both with other numerical tasks and more importantly also with math achievement as measured by standardized tests (Booth & Siegler, 2006; Booth & Siegler, 2008). Accordingly, children with math disability have lower estimation accuracy positioning numbers onto the physical line, thereby displaying an intuitive logarithmic representation instead of a formal linear representation (Geary et al., 2008; Landerl et al., 2009). In the present study, we tested the mapping between numbers and the spatial position onto the line in a selected sample of primary school Italian children with formal diagnosis of DD as compared to a group of TD children matched for gender and age. It is worth noting that children with DD displayed a time response that was similar to TD children. This result excludes that children with DD were more impulsive and that lower performance was the consequence of a speed-accuracy trade-off. Furthermore, all children were able to map numbers confirming the easiness in understanding task instructions. Poor accuracy in children with DD can be reliably ascribed to a specific deficit in representing numbers formally.

In line with previous studies, group and individual results indicate that children with DD mainly relied on an immature and biased-logarithmic mapping compared to TD controls. Half of the children with DD showed a logarithmic and less accurate mapping on both interval sizes. Compared to the group tested by Landerl and colleagues (2009), our sample of children with DD included a larger age range in which children were approximately one-year older. This might suggest that the deficit in the spatial mapping of numbers is still present in one-year-older children and not normalize for the 0-1000 interval. This supports the delayed development of an accurate numerical representation in children with DD. Indeed, 3- to 4- year younger TD children tested by Opfer and Siegler (2007) were able to perform the 0-1000 interval task linearly. The finding that children with DD have a performance that is delayed compared to TD peers is also in agreement with a previous study showing a basic deficit of the non-symbolic numerical representation (Piazza et al., 2010).

In contrast to more sophisticated mathematical tests to diagnose children with DD, the number line task only requires a core knowledge of numerical magnitudes and excludes possible deficits in more general or higher-order cognitive process such as working memory, attention or procedural knowledge. Furthermore, the task instructions are easy to understand and the materials (i.e., paper and pencil) are minimal, making it easy for teachers and clinicians to apply. The possibility of using different interval ranges makes it a potential tool for early diagnosis. Indeed, it has been shown that children prior to formal education already show linearity on the 1-10 interval (Berteletti et al., 2010), therefore making it possible to highlight at-risk children prior to the start of formal teaching. The NP-task has the potential for being a tool to assess early numerical skill in both TD and children with DD.

In summary, the present study highlights the specific delay in basic numerical processing in Italian children with DD: they display an immature representation of numbers compared to TD children with performances comparable to 3- to 4- year younger peers, and confirms the reliability of the NP-task to assess a delay in the representation of numerical symbols.

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Analyzing the Effects of Story Mapping on the Reading Comprehension of Children with Low Intellectual Abilities

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This single-case study examined the effects of a graphic organizing strategy on the ability of children to improve their text comprehension abilities. Participants were six students between ten and fourteen years old with major problems in understanding what they read. The intervention intended to teach them to visually highlight key elements of a passage, and thus, to deepen their understanding of it (story mapping). An AB multiple baseline design across subjects was applied. The intervention points were randomly determined within a preset range for each participant. In accordance with the emerging trend to apply inferential statistics as a supplement to visual inspection and the calculation of effect size measures, a randomization test and a piecewise regression procedure were used to analyze the data. Results suggested that the story mapping technique was very beneficial in improving reading comprehension of struggling learners. The potentials of the intervention as well as of the statistical tests in analyzing data from single-case studies are discussed.

Keywords: **Text comprehension, story mapping, single-case analysis, randomization test, piecewise-regression analysis**

Introduction

Reading comprehension is the ability to construct and extract meaning from a written text (Mastropieri & Scruggs, 1997). It is considered to be the most critical skill that is needed to succeed in school. If readers have serious difficulties to gather relevant information from a historical account, a mathematical word problem, or a passage in a biology book, they are bound to fail in most every task that is put before them. To be able to understand a written text, students must be proficient in lower levels of reading (phonemic awareness, phonics, fluency, and vocabulary) (National Reading Panel, 2003; RAND Reading Study Group, 2002). In addition, they have to hold in their working memory a mental model of a circumstance, event, or problem being described. Readers need to revise existing understanding of a certain matter while gathering new information (Blanc, Kendeou, Van den Broek, & Brouillett, 2008). They must make connections to their prior knowledge. In order to do so, it is helpful to have a broad knowledge base to fall back on (Van den Broek, Rapp, & Kendeau, 2005). Sometimes, ideas in a text are unfamiliar or not well defined. In such cases, students have to be able to bridge conceptual gaps. Finally, they need to be familiar with different text structures and must know how ideas are organized in either narrative or expository material (McCormick & Zutell, 2011).

Most children develop sufficient comprehension abilities until they reach 3rd grade. This happens even though most teachers just focus on basic skills like phonological awareness, decoding, and fluency (Whitehurst & Lonigan, 1998). Proficient readers use effective comprehension strategies without being taught, and without being aware of implementing them (Swanson & De La Paz, 1998). However, a considerable number of students do not acquire the necessary skills to derive meaning from written material, even though they do not exhibit problems in decoding (Lipka, Lesaux, & Siegel, 2006). This might be due to insufficient abilities to make inferences, draw conclusions, recall and summarize information, actively monitor their comprehension, to a limited working memory capacity, to a lack of prior knowledge, as well as to other reasons (Adlof, Catts, & Lee, 2010; Catts, Adlof, & Weismer, 2006).

Fortunately, there are many evidence-based practices to improve reading comprehension in students, who are struggling. Reed and Vaughn (2012) list the following approaches, which have all proven to be helpful: (1) Teaching relevant background knowledge (like definitions of unknown vocabulary, translation of foreign phrases, clarification of difficult concepts, etc.), (2) outlining different kinds of text structure, (3) helping to identify the main ideas in a text, (4) demonstrating how to summarize a text by making inferences and synthesizing the information, and (5) using an instructional activity called reciprocal teaching, where a student and a teacher (or a tutor) engage in a dialogue concerning different parts of a text in order to construct the meaning. Another effective and well-known approach is the use of graphic organizers. These are visual learning strategies that make the structure of concepts as well as relationships between them apparent. They help students to create an organized schema and to connect prior knowledge with the content of a text that a learner is reading (Shanahan, Callison, Carriere, Duke, Pearson, Schatschneider, & Torgesen, 2010). By using these tools, a child can reduce the amount of semantic information he or she needs to process in order to extract meaning (Faggella-Luby, Schumaker, & Deshler, 2007; Jitendra & Gajria, 2011). Graphic organizers thus reduce working memory overload (O'Donnell, Dansereau, & Hall, 2002).

Among all the different kinds of graphic organizers (semantic maps, concept maps, semantic feature analysis, Venn diagrams, etc.), story maps are probably the ones used most widely. With these tools, the teacher can model for the students how to locate the elements (settings, characters, problems, events, solutions, and conclusions) of a narrative. He or she writes the relevant information into a visual depiction, while thinking aloud. Graph number 1 shows a typical story map.

But even though story maps and the other approaches mentioned above have proven to be effective as a whole (e. g. Kim, Linan-Thompson, & Misquitta, 2012; Sencibaugh, 2007), looking at the findings in detail offers a rather ambivalent picture. Apparently, using the same intervention with different students showing comprehension problems does not result in improvements of similar magnitude. Watson, Gable, Gear, and Hughes (2012) reason that what is beneficial for one particular reader is not necessarily very profitable for another. One student might have problems with vocabulary, another with making inferences, and a third one with finding the main idea. They all need different kinds of interventions, focusing on different goals. In addition, strategies which are effective for younger learners may not be useful for older students. Further, it should be noted that even research-based approaches can yield poor results if applied in an inconsistent or highly modified manner (Kim, Linan-Thompson, & Misquitta, 2012).

In this paper, we evaluated the effectiveness of a story mapping procedure with a small group of subjects who seemed to be especially receptive to benefit from this approach. Previous research suggests that graphic organizers like story maps are particularly helpful for prepubescent students with rather low general intellectual abilities and low comprehension skills, but with a sound proficiency in reading fluently (Grünke, 2011). Children with these characteristics oftentimes struggle to find the main idea in a text or to grasp its overall theme. This is a scenario where story mapping seems to be particularly useful. We thus selected a group that met the aforementioned description. Using a single-case design, we investigated whether applying the story mapping technique with these kind of children yields especially great treatment effects.

Method

Subjects and Setting

The study was conducted in Germany. Three 5th grade students from a regular education public school and three 8th grade students from a school for children with learning difficulties served as subjects. Four of them were female (Anna, Bella, Christina, and Dunja), two of them were male (Egor and Fabian) (names altered, for anonymity). The girls were 11, 10, 14, and 14 years old, the boys were 11 and 13 years old. According to their teacher, the three students from the school for children with learning difficulties (13, 14, and 14 years old) were approximately three years behind in their emotional development and behaved generally very childlike. Bella's parents were from Kazakhstan, Dunja's parents from Serbia, and Egor's parents from Russia (the remaining children did not have an immigrant background). The schools that the subjects attended were located in a major city in North Rhine-Westphalia, Germany. All students were identified by their teachers as having outstanding difficulties in text comprehension despite an adequate ability to read fluently. A screening using the German Reading Comprehension Test for First to Six Graders (ELFE 1-6, Lenhard & Schneider, 2006) revealed that all six children possessed reading comprehension skills below the 25th percentile of 4th graders. The general intellectual abilities of the subjects as measured with the German Number Combination Test (ZVT, Oswald & Roth, 1987) ranged also in the lowest quartile.

Observation and intervention occurred in separate rooms of the two schools during a daily period of independent class work, which was still in progress when the subjects returned.

Dependent Variable and Measurement Procedures

We selected 18 narratives from three different German story books (Wölfel, 1974; 2010a; 2010b). All of them were altered in a way that it was possible to formulate exactly ten comprehension questions about each tale that covered its main content. Sometimes, additional information had to be added, sometimes, information had to be eliminated to make narratives comparable. The comprehension questions were stated in a way that only one specific and distinct answer was possible to be counted as correct. Subsequently, we standardized the texts, so that each of them consisted of exactly 150 words. In a preliminary survey, the stories and comprehension questions were presented to twenty low achieving children between 9 and 10 years old in order to identify items that were either too easy or too hard to solve. We involved the insights from this preliminary survey to compose the final version of their measures.

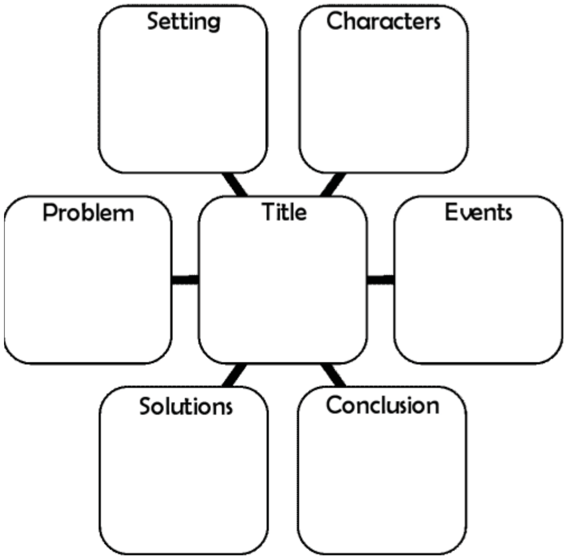
In the course of the study, each student was individually presented with a different story and a different set of comprehension questions for 18 consecutive school days. The order of the tales was randomly chosen for each child. Each student was asked to read a respective story out loud and then to write down the answers to the corresponding questions on a worksheet. While reading, the children were allowed to do whatever seemed meaningful to them to memorize the main content of each text (take notes, rehearse the information verbally, draw pictures, …). When the students decided to take the questionnaire, the sheet with the story as well as any aids (notes, pictures, story maps, …) were taken away. The children were given a time limit of 15 minutes to finish their daily assignment (reading a text, rehearsing its content, and answering the comprehension questions).

Intervention

The teaching of the use of story mapping strategy was conducted by a male graduate student. Before working with the children, he was extensively prepared by the first author on how to instruct boys and girls to effectively apply this graphic organizing technique. Daily individual training for each child lasted 30 minutes. The student instructor used a German version of figure 1 for the intervention. Reading passages were taken from the aforementioned story books (Wölfel, 1974; 2010a; 2010b). Of course, the 18 narratives that were used to measure the children's performance were exempt.

To teach the boys and girls how to better comprehend narrative texts by using a story map, the student instructor followed a procedure outlined by Idol (1987): (1) Modeling phase (the teacher demonstrates how a story map is used by reading a tale out loud and by stopping whenever important information is mentioned to fill out parts of his or her worksheet), (2) lead phase (the children read stories independently and complete their maps while the teacher prompts and encourages them to review their work results and to add details that they might have overlooked), (3) test phase (the children read texts, draw maps of their own, ask questions pertaining to the content, answer them, and fill in the components into their maps without close supervision by the teacher - the teacher only intervenes if the students ask for or obviously needs help). The first session always focused on the modeling phase. During the following two to three sessions, the lead phase took up the greatest share of instructional time. Depending on the skill level that a child had reached until then, the remaining sessions were either devoted entirely to the test phase or to other phases that still needed rehearsal.

Figure 1. **A Story Map**



To ensure that the intervention procedures were carried out as designed, the student instructor and the first author stayed continuously in close contact via e-mail and met on a weekly basis to evaluate past lessons and to discuss any further procedures.

Experimental Design

An AB multiple baseline design across subjects was applied. Usually, researchers continue with baseline observations until the baseline stabilizes. But this procedure constitutes a threat to the internal validity of a study. It creates a bias in favor of identifying an intervention effect where none exists. There is no way of knowing what the baseline would have looked like if it had continued for a little longer. A couple of upward random variations followed by a couple of downward random variations could easily and wrongly be interpreted as stabilization of the baseline (Todman, 2002). An alternative to wait until a baseline stabilizes would be to come up with a preset number of total probes and a minimum number of baseline sessions as well as a minimum number of intervention sessions, and then to determine the beginning of the treatment by chance. This procedure cannot avoid random variations, but it turns potentially systematic nuisance variables into random nuisance variables, and thus increases the internal validity of the findings. In the present study, a total number of 18 daily observations was determined for the baseline and the intervention sessions. It was previously decided that the baseline phase had to consist of at least three, but not more than eight probes. This yielded six possible intervention points for each subject (the treatment could either start after the third, the fourth, the fifth, the sixth, the seventh, or the eighth baseline observation). According to a random drawing of these options, teaching the story mapping technique started for Anna after the fourth, for Bella after the seventh, for Christina after the fourth, for Dunja after the sixth, for Egor after the fifth, and for Fabian after the eighth baseline probe.

Results

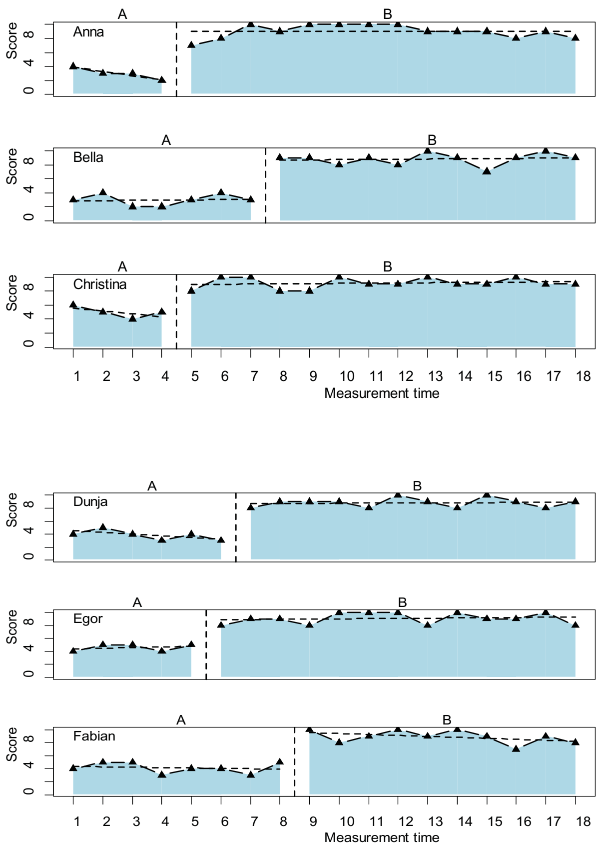
Information on the number of correctly answered comprehension questions is reported in Table 1.

Table 1. ***Correctly answered comprehension questions***

Student		Baseline	Intervention
Anna	N (Probes)	4	14
	Raw Scores	4; 3; 3; 2;	7; 8; 10; 9; 10; 10; 10; 10; 9; 9; 9; 8; 9; 8;
	M	3.00	9.00
Bella	N (Probes)	7	11
	Raw Scores	3; 4; 2; 2; 3; 4; 3;	9; 9; 8; 9; 8; 10; 9; 7; 9; 10; 9;
	M	3.00	8.82
Christina	N (Probes)	4	14
	Raw Scores	6; 5; 4; 5;	8; 10; 10; 8; 8; 10; 9; 9; 10; 9; 9; 10; 9; 9;
	M	5.00	9.14
Dunja	N (Probes)	6	12
	Raw Scores	4; 5; 4; 3; 4; 3;	8; 9; 9; 9; 8; 10; 9; 8; 10; 9; 8; 9;
	M	3.83	8.83
Egor	N (Probes)	5	13
	Raw Scores	4; 5; 5; 4; 5;	8; 9; 9; 8; 10; 10; 10; 8; 10; 9; 9; 10; 8;
	M	4.60	9.08
Fabian	N (Probes)	8	10
	Raw Scores	4; 5; 5; 3; 4; 4; 3; 5;	10; 8; 9; 10; 9; 10; 9; 7; 9; 8;
	M	4.13	8.90

For a first rough estimation of the data, we conducted a visual inspection by considering slopes, phase changes, and variability in the measure set (Gast & Spriggs, 2010). Figure 2 maps the performance progress for all students including reference lines depicting the slope of both phases. The variable within students and phases is considerably small compared to differences between students and phases. We found a uniform increase of performance with the beginning of the B-phase for all students, while the slope lines did not show a consistent increase in the B-phase.

Figure 2. **Number of correctly answered questions for each student across the course of the study. The vertical dashed line indicates the beginning of the intervention phase. The horizontal dashed lines depict the slope parameter of a linear regression of the A and B-phase for each student**



In addition, non-overlapping indices were calculated for all participants (Parker, Vannest, & Davis, 2011) as a means to measure the strengths of the treatment outcomes (effect sizes). Table 2 shows no overlap of data for any applied measure. Percentage of non-overlapping data, non-overlap of all pairs, percentage exceeding the median, and percentage of all non-overlapping data were all 100%.

Table 2. ***Descriptive statistics for the six single-cases and two aggregations. The first aggregation results from an interpolation or summing up of the values of the six cases. The second aggregation is based on a procedure described in Wilbert (2014). The subscripted characters refer to the respective measurement phase.***

	Case							
statistics	Anna	Bella	Christina	Dunja	Egor	Fabian	Aggregation (weighted average/sum)	Aggregation (overlapping)
n_A	4	7	4	6	5	8	34	34
n_B	14	11	14	12	13	10	74	74
M_A	3.0	3.0	5.0	3.8	4.6	4.1	3.9	0.0
M_B	9.0	8.8	9.1	8.8	9.1	8.9	9.0	5.0
$M_B - M_A$	6.0	5.8	4.1	5.0	4.5	4.8	5.0	5.0
min_A	2	2	4	3	4	3	2	-1.1
min_B	7	7	8	8	8	7	7	2.9
max_A	4	4	6	5	5	5	6	1.2
max_B	10	10	10	10	10	10	10	7
SD_A	0.8	0.8	0.8	0.8	0.5	0.8	0.8	0.7
SD_B	1.0	0.9	0.8	0.7	0.9	1.0	0.9	1.1
ac_A	0.0	0.0	0.0	0.0	-0.5	-0.2	-0.1	0.2
ac_B	0.3	-0.2	-0.2	-0.4	-0.3	-0.1	-0.1	0.1
b_A	-0.6	0.0	-0.4	-0.3	0.1	-0.1	-0.2	-0.1
b_B	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.0
b_{AB}	0.3	0.5	0.2	0.4	0.3	0.4	0.4	0.3
$b_B - b_A$	0.6	0.0	0.4	0.3	-0.1	-0.1	0.2	0.1
PND	100	100	100	100	100	100	100	100
PEM	100	100	100	100	100	100	100	100
NAP	100	100	100	100	100	100	100	100
PAND	100	100	100	100	100	100	100	100

Note. *n* = number of data points, *M* = mean, *SD* = standard deviation, *ac* = lag one autocorrelation, *b* = slope of a linear regression, *PND* = percent non-overlapping data, *PEM* = percent exceeding the median, *NAP* = non-overlap of all pairs, *PAND* = percent all non-overlapping data.

Supplementally, we analyzed the data using inferential statistics. It is becoming a common standard in single-subject research to not rely only on visual inspection and effect size measures when drawing inferences from case studies. Unfortunately, most of the usual parametric tests are unsuitable for this purpose. One of the major objections in this respect are statistical problems caused by auto-correlated data. When dealing with AB designs, however, randomization tests (e. g. Dugard, File, & Todman, 2011) and piecewise regression analysis (e. g. Center, Skiba, & Casey, 1986) have proven to be very helpful approaches in a lot of instances where data from case studies had to be statistically analyzed. Explaining how these procedures can be applied in single-subject research would go beyond the scope of this paper. We thus refer the reader to the above mentioned literacy sources for greater details.

In order to decide if at least one of these two strategies is suitable for our purposes, we computed an empirical power and alpha-error estimation of the randomization test and of the piecewise-regression analysis for the given structure and distribution of our data. The empirical power and alpha-error analyses were based on a Monte Carlo study. We simulated 2000 data sets with the same distributions of parameters that were prevalent in the observed data. Thereby we assumed that all the effects that we found in the data were systematic and not random. We subsequently computed statistical tests on the simulated data to estimate their power. In a second step, we simulated new data sets with specific effects set to zero. We thereby produced data sets with the same structure, but without level or slope effects. Furthermore, we conducted statistical analyses on these data sets to estimate the proportion of false positive results that the tests produce under the given circumstances for level and slope effects. The proportion of false positive results is an estimantion for the alpha-error probability of the method of analysis that we used.

All calculations were carried out with an SCDA-package (Wilbert, 2014) which contains a convenient function for this procedure. The random data generating model assumed the following parameters: a six cases multiple baseline with a B-phase beginning at the 5^{th}, 7^{th}, 9^{th}, 5^{th}, 8^{th}, and 6^{th} measurement-point and each case with a total of 18 measurements. The underlying distribution of the measured values was set to $M = 3.90$ ($SD = 0.80$) and we assumed a reliability of measurement of ${}_{tt}$ = .80. The effects of the intervention were estimated $d_{level} = 6.52$, $d_{slope} = 0.10$, and $d_{trend} = -0.10$. Table 3 depicts the resulting power and alpha-error. Both randomization and regression analysis have a very high power (both 100%) and low alpha-error (1.20% and 7.00%, respectively), when estimating a level effect due to the intervention. However, the slope-effect was far too small and the measurements were too little for a sufficient power of the analysis (31.80% for the randomization test and 47.60% for the regression model). These results suggest that a statistical test on significance of the slope effect not be performed.

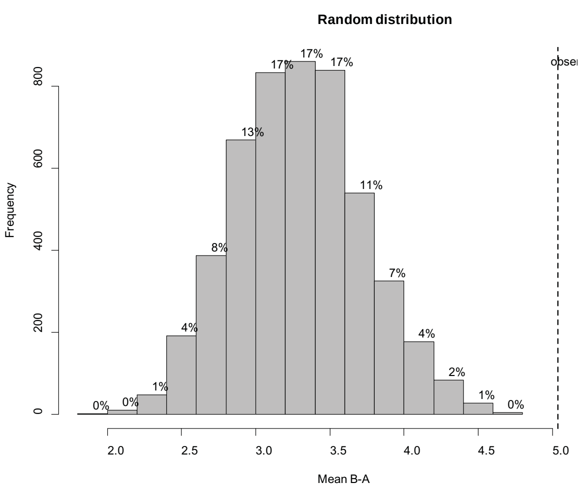
Table 3. ***Power and alpha-error of randomization test and piecewise-regression model analyses for level and slope effects based on the parameters of the study at hand.***

	Power	Alpha-error
Randomization Test Level	100.0	1.2
Randomization Test Slope	31.8	13.8
PLM Level	100.0	7.0
PLM Slope	47.6	3.8

Based on the results of the power analysis we decided to conduct both a randomization test and a piecewise-regression analysis. For the randomization test, we computed the difference of the mean values of the two phases (M_B - M_A) as the target statistic under randomly varying combinations of starting positions of the B-Phase (see above). The actual observed mean difference was then compared to the resulting distribution (see Figure 3). The percentile of the observed value within this distribution is the resulting p-value of the test.

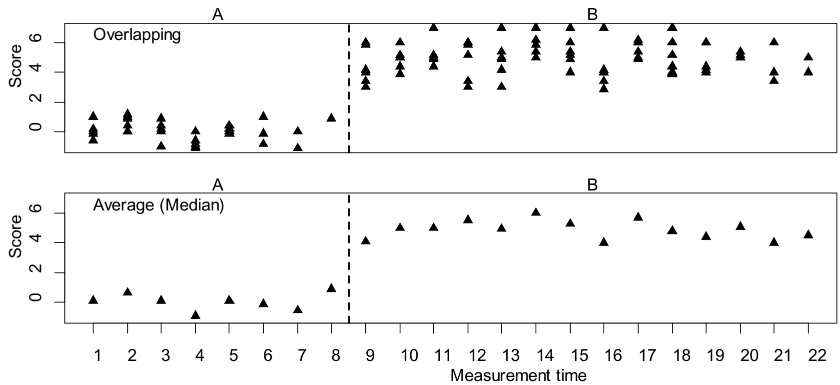
The random sample was created based on the assumption that each phase has a minimal length of four measurements. From the resulting possible 1.771.561 combinations of starting points of the B-phase, a sample of 5.000 was drawn. All mean differences (M_B – M_A) for this 5.000 random combinations were below the observed value of M_B - M_A = 5.04 (distribution of mean differences: $M = 3.3$, $SD = 0.4$, min = 1.99, max = 4.64) giving a $p < 0.0002$ (assuming a normal distribution of the mean differences: $z = 4.03$, $p < 0.0001$).

***Figure 3*. Reference distribution of the randomization test**



In order to carry out a piecewise-regression analysis, we firstly aggregated the six single cases to one single case following the procedure described in Wilbert (2014) and using the SCDA-package. This was done by centering the data of all cases on the mean of the A-phase of each single-case. In a second step, we sorted the values of all A-phases by their measuring time and merged them into one single A-phase. We then did the same with the values of the B-phases. Finally, the measuring times of the B-phases were increased to start one measurement after the last measurement of the A-phase. We subsequently recombined the resulting merged A- and B-phase into a new single-case including the measurements of all the cases. This aggregation allowed for a combined analysis of all six single-cases. Figure 4 depicts the resulting aggregated case.

Figure 4. **Plot of the aggregated data of the six single-cases. In the lower figure, multiple measurements for one measurement point are median-averaged**



The complete regression model had a significant fit ($F[3, 104] = 199.12$; $p < 0.001$; adjusted $R^2 = .85$). Applying an auto-regression model based on a general least square estimation led to a negligible difference in model parameters (see Table 4).

Table 4. ***Piecewise-regression model for the aggregated six single cases. ΔR^2 is computed with likelihood-ration test comparing the full model with the model without the target predictor (see Beretvas & Chung, 2008).***

	B	*SE*	*t*	*p*	ΔR^2
Intercept	0.28	0.36	0.79	.43	
Trend	-0.08	0.09	-0.90	.37	.001
Level	5.36	0.49	10.87	.00	.169
Slope	0.08	0.09	0.88	.38	.001

Discussion

Main Findings

The current study investigated the effects of a graphic organizing technique (story mapping) on the reading comprehension of six students between ten and fourteen years old, who had sufficient decoding abilities, but possessed rather limited intellectual skills and struggled with constructing and extracting meaning from a text. Results suggested that the strategy was extremely effective. All subjects were able to dramatically increase the number of correct responses in the continuously administered probes (from M = 3.88 during baseline to M = 8.97 during intervention). All applied procedures to measure the effectiveness of the treatment (visual inspection, effect size calculation, randomization test, piecewise regression analysis) indicated that teaching to use story maps has a tremendous potential to help children like the ones involved in our experiment to better understand a text. Previous studies were able to demonstrate that this method can be a powerful intervention (e. g. Babyak, Koorland, & Mathes, 2000; Boon, Fore III, Ayres, & Spencer, 2005; Boulineau, Fore III, Hagan-Burke, & Burke, 2004; Gardill & Jitendra, 1999; Lapp, Fisher, & Johnson, 2010; Smith, Boon, Stagliano, & Grünke, 2011). However, the effects that are outlined in these earlier research papers have never reached the magnitude of ours. We were thus able to demonstrate that story mapping can be particularly effective when it is used with children who are especially eligible for this kind of intervention.

Limitations

One often-raised concern with single-case studies is their purported limited generality. Because these designs include only a very small number of subjects, they are often considered to possess a rather constricted external validity. However, generality can easily be demonstrated via direct replication. As indicated above, there are already quite a number of studies that document the benefits of story mapping with struggling learners. Generality could certainly be established if more reports emerge that support the assumption that this technique is especially helpful with students who fit the criteria that we used to select our sample. Another objection to the explanatory power of this study is the reference to the rather specific type of text that was used. Students only worked with short stories (narratives) that were taken from books written by a certain author. It has yet to be determined whether story mapping is equally effective expository texts. The comprehension questions for each story were obviously equally difficult to answer. There were only marginal variations in the scores during the baseline and the treatment phases for each student. Performance changes were apparently due to whether or not the children had received some instructions on how to use the strategy. As mentioned above, the order in which the stories were presented to each individual subject was randomly chosen. The increases in correctly answered comprehension questions came about very abruptly. But even if they developed steadily over time, it would have not constituted a threat to the internal validity of the study.

One serious limitation of the study pertaining to the design was that no post treatment data were collected. Considering the large and instant treatment gains, it appears unlikely that the performance of the subjects would return anywhere close to base level upon finishing the intervention. However, this is just an assumption. No data is available to support this hypothesis.

In this study, we followed the trend of using inferential statistics as a supplement to the typical routine of analyzing data from case studies by just visually inspecting them or calculating effect sizes. One could argue that this undertaking was dispensable in our instance, because the effects were very apparent. As Edwards, Lindman, and Savage (1963) have commented on obvious treatment outcomes in single-subject studies, "… you know what the data mean when the conclusion hits you between the eyes" (p. 217). However, the conclusions that a researcher draws from a given data set are not always obvious. And even if they are for one person, this does not mean that someone else arrives at the same bottom line. Oftentimes, the interpretation of the findings seems to be left too much to the subjective discretion of the respective authors. Brossart, Parker, Olson, and Mahadevan (2006) point out that the inter-rater-reliabilities of visual inspections are remarkably low. Even if raters have been excessively trained in how to make sense of graphs depicting the course of the measurements, they still do not come up with very homogeneous interpretations. The line between an instance where a statistical analysis seems advisable and one where it seems redundant is virtually impossible to draw. Thus, it is reasonable to apply statistical tests when analyzing data from single-subject designs whenever possible.

Instances where this seems inappropriate are situations in which the robustness of such approaches has to be questioned due to high auto-correlations among original scores (e. g. Sierra, Solanes, & Quera, 2005). But as mentioned above, this did not constitute a threat to the internal validity of our study. The tests that we used are very immune to this jeopardy, when they are applied with data from an AB multiple baseline design across subjects (Wilbert, in press).

Practical Implications and Future Research

Teaching children to effectively extract meaning from a text is certainly one of the most important tasks that schools have to face. Without this ability, students will inevitably fail in their academic endeavors. In addition, they will miss out on a whole array of activities that make life enjoyable (like reading a book or communicating through social networking tools) and will struggle immensely in many of their daily routine activities (like understanding an instruction book, a letter from an agency, or the latest news on an iPad).

According to the findings of our study, helping children like the ones in our experiment to better extract meaning from a text through the use of story maps is anything but an insurmountable challenge. The student instructor who functioned as teacher to our sample did not receive extensive training prior to familiarizing the six boys and girls with the particular graphic organizing technique that we used. This experience raises hopes that this strategy could profitably be applied by a tutor on a one-to-one basis in a regular or inclusive classroom. Peer-tutoring has proven to be one of the most effective ways in a whole array of different academic content areas (Bowman-Parrot, Davis, Vannest, & Williams, 2013; Greenwood, Arreaga-Mayer, Utley, Gavin, & Terry, 2001). But finding effective procedures for struggling students that can easily carried out by their class mates, remains a great challenge. A lot of evidence-based interventions require a considerable amount of expertise on the side of the instructor. In contrast, story-mapping seems to be a very expedient tool to be used in peer-tutorial settings by children who do not necessarily have to possess an abundance of teaching skills. It can thus effectively contribute to break through the "… declining spiral of frustration, anxiety, and more failure" (Slavin, 2005, p. VIII) that students with low comprehension and low intellectual skills so often experience.

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