Desoete, A., De Weerdt, F., Vanderswalmen, R., & De Bondt, A. (2014). How persistent is a diagnosis of mathematical disorder at an early age? A longitudinal study. *International Journal for Research in Learning Disabilities, 2*(1), 42-71.

How Persistent is a Diagnosis of Mathematical Disorder at an Early Age?

A Longitudinal Study

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Abstract

The study was conducted to look at differences between children who outgrew and did not outgrow an early diagnosis of mathematical learning disorder (MD; *n*=13), and peers without MD (*n*=13). Children were tested at 5, 6, 7 and 10 years of age. About 54% of the children with an early diagnosis of MD still experienced mathematical difficulties at the age of 10. All 10-year-olds with MD still had more difficulties than peers without MD on fact retrieval. Seriation in kindergarten and spelling and reading pseudo words in elementary school, but not gender and intelligence, predicted whether MD was outgrown. Spatial span best predicted children outgrowing MD. Digit recall was a good predictor of persistent MD. Results emphasize the dynamic aspect of MD and the importance of assessing the numerical and central executive domain of working memory, as well as seriation, reading and spelling, in children at risk for MD.

Children with a specific learning disorder with impairment in mathematics, also called *mathematical learning disorder* (*MD*), show a significant degree of impairment in mathematics. Their mathematical abilities are situated substantially and quantifiably below those expected for the individual's chronological age, causing interference with academic performance. In addition, the MD-related problems cannot be better accounted for by intellectual disabilities or external factors (such as inadequate educational instruction) that could provide sufficient cause for scholastic failure. Finally, the symptoms persist for at least 6 months despite the provision of interventions that target the specific difficulties (APA, 2013; Fletcher, Francis, Morris, & Lyon, 2005; Landerl, Bevan, & Butterworth, 2004; Mazzocco, Devlin, & McKenney, 2008; Mazzocco & Myers, 2003; Passolunghi, Cargnelutii, & Pastore, 2014).

The operationalization and cut-off scores used to define MD have varied substantially (Bartelet, Ansari, Vaessen, & Blomert, 2014; Moeller, Fischer, Cress, & Nuerk, 2012), with measuring mathematics performance multiple times and documenting symptoms persisting for at least 6 months as two of the important criteria to consider in assessing MD (APA, 2013). Although they might contribute to our understanding of the development of mathematical ability, studies whose conclusions do not not including stability as a criterion (e.g., Bartelet et al., 2014) might not be generalizable to children who experience math impairments across grades (e.g., De Weerdt, Desoete, & Roeyers, 2013; Mazzocco & Myers, 2003; Pieters, Roeyers, Rosseel, Van Waelvelde, & Desoete, 2013; Toll, Van der Ven, Kroesbergen, & Van Luit, 2011). The latter definition is more restricted than the first one and might indicate a more stable, chronic pattern of MD. However, even the empirical picture provided by the existing studies that include a 'persistence criterion' is still far from clear-cut (Geary, 2011a, 2011b; Murphy, Mazzocco, Hanich, & Early, 2007; Vukovic & Siegel, 2010). Although stability is one of the criteria for MD (APA, 2013), some children with MD do appear to outgrow their math problems to some extent (Jordan, Mulhern, & Wylie, 2009), with MD only persistent in between 40% and 63% of cases (Mazzocco & Myers, 2003; Shalev, Manor, & Gross-Tsur, 2005; Silver, Pennett, Black, Fair, & Balise, 1999). A major drawback of previous research is that only a few studies have compared in detail children outgrowing and not outgrowing MD with a control group of children of the same age but experiencing no learning disabilities at the start of elementary school (at the ages of 6 and 7). It also remains unclear whether different general (gender, intelligence, working memory) or more specific (preparatory math skills) factors influence the outgrowing or chronicity of MD during elementary school.

Since mathematics is a complex ability composed of a variety of skills (Bartelet et al., 2014; Dowker, 2005b; Shalev, 2004), the development of mathematics learning in elementary education might not be a linear process, with timed fact retrieval skills, performances on untimed mental arithmetic and number knowledge having different rates of progress. In most studies, researchers hypothesized that fact retrieval difficulties in MD would be rather persistent and show little improvement over time (Jordan, Hanich, & Kaplan, 2003a), whereas an impairment in procedural skills (e.g., in mental arithmetic or in number knowledge) might reflect a developmental delay with slow improvement over grades (Geary, 2011a, 2011b). Thus, the evidence on stability of problems might depend on the arithmetic skill that is tested. Since several studies in the field of MD emphasize the importance of incorporating a multicomponent approach (Hart, Petrill, & Thompson, 2010; Jordan et al., 2009; Mazzocco, 2009; Simms, Cragg, Gilmore, Marlow, & Johnson, 2013) and because arithmetic is a complex ability composed of a variety of skills (Bartelet et al., 2014; Dowker, 2005b), it will be important to include several timed and untimed math skills simultaneously to address the gap in the previous studies.

The current study was intended to better refine MD assessment by investigating whether all children with an early diagnosis of MD based on the acquisition of arithmetic skills at the ages of 6 and 7 still have problems with timed fact retrieval and untimed mental calculation and number knowledge at the age of 10.

The Contribution of Gender, Socio-economic Status and Intelligence to Mathematics Achievement at Age 10

In MD, a number of studies have provided evidence in favour of balanced gender ratios (Lachance & Mazzocco, 2006; Shalev et al., 2005) with a gender distribution across subtypes of MD that is not significantly different (Bartelet et al., 2014). However, not all studies agree on this topic. Indeed, Landerl and Moll (2010) have lent support for a preponderance of girls with MD and Judge and Watson's longitudinal study (2011) reported an association between gender and mathematics growth, with girls experiencing smaller growth than boys.

Mixed results were also found for the influence of socio-economic status (SES) on MD. Whereas some longitudinal studies did not find any influence of educational status and profession of parents (Barnes et al., 2014; Krajeswki & Schneider, 2009; Navarro et al., 2012; Shalev et al., 2005); others did (e.g., Aunio, Hautamaki, Heiskari, & Van Luit, 2006).

Finally, several studies have demonstrated that intelligence is a strong predictor for mathematics achievement (Geary, Hoard, Nugent, & Bailey, 2012; Passolunghi et al., 2014; Passolunghi & Lanfranchi, 2012; Praet & Desoete, 2014). However, only a few studies have investigated the contribution of intelligence to the persistence of an early diagnosis of MD. Those that did found that this factor had a significant impact: children not outgrowing MD had a lower IQ than children outgrowing MD or control children (Shalev et al., 2005; Stock Desoete, & Roeyers, 2010).

Thus, previous studies have generated a mixed empirical picture of gender, SES and intelligence as contributors to mathematics achievement. One purpose of the current study, therefore, was to compare children outgrowing and not outgrowing MD and peers without MD on these components.

The Contribution of Preparatory Mathematical Abilities to Mathematics Achievement at the Age 10

Research has demonstrated how preparatory mathematical abilities, such as the Piagetian logical abilities seriation and classification and post-Piagetian conceptual and procedural counting knowledge, are able to predict math achievement in primary school (e.g., Aunola, Leskinen, Lerkkanen, & Nurmi, 2004; Desoete, 2014; Praet, Titeca, Ceulemans, & Desoete, 2013; Stock, Desoete, & Roeyers, 2009). However, the empirical picture provided by existing studies on the value of preparatory abilities for MD is less clear-cut. Stock et al. (2010) revealed how 7-year-old children with MD already performed worse than 5-year-old (kindergarten) control children on seriation, classification and magnitude comparison. Further, Toll et al. (2011) showed how preparatory mathematical skills, measured at the end of kindergarten, predicted MD in second grade to a lesser extent than did working memory. Attout, Noel and Majerus (2014) confirmed the importance of working memory for order in early calculation acquisition, as well as in recognizing ordinal and magnitude representations.

Thus, previous studies have provided evidence for the need to explore the combined effect of predictors, such as working memory and preparatory mathematical skills, over a longer period of time. This study addressed this need by investigating preparatory abilities in addition to working memory in children outgrowing and not outgrowing MD at age 10.

Reading and Spelling Skills in the Prediction of MD

Several studies have revealed genetic factors as overlapping predictors contributing to typical reading and mathematics abilities (e.g., Davis et al., 2014; Desoete, 2008; Hart, Petrill, & Dush, 2010; Hart, Petrill, Thompson, & Plomin, 2009; Kovas & Plomin, 2006; Kovas, Harlaar, Petrill, & Plomin, 2005, Kovas, Haworth, Petrill, & Plomin, 2007), as well as to atypical development or learning disorders (Alarcon, DeFries, Light, & Pennington, 1997; Gross-Tsur, Manor, Kerem, Friedlander, & Shalev, 1998; Shalev et al., 2001). Recently, using twin and genome-wide analysis, Davis and colleagues (2014) revealed that around one half of the observed correlation between reading and mathematics ability at age twelve is due to shared genetic effects (so-called “generalist genes”). Attout, Fias, Salmon and Majerus (2014) demonstrated shared neural correlates in the intraparietal cortex, suggesting the existence of domain-general, potentially ordinal comparison processes, supported by the left intraparietal sulcus. Strong relationships were also found on a behavioural level among mathematics, reading and spelling (e.g., Davis et al., 2014; Landerl & Moll, 2010). Bull and Scerif (2001) demonstrated a correlation of .61 between reading and mathematics and a longitudinal study by Jordan et al. (2003a) revealed that reading influenced math achievement.

It is estimated that between 3.4% (Badian, 1999) and 7.6% (Dirks, Spyer, van Lieshout, & de Sonneville, 2008) of children with MD also have a reading disorder. Moreover, children with combined reading and mathematical learning disorders experienced more generalized and persistent problems than children with isolated MD (Dirks et al., 2008;

Peng & Fuchs, 2014). Strong relationships were also found among behavioural-level deficiencies in mathematics, reading and spelling skills (e.g., Davis et al., 2014; Landerl & Moll, 2010). Several longitudinal studies have demonstrated a relationship between MD and spelling (Shalev et al., 2005) and between MD and a lower level of reading (e.g., Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007; Mazzocco & Myers, 2003). For instance, results of a study by Murphy et al. (2007) revealed that performance of children with MD on a pseudo word reading test was worse than performance of control children on the same test, from the age of 5 (kindergarten) to the age of 8 (third grade). A longitudinal study with elementary school children from 6 to 9 years of age showed that children with MD were more likely than control children to experience reading problems (Vukovic & Siegel, 2010). However, other longitudinal studies in elementary school children found no association between reading and MD (e.g., Shalev et al., 2005). Moreover, research examining spelling in children with MD is scarce (Dirks et al., 2008).

In summary, although inconsistent, findings from the literature highlight the importance of attending to reading and spelling skills in order to understand mathematical performance over time. This study aimed to investigate the contribution of reading and spelling proficiency in children outgrowing and not outgrowing MD at the age of 10 years.

The Importance of Working Memory in the Prediction of Achievement in Mathematics

Baddeley (1986, 2000) defines working memory as the active system that regulates complex cognitive behavior and consists of a central executive (CE) attentional control system, answering for the processing aspect of a task and strongly interacting with two domain-specific storage systems, and a multidimensional capacity store. The phonological loop (PL) is responsible for the storage and maintenance of verbal information (Raghubar, Barnes, & Hecht, 2010). The visuospatial sketchpad (VSSP) has similar responsibilities for visual and spatial information (Baddeley, 1986; Barnes & Raghubar, 2014). The episodic buffer was added to the model at a later stage (Baddeley, 2000) and conceptualized as a multidimensional but essentially passive store that can be fed from the other working memory components, from long term memory or through perception (Baddeley, Allen, & Hitch, 2010). To our knowledge, no research on working memory in children with learning disorders has taken this component into account, probably because the episodic buffer has to be seen as a vague, shadowy concept, research on which – in spite of its high importance – is still in its infancy (Baddeley et al., 2010). Since Baddeley's 1986 model is without doubt the most empirically verified (Miyake et al., 2000), the focus of our study lies in this model.

Several studies have demonstrated that working memory is involved in learning mathematics (Andersson & Lyxell, 2007; Attout, Noel, et al., 2014; Barnes et al., 2014; Bull, Espy, & Wiebe, 2008; De Smedt et al., 2009; Desoete & De Weerdt, 2013; De Weerdt et al., 2013; Gathercole, Alloway, Willis, & Adams, 2006; Geary et al., 2007; Meyer, Salimpoor, Wu, Geary, & Menon, 2010; Passolunghi et al., 2014; Passolunghi & Siegel, 2004; Passolunghi, Vercelloni, & Schadee, 2007; Raghubar et al., 2010; Vukovic & Siegel, 2010).

However, a recent data-driven cluster analysis by Bartelet et al. (2014) strengthened the notion that MD is a heterogeneous disorder, with their data providing support against the notion that MD is strongly underpinned by domain-general factors, such as working memory. In addition, Peng and Fuchs (2014) revealed in their review that children with reading and mathematical disabilities show more severe working memory deficits than peers with isolated learning disorders. Moreover, they noted that MD and RD children showed comparable verbal working memory deficits, but MD children had more severe numerical WM deficits than RD children.

The present study aimed to add some nuance to the literature by highlighting differences between children outgrowing and not outgrowing MD. Research focusing on this aspect might explain some of the inconsistencies across studies and reveal potential risk factors and strengths that can be used as protective factors.

Research Objectives

The purpose of this longitudinal study was to examine the differences between children outgrowing and not outgrowing their math difficulties during elementary school (by the age of 10 years), although they had been previously diagnosed as children with MD (at ages 6 and7).

This research objective resulted in the following research questions:

1. Do all children diagnosed with MD at the age of 7 years still have mathematical difficulties at the age of 10 years, or is there a group of children who outgrow MD during elementary school?
2. What is the differential contribution of gender, SES, intelligence, and preparatory mathematical abilities (at age 7) to the development of fact retrieval, mental arithmetic and number knowledge at age 10?
3. What are the differential contributions of working memory, reading and spelling to outgrowing math difficulties?

Method

Participants

A three-year longitudinal study was conducted with a large sample (*n*=471). Children were followed from kindergarten to elementary school and tested at the ages of 5, 6, and 7 (Stock et al., 2010). At the age of 7, 43 children were retrospectively assigned to the MD group. To belong to this group, one had to score below the 25th percentile on at least one mathematics test both at age 6 and 7, have a clinical diagnosis of MD, and be non-responsive to remediation (measured by the stability of the below average performance on encoding arithmetic facts into long-term memory and the use of effortful procedures to solve arithmetic problems such as finger counting). We refer to Stock et al. (2010) for an overview of these results.

Fifteen 10-year-old children from the MD group of the large sample were randomly selected for the present follow-up study. For practical reasons it was not possible to follow up more children. In order to control for possible confounding variables, this MD group was matched individually on age, gender and intelligence with 15 children without learning problems who scored above the 25th percentile on all mathematics measures at both ages 6 and 7. The children in the control group all had arithmetical scores above the 50th percentile (although this was not an a priori criterion, it strengthened the fact that control children were not at risk for MD). After the first of two test sessions at age 10, two children with MD dropped out because of their parents' lack of time. For this reason, the two control children who were individually matched with these two MD children were eliminated from the study as well. Hence, the final sample consisted of 13 children with MD and 13 control children (*n* =26). Participant characteristics are presented in Table 1.

Table 1
Participant Characteristics

Characteristic	No MD Control (*n*=13)	MD (*n*=13)
	M *(SD)*	M *(SD)*
Age in months		
First test session	69.46 (1.41)	69.92 (1.41)
Second test session	81.23 (3.83)	81.46 (4.27)
Third test session	92.62 (4.13)	92.08 (5.30)
Fourth test session	123.08 (8.69)	121.15 (8.57)
Male : female	6:7	6:7
IQ	104.54 (10.63)	104.54 (10.63)
SES Mother	15.46 (1.61)	15.33 (3.11)
SES Father	16.17 (2.33)	15.00 (3.42)

Note. MD = mathematical disorder group; SES Mother = socio-economic status of the mother, as measured by years of education; SES Father = socio-economic status of the father, as measured by years of education.

Measures

At all ages, parents were asked to complete a questionnaire concerning familial history and SES, as measured by years of education of both the father and mother (e.g., Shalev et al., 2005). At the age of 5, preparatory mathematical abilities were tested. At the ages of 6, 7 and 10, math performance was assessed. In addition, a shortened intelligence test was administered at the age of 7, while at the age of 10 these children were tested on reading, spelling and working memory as well. For a chronology of the tests, see Table 2.

Intelligence. At the age of 7, an estimated IQ was calculated, using an abbreviated version of the Dutch WISC-III (Wechsler et al., 2005). This shortened version is recommended by Grégoire (2000) and has a high correlation (*r* = .93) with a Full Scale IQ (Kaufman, Kaufman, Balgopal, & McLean, 1996). It consists of four subtests: Vocabulary, Similarities, Picture Arrangement and Block Design.

Table 2

Tests Used in This Study.

Tests	5 years	6 years	7 years	10 years
Preparatory mathematical abilities	X	-	-	-
Intelligence	-	-	X	-
Reading (words, pseudowords)	-	-	-	X
Spelling	-	-	-	X
Mental arithmetic/number knowledge	-	X	X	X
Fact retrieval	-	X	X	X
Working memory	-	-	-	X

Mathematics. In kindergarten**,** at the age of 5, the preparatory mathematical abilities (namely procedural and conceptual knowledge of counting, seriation, classification and magnitude comparison) were individually tested with the Test for the Diagnosis of Mathematical Competencies (TEDI-MATH; Grégoire, Noel, & Van Nieuwenhoven, 2004).

Procedural knowledge of counting was assessed with subtest 1 of TEDI-MATH (Grégoire et al., 2004), using accuracy in counting numbers, counting forward to an upper bound (e.g., 'count up to 6'), counting forward from a lower bound (e.g., 'count from 3'), and counting forward with an upper and lower bound (e.g., 'count from 5 up to 9') as indications of procedural counting knowledge.

Conceptual knowledge of counting was assessed with subtest 2 of TEDI-MATH (Grégoire et al., 2004). Children were 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.

Seriation was tested with subtest 4 of TEDI-MATH. Children had to seriate numbers (e.g., "Sort the cards from the one with the fewest trees to the one with the most trees.") *Classification* was also tested with subtest 4, where children had to make groups of cards in order to assess the classification of numbers (e.g., "Make groups with the cards that go together.").

Magnitude comparison was assessed by comparison of dot sets. Children were asked where they saw the most dots. One point was given for a correct answer.

Raw scores were the number of correct items and were converted into percentile- and z-scores. All z-score conversions were based on the entire sample of a longitudinal mathematical study (*n* = 471, see Stock et al., 2010). TEDI-MATH is an individual assessment battery that was constructed to detect MD. For a more detailed description of this test, we refer to Stock et al. (2010).

In elementary school, at 6, 7 and 10 years, all children were tested on mental arithmetic, number knowledge and on fact retrieval skills (see Table 2). *Mental arithmetic* and *number knowledge* were tested with the Kortrijk Arithmetic Test Revision (KRT-R; Baudonck et al., 2006) at the age of 6, 7 and 10 years. The KRT-R is frequently used in Flemish education as a measure of math achievement (e.g., Stock et al., 2010). Raw scores were the numbers of correct items and were converted into percentile- and z-scores. At the ages of 6 and 7, all z-score conversions were based on the entire sample of a longitudinal mathematical study (*n* = 471, see Stock et al., 2010). At the age of 10, raw scores were converted to z-scores based on the entire sample (*n* = 204) of a study of working memory (De Weerdt et al., 2013).

Fact retrieval was tested with the Arithmetic Number Facts Test (TTR; De Vos, 1992) at the ages of 6, 7 and 10. The TTR is a numerical facility test consisting of five subtests with arithmetic number fact problems: addition, subtraction, multiplication, division and mixed exercises. Children have to solve as many items as possible in five minutes; they can work for one minute on every column. The TTR is a standardized test that is frequently used in Flemish education as a measure of number fact retrieval (e.g., Stock et al., 2010). Raw scores were the numbers of correct items and were converted into z-scores.

Reading and spelling. In elementary school, children were also tested on reading and spelling proficiency. At 10 years of age, all children were tested with standardized Dutch reading and spelling measures. *Word reading accuracy* was assessed using the One Minute Reading Test (EMT; Brus & Voeten, 1999) and *pseudo word reading* using the Klepel test (Van den Bos, Spelberg, Scheepstra, & de Vries, 1994). Both reading tests consist of lists of 116 unrelated words. Children are instructed to read as many words as possible in one (EMT) or two minutes (Klepel) without making errors. On both tests, the raw scores were the numbers of words read correctly. These raw scores were then converted into standard scores (SS) (mean: 10, SD: 3) and z-scores based on the entire sample (*n* = 204) of a working memory study (De Weerdt et al., 2013).

Spelling was assessed using Paedological Institute-dictation (PI-dictation; Geelhoed & Reitsma, 2000), a Dutch standardized test in which children have to write down the repeated word from each sentence. The test consists of nine blocks of 15 words. Each block has a higher difficulty level and testing is stopped once a child makes seven or more errors in a block. The raw score was the number of words spelled correctly and was converted into a z-score based on the entire sample (n = 204) of a working memory study.

Working memory. Working memory was tested in elementary school at age 10. Besides the backward digit, word list, listening, and block recall subtests of the Working Memory Test Battery for Children (WMTB-C; Gathercole & Pickering, 2001; Gathercole, Pickering, & Braams, 2002), backward word list recall and backward block recall (e.g., Passolunghi & Mammarella, 2010) were used. In addition, in line with St. Clair-Thompson and Gathercole (2006), all children were tested on spatial span, an adapted version of the Automated Working Memory Assessment (AWMA, Alloway, 2007). Each block consisted of six trials. The task was discontinued if three errors or more were made in one block. Span score was calculated by counting each correct trial as one sixth and adding the total number of sixths – except for backward digit, backward word list, and backward block recall, where the total number of sixths was counted and incremented by one (Imbo, Szmalec, & Vandierendonck, 2009; Smyth & Scholey, 1992).

All tasks were programmed in Affect 4.0 (Hermans, Clarysse, Baeyens, & Spruyt, 2005) and presented on a desk top computer. The main task was not started until the child thoroughly understood the task instructions. For spatial span and backward block recall, a mouse was used as the response device. For backward digit recall, backward word list recall and listening recall, a voice key was used. In all tasks, the experimenter pressed a key in order to trigger the next item (Landerl et al., 2004). As the subtest order of the WMTB-C was followed, all tasks were presented in a fixed order.

Phonological loop. Digit- and word-list recall are measures of the verbal recall of sequences. Children have to repeat sequences of digits or high frequency words (see Figure 1 for a trial representation). Digit sequences were random lists of digits ranging from 1 to 9.

Visuospatial sketchpad. Block recall measures visuospatial recall of sequences of cubes. Places of the nine cubes stayed fixed during the whole task. Cubes that were part of a to-be-recalled sequence were highlighted in orange. Cubes that were not, remained blue. After the sequence ended, a screen with nine blue cubes was shown. Children were asked to repeat the sequence of the orange cubes by clicking on the different blue cubes (see Figure 1).

Central executive. In backward digit recall and backward word list recall, children are required to recall sequences of digits or words in the reverse order (see Figure 1). In listening recall, children are presented with a sequence of spoken sentences (e.g., ‘Lions have four legs’). In the processing task, they have to verify the sentence by stating ‘true’ or ‘false’. In the memorization task, the final word of each sentence has to be recalled in sequence (see Figure 1). In the spatial span, a picture of two identical shapes in which the shape on the right side has a red dot is shown to the children. In the processing task, the child has to identify whether the shape on the right side is the same as or opposite to the shape on the left. In the recall task, the child has to show the location of each red dot on the shape in the correct sequence (see Figure 1). Backward block recall measures visuospatial recall of sequences of cubes in the reverse order (see Figure 1).

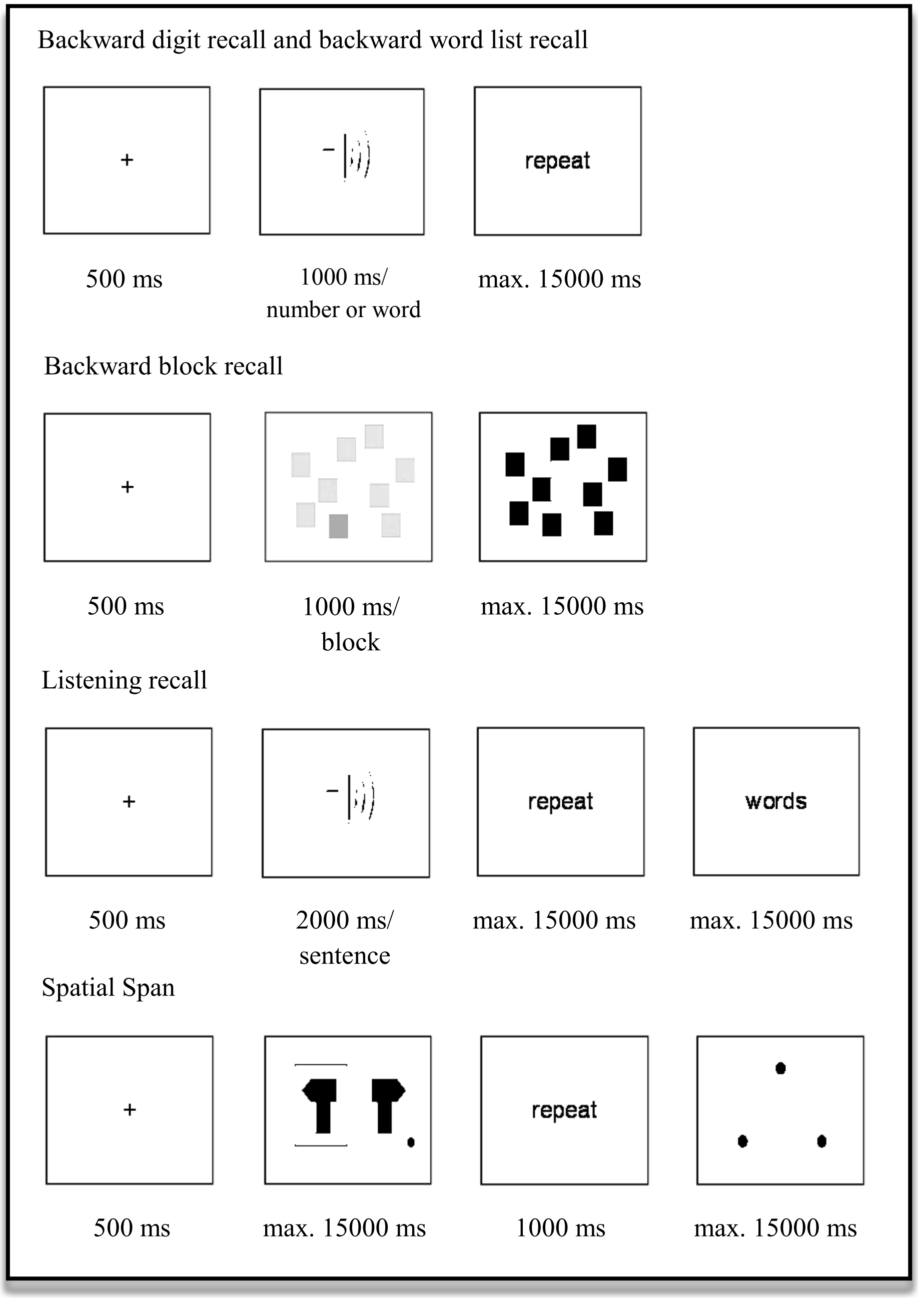

Figure 1. Visualization of the working memory tasks

Procedure

Data collection. All children were tested (refer to Table 2) by a trained researcher. At 5, 6 and 7 years of age, preparatory math tests were conducted during school hours in a separate and quiet room at school. This lasted for a maximum of 50 minutes. At age 7, a short version of the WISC-III was administered individually, and the duration was approximately 45 minutes. At age 10, all children were tested in a quiet room at home for two different sessions, each session lasting up to 70 minutes. During the first session, tests were used to tap mathematics, reading and spelling. In the second session, working memory tasks were administered. To maximize vigilance and persistence in completing tasks, breaks were included.

Outlier analysis. Outlier analysis was done for working memory data. At the sample level, accuracy measures exceeding the group mean by 3 SDs were replaced by values 3 SDs from the group mean (Friedman & Miyake, 2004). Outliers represented less than 1% of responses.

Statistical analyses. A 3 (children not outgrowing MD, children outgrowing MD and control) x 3 (z-scores on the TTR at 6, 7 or 10 years) factorial repeated measures analysis was performed to examine fact retrieval performances over time. Since assumptions of normality and homogeneity were not met for mental arithmetic and number knowledge, non-parametric tests were performed using z-scores on the KRT-R Mental Arithmetic and the KRT-R Number Knowledge results. The Kruskal-Wallis test was used to compare the three groups at the age of 6, 7 and 10 years. Performance over time was analyzed with the Wilcoxon signed-rank test. In addition, multinomial logistic regression analyses were carried out to clarify to what extent SES, intelligence, preparatory mathematical abilities, working memory, reading and spelling predicted the probability of outgrowing MD.

Results

Persistence of Mathematical Disorders

In line with Vikovic and Siegel (2010), the 25th percentile was used as a cutoff to define mathematical abilities that situate themselves below those expected for the individual's chronological age, one of the criteria of MD (APA, 2013). Three girls and three boys with an early diagnosis of MD at the age of 6 and 7 years (46% of the MD group) achieved math scores above the 30th percentile on all math tests at the age of 10 years. In addition, there was no longer severe interference with academic mathematics performance, so these children were classified in the group of children who had outgrown MD during elementary school. One of these children, however, revealed a severe and persisting reading disorder at 10 years of age.

In seven children (four girls and three boys) with an early diagnosis of MD at the age of 6 and 7 years, there was still evidence of scholastic failure. Math abilities were situated below the 25th percentile on at least one math test at 10 years of age. Three of the children still had scores below the 10th percentile. One boy scored at the 11th percentile on mental arithmetic and number knowledge. One girl and one boy scored at the 23 percentile, with additional clinical scores for spelling and/or reading (due to a comorbid reading disorder).

Except for one child, all control children (children without learning disorders at the age of 7) achieved math scores above the 25th percentile at 10 years of age. For fact retrieval, scores were even above the 75th percentile. We decided not to exclude the child with math scores below the 25th percentile from the control group, since the focus of our study was on the profiles of the children who did not outgrow MD (MD for 3 years) and the children who did outgrow MD (MD for two consecutive years), and the child's parents reported no interference with academic performance (APA, 2013) and at least average math performance at school.

Math Performance over Time

A significant main effect on the factorial repeated measures analysis was found for the within factor, "fact retrieval" ($F(2, 22) = 12.36$, $p < .001$, $\eta^2 = 0.53$). Contrasts revealed that fact retrieval skills at the age of 6 ($p = .002$) and 7 ($p < .001$) were significantly worse than at the age of 10. Moreover, results revealed a main effect for group ($F(2, 23) = 27.85$, $p < .001$, $\eta^2 = 0.71$). Both the children not outgrowing MD ($p < .001$) and the children outgrowing MD ($p < .001$) achieved lower fact retrieval scores than the control children. There was no interaction effect of group and time measurement ($F(4, 44) = 0.81$, $p = .525$).

Kruskal-Wallis tests showed significant group differences for mental arithmetic ($\chi^2(2) = 8.56$, $p = .014$) and a trend for number knowledge ($\chi^2(2) = 8.56$, $p = .065$), as measured at the age of 6. The children who did not outgrow MD differed significantly from the control group on both mental arithmetic ($p = .016$) and number knowledge ($p = .046$). The children who did outgrow MD differed significantly from the control group on mental arithmetic ($p = .017$), with only a trend for number knowledge ($p = .072$). Performances of both groups of children with MD did not differ significantly from each other. No significant results were found for mental arithmetic at the ages of 7 ($\chi^2(2) = 4.54$, $p = .103$) and 10 ($\chi^2(2) = .91$, $p = .634$), nor for number knowledge at the ages of 7 ($\chi^2(2) = 3.58$, $p = .167$) and 10 ($\chi^2(2) = 3.25$, $p = .197$). Wilcoxon Rank tests revealed a significant difference only between mental arithmetic performance at the age of 10 and at the age of 6 for the children who did not outgrow MD ($Z = -2.03$, $p = .043$).

Significant differences in performance of the children who outgrew MD over time were found between number knowledge scores at the ages of 6 and 7 ($Z = -1.99$, $p = .046$), at the ages of 6 and 10 ($Z = -2.20$, $p = .028$), and at the ages of 7 and 10 ($Z = -1.99$, $p = .046$), as well as between mental arithmetic scores at the ages of 6 and 10 (Z = -2.00, p = .046). No significant differences over time were found for the control group. Math performance over time is plotted in Figure 2.

Influential Factors

To detect the influence of intelligence, SES, etc. on children who outgrew MD or not, in comparison with control children, multinomial logistic regression analyses were carried out (see Table 3 for an overview of means and standard deviations). Children with an early diagnosis of MD who did not outgrow their mathematic learning difficulties at the age of 10 performed more poorly on digit recall (*M*=3.95; *SD*=0.14) than did control children (*M*=4.89; *SD*=0.14) of the same age. In addition, our data demonstrated poorer spatial span performance in children who outgrew MD (*M*=2.11; *SD*=0.24) as compared to the control children (*M*=3.60; *SD*=0.27). The differences between children who not outgrow MD (*M*=2.60; *SD*=0.38) and control children (*M*=3.60; *SD*=0.27) were not significant on spatial span tasks.

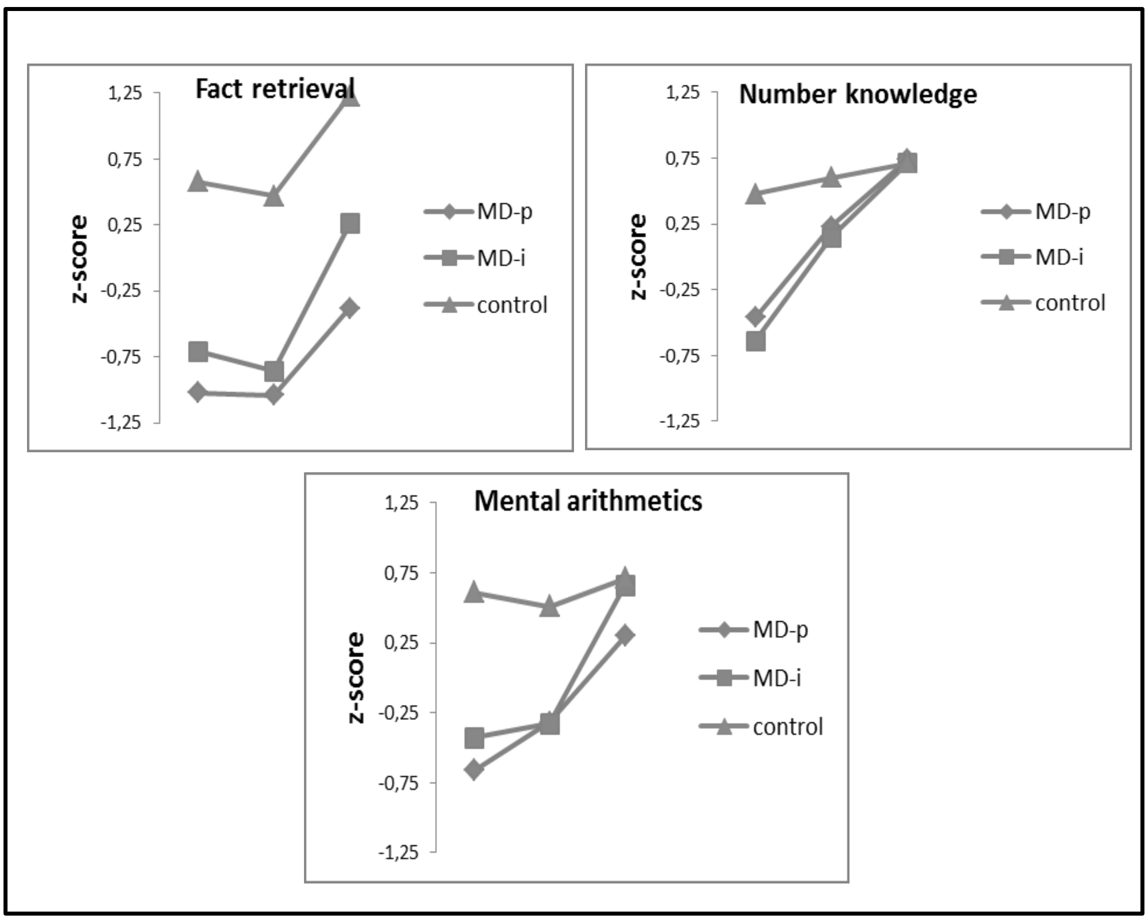

Figure 2. Plotted means at six, seven and ten years of age.

Logistic regression analyses were conducted with the predictors, producing odds ratios. Odds ratios represent the ratio change in the odds of the event (e.g., belonging to the control group) for a one unit change in the predictor variable (e.g., accuracy of the phonological loop) and may vary from 0 to infinity. An odds ratio can be seen as an estimate of effect size. An odds ratio below 1 indicates a higher risk not to be in the reference group and as such reflects problems if the control group functions as the reference category. In contrast, an odds ratio higher than 1 suggests a higher chance of belonging to the reference category and thus suggests a protective factor if the control group is the reference group. When the odds ratio is 1 (or close to it), no effect is found. Not only their nearness to 1, but also the significance of odds ratios - indicated by the *p* value of the Wald statistic - plays an important role in the decision process about the strength of a model.

Table 3

Means and Standard Deviations on Predictors of Achievement

	No MD Control (*n*=13)	Not outgrowing MD (*n*=7)	Outgrowing MD (*n*=6)
	M (SD)	*M (SD)*	*M (SD)*
Age	123.08 (2.41)	122.57 (2.97)	119.50 (4.01)
SES Mother	15.46 (0.45)	14.43 (0.48)	16.33 (1.69)
SES Father	16.15 (0.62)	13.57 (0.57)	16.67 (1.78)
Intelligence	104.54 (2.95)	100.43 (3.32)	109.33 (4.60)
Preparatory Math Abilities			
Conceptual counting	0.80 (0.23)	0.33 (0.32)	0.84 (0.19)
Procedural counting	0.53 (0.10)	-0.20 (0.42)	0.22 (0.19)
Seriation	0.64 (0.38) [a]	-0.16 (1.08) [b]	-0.01 (1.00) [ab]*
Classification	-0.06 (0.70)	-0.62 (0.70)	-0.10 (1.01)
Magnitude comparison	0.04 (0.23)	-0.19 (0.41)	-0.31 (0.47)
Reading and spelling			
Reading existing words	1.00 (1.86)[a]	- 0.26 (0.15)[b]	0.18 (0.22)[b]***
Reading pseudo words	1.05 (0.15)[a]	- 0.33 (0.18)[b]	0.36 (0.26)[b]***
Spelling	1.05 (0.10)[a]	- 0.03 (0.20)[b]	0.25 (0.26)[b]***
Working memory			
Phonological loop			
Digit recall	4.89 (0.14)[a]	3.95 (0.14)[b]	4.39 (0.25)[ab]**
Word list recall	3.92 (0.11)	3.67 (0.15)	4.06 (0.14)
Visuo-spatial sketchpad			
Block recall	4.82 (0.15)	4.41 (0.08)	4.36 (0.08)
Central executive			
Backward digit recall	3.59 (0.17)	3.12 (0.18)	3.22 (0.07)
Backward word recall	3.03 (0.12)	2.79 (0.14)	2.92 (0.10)
Listening recall	2.23 (0.13)	1.93 (0.13)	2.11 (0.13)
Backward block recall	4.40 (0.10)	4.16 (0.06)	4.11 (0.16)
Spatial span	3.60 (0.27)[a]	2.60 (0.38)[ab]	2.11 (0.24)[b]**

Note. SES = socio-economic status, as measured by years of parental education;
p* < .05; ** *p* ≤ .01; * *p* ≤ .001. [a,b] posthoc indices at *p* < .05.

Besides, model fitting results provide information about the significance of the model and log likelihood ratio tests show us to what extent the model changes if we omit a particular predictor. Nagelkerke's R^2 is used to express the explanation power; it ranges from 0 to 1. Finally, the model predicts group membership by trying to classify participants correctly. Due to the small sample size, no more than two predictors at a time were entered in one model. Only predictors with a good fit were combined together until the model could not be improved anymore and, hence, was maximized.

For each influential factor, the best logistic regression model is presented in Table 4.

Table 4

Prediction of Outgrowing MD or Not, or Having No Learning Difficulties, at 10 Years of Age

			95% CI for OR		
Group comparison	Model	OR	Lower	Upper	Wald *(df)*
SES					
Outgrowing MD vs control[a]	SES Father	0.57	0.33	0.97	4.23 (1)*
Not outgrowing vs control[a]	SES Father	1.07	0.76	1.50	0.14 (1)
Outgrowing or not MD[b]	SES Father	0.53	0.30	0.96	4.42 (1)*
Intelligence					
Outgrowing or not MD[b]	Intelligence	1.11	0.96	1.28	2.02 (1)
Preparatory Math					
Not outgrowing vs control[a]	Seriation	0.18	0.03	1.06	3.59 (1)
Outgrowing MD vs control[a]	Seriation	0.21	0.03	1.28	2.87 (1)
Outgrowing or not MD[b]	Seriation	0.85	0.27	2.70	0.08 (1)
Reading and spelling					
Outgrowing MD vs control[a]	Klepel	0.01	0.00	1.04	3.79 (1)*
	PI-dictation	0.05	0.00	11.39	1.17 (1)
Not outgrowing vs control[a]	Klepel	0.24	0.01	4.34	0.94 (1)
	PI-dictation	0.01	0.00	0.74	4.36 (1)*
Outgrowing or not MD[b]	Klepel	0.03	0.00	2.41	2.50 (1)
	PI-dictation	6.36	0.14	300.33	0.88 (1)
Working memory					
Not outgrowing vs control[a]	Digit recall	0.02	0.00	0.72	4.59 (1)*
	Spatial span	0.52	0.13	2.08	0.86 (1)
Outgrowing MD vs control[a]	Digit recall	0.29	0.02	4.02	0.84 (1)
	Spatial span	0.17	0.03	0.92	4.24 (1)*
Outgrowing or not MD[b]	Digit recall	0.07	0.00	2.11	2.34 (1)
	Spatial span	3.03	0.57	16.10	1.69 (1)

Note. OR = odds ratio; CI = confidence interval; SES = socio-economic status, as measured by years of parental education.[a] control group as reference category; [b] outgrowing MD as reference category.
* $p \leq .05$.

Socio-economic status. For SES, only the father's was a significant predictor, χ^2 (2, n = 26) = 6.80, p = .033, Nagelkerke's R^2 = 0.26. The model could classify 53.8% of the children correctly: 57.1% of the children who had not outgrown their early diagnosis of MD, 0% of the children who had outgrown their MD and 76.9% of the control group without learning difficulties at age 7 were classified correctly.

Intelligence. The MD group was carefully matched with the control group on intelligence, in order to rule out the possible influence of this factor. For this reason, only the children who had and had not outgrown the early diagnosis of MD were compared with each other. There was no significant result for the model, χ^2 (2, n = 26) = 2.69, p = .101, Nagelkerke's R^2 = 0.25; 71.4% of the children who had not outgrown MD and 83.3% of the children who had outgrown MD were classified correctly.

Preparatory mathematical abilities. Seriation appeared to be the only significant preparatory mathematical abilities predictor, χ^2 (2, n = 26) = 6.37, p = .041, Nagelkerke's R^2 = 0.25. Overall, 57.7% of the children were classified correctly: 57.1% of the children who had not outgrown an early diagnosis of MD, 0% of the children who had outgrown an early diagnosis of MD and 84.6% of the control group without learning difficulties at age 7 were classified correctly.

Reading and spelling. The best model consisted of pseudo word reading and spelling, χ^2 (4, n = 26) = 27.21, p < .001, Nagelkerke's R^2 = 0.74. Log-likelihood tests showed significant results for both pseudo word reading (χ^2 (2, n = 26) = 7.32, p = .026) and spelling (χ^2 (2, n = 26) = 7.57, p = .023). About 71.4% of the children who had not outgrown an early diagnosis of MD, 50% of the children who had outgrown an early diagnosis of MD and 92.3% of the control group without learning difficulties at age 7 years were classified correctly. Overall, the model classified 76.9% of the children correctly.

Working memory. The best logistic regression model consisted of numerical and visuospatial central executive working memory components. Digit recall (numerical component) and spatial span (central executive component) appeared to be the best working memory predictors. Relative to the control group, the odds ratios of the children who outgrew or did not outgrow an early diagnosis of MD showed a significant decrease in both domains: the higher the numerical (phonological) and visuospatial central executive working memory scores, the higher the chance of belonging to the control group of children without mathematic learning difficulties at the ages of 6 and 7. The model was significant, χ^2 (4, n = 26) = 20.77, p < .001, Nagelkerke's R^2 = 0.63. Moreover, log-likelihood tests showed significant results for digit recall (χ^2 (2, N = 26) = 9.51, p = .009) and spatial span (χ^2 (2, N = 26) = 6.61, p = .037). The model was able to classify 76.9% of the children correctly: 66.7% were correctly categorized as the group of children who outgrew an early diagnosis of MD they had received at ages 6 or 7.

Discussion

A first aim of this study was to investigate whether children with an early diagnosis of MD, including the criterion of consistency in performance over time (at the ages of 6 and 7) and receiving interventions that target their difficulties, can outgrow their mathematical difficulties by 10 years of age. Fact retrieval, mental arithmetic and number knowledge were measured at the ages of 6, 7 and 10.

The results demonstrated that about 46% of the children with an early diagnosis of MD no longer experienced severe mathematical difficulties in fact retrieval, number knowledge and mental arithmetic at 10 years of age. These children no longer situated themselves substantially and quantifiably below non-diagnosed children at the chronological age of 10. However 54% (7 out of 13) of the children diagnosed as 'children with MD' at the age of 7 still experienced severe mathematical difficulties at the age of 10. This was the case for four girls, and hence a balanced gender ratio was found (Shalev et al., 2005). This percentage is in line with previous findings (Mazzocco & Myers, 2003; Shalev et al., 2005; Silver et al., 1999), pointing to the fact that although some children seem to be non-responsive to remediation at the beginning of mathematical instruction (ages 6 and 7), we cannot speak of stability of the mathematical difficulties in all children with an early diagnosis of MD.

Math Performance over Time

An objective of the current study was to gain insight into children outgrowing or not outgrowing an early diagnosis of MD. Our results concerning fact retrieval are to some degree in congruence with literature which states that children with MD experience persistent fact retrieval deficits (Jordan, Hanich, & Kaplan, 2003b; Rousselle & Noel, 2007). In accordance with the cumulative growth model (Aunola et al., 2004; Morgan, Farkas, & Wu, 2009), all children with MD (outgrowing their mathematical difficulties or not) still experience more difficulties in the retrieval of arithmetic facts from long-term memory compared to age matched peers without learning problems (control children) at 10 years of age. These results point to the fact that encoding facts into long term memory is a problem in MD during the whole of elementary school and not only at the beginning of mathematical instruction. Therefore, it will be important to attune instructional strategies to this persisting memory-related difficulty in order to optimize the mathematical learning, and hence, performance, of children with MD.

The findings of the present study are also suggestive of a developmental pathway, with children with MD catching up on number knowledge, especially those who outgrow their early diagnosis of MD. This catching up shows some resemblance to the theoretical lag model of mathematical development. This lag model (Aunola et al., 2004; Morgan et al., 2009) suggests that children with less mathematical knowledge can catch up with their higher skilled peers due to the provision of systematic instruction. In this study, children with MD received extra interventions that targeted their difficulties due to their diagnosis of MD at the ages of 6 and 7. However, the theoretical lag model seems to be in contrast with the cumulative growth model (Aunola et al., 2004; Morgan et al., 2009) that could serve as an explanation for the remaining severe difficulties of all children with MD diagnosed at an early age, and in fact for problems with retrieval at 10 years of age.

Outgrowing MD or Not and Possible Influential Factors

In congruence with previous MD studies (e.g., Shalev et al., 2005), no gender differences were found. There were an equal number of boys and girls with MD who both outgrew and did not outgrow their mathematical difficulties.

In this study, SES was indicated by the years of parental education. Results revealed that the less educated the father was, the higher the child's chance of belonging to the group of children who did not outgrow MD. However, the model could not correctly classify the children who outgrew MD. Except for one child, they were all categorized as control children. This might be explained by the longitudinal research of Krajewski and Schneider (2009), revealing that parental SES, as measured by educational status and trained and current professions, only became important at 10 years of age (and not at ages 6 to 8). Intelligence was not significant predictor of outgrowing MD. This result contradicts other findings, for instance those of Stock et al. (2010), and may be due to the small sample size and power of the study.

As to preparatory mathematical abilities, in contrast with previous research (e.g., Praet & Desoete, 2013; Stock et al., 2010), only seriation was a significant predictor in kindergarten. We found no significant results for classification, counting and magnitude comparison tested in kindergarten in the prediction of mathematical performance at the age of 10. However, in line with the importance of ordinal processing in the numerical domains (Attout, Fias, et al., 2014), seriation predicted the failure to outgrow mathematical difficulties in children with an early diagnosis of MD.

This finding might encourage clinicians to select preparatory mathematical subtests in kindergarten with caution when assessing and aiming to define MD at an early age. The fact that none of the other preparatory mathematical abilities was of importance might be clarified by considering the dynamic aspect of mathematical abilities (Shalev et al., 2005). Most preparatory mathematical abilities research is restricted to the first years of elementary school. Hence, one can expect a declining influence of preparatory mathematical abilities such as classification, counting and magnitude comparison on MD over time (e.g., by the age of 10 years). Indeed, Toll et al. (2011) could classify 76.9% of the children correctly if persistence was not taken into account, against 57.1% when controlling for chronicity.
This study also aimed to test whether reading- and spelling-related abilities contributed to the prediction of children with an early diagnosis of MD outgrowing or not outgrowing their mathematical difficulties. We demonstrated that five children who did not outgrow MD and one child who did outgrow MD achieved a score below the 25^{th} percentile on at least one reading or spelling test, and that all reading and spelling accuracy scores were significantly

lower in children with MD than in control children. In addition, children with an early diagnosis of MD still having mathematical difficulties at the age of 10 showed lower spelling and pseudo word reading accuracy scores than peers without learning difficulties. These results are in line with the findings of Geary et al. (2007), Mazzocco and Myers (2003) and Murphy et al. (2007), but contradict the findings of Shalev et al. (2005), who found that spelling, but not reading, was associated with the persistence of MD. However, our longitudinal study provided evidence for the importance of assessing the accuracy of reading pseudo words and spelling in mathematics achievement and in the prediction of whether MD can be outgrown or not.

Working Memory in the Prediction of MD

In line with previous studies (Attout, Noel, et al., 2014; Raghubar et al., 2010; Toll et al., 2011) that have demonstrated the importance of working memory for order in early calculation acquisition, working memory was the strongest predictor of whether MD was outgrown or not, even stronger than the children's reading and spelling scores. Children not outgrowing an early diagnosis of MD performed more poorly on digit recall (phonological loop, numerical working memory) than control children. These results are in line with the meta-analysis of Peng and Fuchs (2014) revealing, among other differences, poorer numerical working memory in children with MD in comparison with control children. In addition, research has shown that the phonological loop plays an important role in mathematical abilities, in particular in mental calculation, mature addition strategies, verbal counting strategies and fact retrieval, especially later on in elementary school (De Smedt et al., 2009; Raghubar et al., 2008). Thus, clinicians might be encouraged to test the numerical working memory component when aiming to predict mathematical proficiency or persistence of MD.

Our findings also revealed poorer spatial span as a central executive component of working memory in children who outgrew MD, compared to the control children. The central executive seems involved in controlling and monitoring complex operations, including the spatial aspects of calculations and the use of concrete representations (De Smedt et al., 2009; McLean & Hitch, 1999). This evidence is in line with the empirical study of Passolunghi and Cornoldi (2008), who also found that a visuospatial central executive task was one of the most important predictors of differences between children with MD and control children at the ages of 8 and 10. However, it remains unclear why this component did not differ significantly between children who did outgrow MD and the control children in this study; this is perhaps due to the small sample size.

Taken together, clinicians might think critically about the selection and interpretation of working memory tests, while being aware of the difference between numerical and visuospatial central executive working memory in the assessment of children at risk. Our results suggest that word list recall, block recall, backward digit and word recall, listening recall and backward block recall may not provide additional prediction of MD, and a shorter test (with a digit recall and a spatial span task) may be given, reducing administration costs and improving scores because participants are less fatigued.

Limitations

We recognize that there are severe limitations to the present study that should be mentioned. This longitudinal study occurred with an individually matched, though small, sample of children with and without an early diagnosis of MD. As a consequence, some results might not be detected due to a lack of power. This might, for example, have been the case for intelligence and spatial span in the prediction of children who outgrew MD. More profound conclusions can only be made by increasing the number of participants with and without MD and by looking at differences between children with isolated MD and children with a combined reading and mathematical disorder (MD+RD). In that way, we would have a more detailed understanding of mathematical development and possible influencing factors in outgrowing or not outgrowing MD. The small number of participants in the current study certainly limited the generalization and implication possibilities of its results.
Moreover, although our sample was carefully matched on gender, age, and intelligence, for practical reasons we were not able to match each child with MD with a control child from the same classroom. This might have additionally affected results in that instruction level, motivation of the teacher, etc., might have influenced the performance of the children, making our findings between children marginally interpretable. In addition, it might be worthwhile to investigate in more depth the evolution in numerical and central executive working memory, and to add language proficiency and ordinal representation and comparison as predictors. Such studies with a larger sample of children with MD and MD+RD are needed before more accurate conclusions about outgrowing MD can be made.

Implications and Future Research

The finding that mathematical abilities strongly develop over time, even in children diagnosed at an early age with MD, may have some implications for both education and clinical diagnostic practice.

For education, it seems important that children with an early diagnosis of MD get enough time with a daily re-looping and explicit rehearsal of number facts, since they seem to continue to experience severe difficulties with fact retrieval, even at 10 years of age. Number fact retrieval appeals to rote memory and is taught systematically and straightforwardly in regular education until age 7 in the Belgian curriculum. Although additional research is needed, it seems that children with MD at the age of 10 persist in non-retrieval or effortful procedures such as finger counting or breaking problems into multiple steps, to solve these kinds of problems (Bartelet et al., 2014), since they remain less accurate in encoding arithmetic facts into long-term memory. Therefore, children with MD might benefit from an adjusted speed and adequate support to solve these kinds of arithmetic problems. In addition, since our findings indicated that number knowledge improved over the years, it might be important to support this number knowledge during educational instruction. Further investigation is needed to determine whether children with an early diagnosis of MD can outgrow difficulties with number knowledge more quickly if help that targets number knowledge difficulties is provided.

In diagnostic practice our findings seem to indicate that one cannot assume that all children diagnosed with MD at an early age (6 or 7) still experience severe learning difficulties at the end of elementary school, even if math problems were present during two consecutive years at the beginning of academic instruction. It is recommended that these children be retested at the end of elementary school to determine whether they outgrow their mathematical difficulties or to confirm the stability of MD based on continuous low arithmetic performance (Fletcher et al., 2005; Murphy et al., 2007). In addition, to get a full picture of children with MD, one should not only assess mathematical performance, but also test seriation skills in kindergarten and the accuracy of reading pseudo words and spelling in elementary school, as well as determine the proficiency of the numerical and central executive working memory components at 10 years of age.

Conclusion

Overall, this longitudinal study revealed that clinicians and researchers should not neglect the results of seriation tasks in kindergarten as a predictor for MD. In addition, in elementary school numerical and visuospatial working memory tasks, reading pseudo words and a spelling test should be included in an assessment battery for children at risk for MD. Finally, nearly half of the children with an early diagnosis of MD seem to outgrow their mathematical difficulties by the age of 10.

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