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Working Memory Sensitive Math Intervention in Students With Learning Disabilities – a Single Case Study

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This study examines the effects of a working memory (WM) sensitive math intervention in students with learning disabilities (LD). The intervention aims to improve early mathematical competencies while accounting for weak cognitive resources through a reduced instructional design. These principles are considered to be effective for learning. Ten students with mild to moderate intelligence impairment participated in our study. We applied an AB single-case intervention study across participants to evaluate the effects of the intervention. The students take part in at least 10 30-minute intervention sessions. Non-overlap indices, as well as regression analysis, support positive effects on students' mathematical competencies. Nevertheless, there are still students for whom the effects were unstable or failed to materialize. Besides the effectiveness of the WM-sensitive math intervention, the results support the assumption that the mathematical learning of students with LD is similar to that of students without LD but delayed.

Keywords: **Intellectual Disabilities, Learning Disabilities, Quantity-Number Competencies, Single-Case Research, Working Memory**

Introduction

Basic mathematical skills are important for independent living and social participation in everyday life – for people with learning disabilities (LD) as well. There are different ideas and constructions of the term *learning disability* (Grünke & Morrison Cavendish, 2016). For the present work, we use the term learning disability in the UK sense. This means that the students not only show low academic performance but also have reduced intellectual abilities associated with difficulties in everyday activities. In other works, the term *(mild or moderate) intellectual disabilities* is also used here. Students with LD typically show lower levels of math performance compared to their nondisabled peers. For students with below-average achievement in mathematics, extra support for basic mathematical skills is suggested (Andersson, 2010; Ise et al., 2012). Early mathematical competencies (i.e. early numeracy) provide an important basis for learning arithmetic. In the German-speaking area, different models describe the development of these early competencies (Aster et al., 2005; Fritz & Ricken, 2008; Krajewski, 2003, 2013).

One model that also underlies the intervention in the present study is Krajewski's model (2003, 2013), which describes how early mathematical competencies are acquired via three developmental levels. At the first level, children have two basic

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skills that are not linked to each other: Quantity discrimination and number word sequence. At the second level, these two competencies gradually link together. First, children "assign number words to rough quantity categories" (Krajewski & Schneider, 2009, p. 517). Subsequently, the children develop the competence to distinguish exactly between adjacent numbers. Finally, the number words are connected to exact quantities. On the third level of quantity-number competence, the awareness develops that a certain quantity is composed of parts and that these parts can be described by numbers as well ("I can split 8 into 5 and 3", "5 and 5 are 10").

Early mathematical competencies are good predictors of later math performance and are useful for fostering students with poor mathematical skills (Ise et al., 2012; Jordan et al., 2007). Evidence-based interventions are recommended to improve the competencies of these students (Schnepel & Aunio, 2022; Witzel et al., 2023). To date, students with LD have been less in the focus of intervention research. For these reasons, we examine the impact of an intervention to improve the early mathematical competencies of students with LD.

Mathematical development of students with LD

Unfortunately, few studies have addressed the mathematical development of students with LD. For example, Bashash et al. (2003) investigate the basic counting and number skills of students with LD, respectively 'moderate intellectual disabilities'. Their results indicate a similar learning pattern for the number-word sequence compared to typically developing students. Students with LD also made the same typical errors, used one-to-one correspondence, used stable-order principle and understood cardinality (Baroody et al., 1999; Bashash et al., 2003; Schnepel et al., 2020). As it is known from typical development, there was a relationship between counting skills and number concepts. Brankaer (2011) and Brankaer et al. (2013) investigated the ability to process numbers and quantities in children and adolescents with LD and found the same mathematical processes as in typical developing learners. Garrote et al. (2015) results show that students with LD (regardless of age and degree of mental retardation) have basic numerical competencies like number word sequence.

However, tasks in which numbers must be linked to a precise quantity, number relations and arithmetical tasks are more difficult. Number binding (or number decomposition) was one of the most difficult tasks for students with LD. Schnepel et al. (2020) investigated the mathematical profiles of students with LD and came to four different groups: (1) Basic knowledge, no quantity-number concept, (2) Basic knowledge up to 100, quantity-number concept up to 20, (3) Basic knowledge up to 100, solid knowledge of quantity-number concept, first computation skills and (4) Basic skills up to 1000, computation, understanding the base-ten system. Furthermore, their results show that prior knowledge in math seems to be the most important predictor for mathematical learning – more important than IQ.

Taken together, there is evidence that the mathematical development of students with LD follows the same sequence as in typically developing students – but delayed and perhaps limited. Thus, the development of early mathematical competencies of students with LD can be explained adequately by the so-called developmental approach (Kuhl et al., 2012; for the developmental approach, see

Burack et al., 1998; Zigler, 1982; Zigler & Hodapp, 1986). This leads to the idea that students with LD can be provided with the same interventions as all other students with mathematical difficulties.

Fostering mathematical competencies in students with LD

Based on their findings, Schnepel et al. (2020) conclude that interventions with a strong focus on arithmetic are not useful for students with LD. It seems to be important – as it is for typically developing students – first to acquire early mathematical competencies (e.g., relational understanding of numbers). However, previous literature reviews on teaching mathematics to students with LD have shown that most intervention studies focus on addition and measurement skills (including money) (Browder et al., 2008; Cannella-Malone et al., 2021). Only a few intervention studies aim to improve early mathematical competencies of students with LD.

For example, Kuhl et al. (2012) evaluate a quantity-number competencies training in students with LD respectively 'intellectual disabilities' and show positive effects. Kuhl et al. (2012) adapted a training designed for typically developing preschool children (Ennemoser et al., 2017; Sinner & Kuhl, 2010) for their study. This training is highly structured, uses direct instruction and includes many tasks on a concrete activity level. Acting with concrete materials is considered very important for comprehending mathematics and is a part of proven didactic principles, e.g. the EIS Principle (enactive-iconic-symbolic) by Bruner (1966). According to Kuhl et al. (2012), the effect comes mainly from improvements in understanding the linkage between quantities and number words. This is an important finding, representing a key milestone in mathematical development. Lanfranchi et al. (2015) have studied the effectiveness of numerical skill training in students with down syndrome. The intervention addresses the reading and writing of numbers up to 19, flexible counting up to 10, precise understanding of quantities up to 10, and solving simple addition and subtraction tasks. After training, the intervention group performed better in numerical tests.

Schnepel and Aunio (2022) examined the characteristics of effective math interventions for students with LD and showed systematic and explicit instruction as effective instructional approaches. "Successful interventions are generally conducted in one-to-one or small group settings with an instructor who adapts the lessons to the student's achievement level by providing prompts, feedback, and repetitions" (Schnepel & Aunio, 2022, p. 672). It is particularly useful if the interventions occur in at least two weekly sessions and employ manipulatives, visual representations and graphic organizers (Schnepel & Aunio, 2022). Most of the studies were published several years ago. So, there is a great need for evidence-based interventions and studies with students with LD.

Working memory sensitive math intervention – for students with LD?

Despite a small number of studies, we have shown that there is some evidence on how an effective intervention for students with LD should be designed. For many students with LD, developing basic numerical skills is appropriate. According to Lanfranchi et al. (2015), low executive functions are one reason for problems in mathematical learning. Attention and working memory skills are needed, as they are important learning requirements (Pressley et al., 1989) and should be considered when fostering students with LD.

Working Memory

Based on a common model provided by Baddeley (Baddeley, 1986, 1996, 2000), working memory (WM) is defined as a mental system that is responsible for the processing and short-term storage of information (the short-term memorizing of images, words or movements). In Baddeley's hierarchical model, WM consists of three subsystems: *Central executive, phonological loop* and *visuospatial sketchpad* (Baddeley, 2012). The central executive controls and regulates the cognitive processes occurring in the two limited-capacity components, coordinating several tasks (Baddeley, 1996). The phonological loop stores auditory or acoustic information for a limited time; for example, it is necessary when we are asked to memorize a telephone number. The visuospatial sketchpad is the counterpart to the phonological loop for visual and spatial information (Baddeley, 2012). Academic learning is about retaining information and connecting it to existing knowledge, so WM is an important domain-general learning requirement (Pressley et al., 1989).

WM in individuals with LD

WM plays a crucial role in every mental task and mathematical learning. This individual learning requirement is particularly weak in individuals with LD (Henry, 2001; Pickering & Gathercole, 2004; Schuchardt et al., 2010; van der Molen et al., 2007). Even findings suggest that the weaker the intelligence, the weaker the WM (Schuchardt et al., 2010). Some studies report the particular importance of the central executive for number skills and arithmetic reasoning in students with LD (Henry & McLean, 2002; Henry & Winfield, 2010). The phonological loop has a lesser impact (Henry & McLean, 2002). Therefore, Henry, and Winfield (2010) recommend reducing the central executive load to support the mathematical learning of students with LD.

We would like to note that it is difficult to interpret the picture that emerges from empirical studies of WM functioning in individuals with LD because the samples examined are as diverse as the WM tests used. Considering all limitations, the findings indicate a relative impairment within the phonological loop, meaning the performance of the phonological loop does not correspond to the functional capacity that would be expected on the basis of mental age (Henry, 2012; Lifshitz et al., 2016). For the central executive, on the other hand, the majority of studies suggest that performance appears to correspond to mental age (Kehl & Scholz, 2021). Regarding the visuospatial sketchpad, some studies show relative strength (Henry & MacLean, 2002; Rosenquist et al., 2003), while others argue that the performance corresponds to the mental age at least (Kehl & Scholz, 2021).

Cognitive Load during learning

Consequently, special attention to weak WM functioning may be appropriate in fostering mathematical competencies in students with LD. However, a look at school practice reveals that tasks in textbooks and intervention programs often place a high load on WM.

For a long time, empirical research has been concerned with this cognitive load during learning, so several theoretical models are available by now. A significant amount of research takes place within the framework of the *Cognitive Load Theory* (CLT, Sweller, 1988; Sweller et al., 1998; overview of the development: Moreno & Park, 2010). The key assumption of CLT is that only a limited amount of cognitive resources can be used for problem-solving and learning (Sweller, 1988). The cognitive load imposed on a person by a particular task can be an important factor in impairing learning (Sweller, 1988). There are three types of cognitive load: *intrinsic cognitive load, extraneous cognitive load* and *germane cognitive load* (Sweller et al., 1998). Intrinsic cognitive load arises from the subject matter itself. It results from the difficulty and complexity of the subject matter. *Extraneous cognitive load* arises from the task design. For example, task-irrelevant information increases extrinsic load (e.g. seductive details, Harp & Mayer, 1997). The g*ermane cognitive load* arises from the demands of the learning process (Sweller et al., 1998). During this process, a range of information must be combined, which requires the information to be maintained and processed in the WM. Having as many resources as possible for this process is beneficial.

The authors of CLT derive principles for the design of learning materials. To use limited WM resources efficiently, the learning material should, for example, not contain unnecessary format switches and irrelevant information. Based on the CLT, principles for designing learning materials and settings have already been formulated (e.g. Gathercole & Alloway, 2008; Krajewski & Ennemoser, 2010; Wiley et al., 2014). However, in Germany, no compact and evidence-based math intervention programs meet these requirements.

Working memory sensitive math intervention

Therefore, Schulze (2020) developed and evaluated the so-called *working memory (WM) sensitive math intervention.* The intervention aims to improve early mathematical competencies and is designed according to the assumptions and findings of the CLT. The program has already been evaluated positively in children with mathematical difficulties (Schulze et al., 2020a; Schulze et al., 2020b). Generally, it is a small-step and structured approach, with few central materials, in order not to put an unnecessary load on the WM. The authors ensured there were no unnecessary changes in task formats and no irrelevant but interesting stimuli. Moreover, they use familiar and meaningful content, reduce the amount of material and emphasize repetitive practice. For example, these principles can be found in Gathercole and Alloway (2008).

Aim and research question

The studies by Lanfranchi et al. (2015) and Kuhl et al. (2012) show that students with LD can improve their basic numerical skills. However, there are hardly any intervention studies with students with LD. Many studies focused on basic reading skills (Cannella-Malone et al., 2021). Schulze's (2020) WM sensitive math intervention aims to improve early mathematical competencies while accounting for weak cognitive resources through a reduced design. The approach was developed to foster students with persistent mathematical learning difficulties. As students with LD tend to learn slower, remain at lower competency levels and show weaker cognitive abilities, WM sensitive math intervention could be an option for individuals with LD as well. Our study addresses the following research question: To what extent does the WM sensitive math intervention affect the early mathematical competencies of students with LD?

We expected a gradual improvement in level and slope during the intervention. Replication of positive effects in a new sample also helps to validate the WM sensitive approach further.

Methods

Consent Procedures

Only students who had the written consent of their parents took part in the study. Parents were informed about the project's aims and received information about the data collection type, security, and processing procedures.

Participants

The present study occurred in five special needs education schools in North Rhine-Westphalia, Germany. Ten students (table 1) from the lower grades – between the third and fifth year of school attendance – participated in this study. We used a German standardized quantity-number competencies test to measure students' mathematical competencies before the intervention (*MBK 1+* by Ennemoser et al., 2017). All students showed a T-value ≤ 32.

According to the ICD-10 categories, intelligence impairment was classified as mild to moderate in all participants. All students visit a school for special needs education. Two students (Lara and Jana) had additional special educational needs in the sensory and physical areas (in Germany, *Förderschwerpunkt körperliche und motorische Entwicklung*). Jana has a developmental language disorder as well. For communication, she uses a talker. Matheo was diagnosed with early childhood autism.

Most students showed below-average performance in most of the WM skills measured (table 2). Here, we used the age-specific norm values. However, in the object span, which is a test for central executive, 6 out of 10 students were even on average (Mia, Marcel, Lara, Jana, Anne, Lisa). In the two other tests for central executive function, all children except Lisa were below the average. Lisa showed the strongest WM performance of all participants. She was in the average range in all tests except counting span and even showed above-average performance in the visuospatial sketchpad tasks. Another eye-catching result is the relatively good performance of Lara, Jana, Anne, Paul, Lisa, and Anna in the nonword repetition task. However, they (except Lisa) were below average in the second phonological loop task (digit span).

Table 1. ***Participant Overview***

			MBK 1+ Raw Score		MBK 1+ T-value			
	Sex	**Age**	**Pre**	**Post**	**Pre**	**Post**	***nA***	***nB***
Mia	f	9	21.50	32.00	17	34	6	12
Marcel	m	8	28.50	31.50	28	33	5	12
Lara	f	8	23.00	31.50	20	33	7	12
Jana	f	7	17.50	31.50	11	33	5	12
Anne	f	8	27.50	38.50	27	44	7	14
Paul	m	8	26.00	39.50	25	46	5	12
Lisa	f	8	20.50	22.50	16	19	4	12
Anna	f	9	31.00	41.50	32	49	4	13
Matheo	m	10	6.00	17.50	<7	11	7	10
Robin	m	10	16.00	24.50	9	22	5	12

Note. f = female, m = male; MBK 1+ = German standardized quantity-number competencies test; *nA* = Number of observations in phase A; *nB* = Number of observations in phase B

Design and procedure

We used a series of AB single-case designs to replicate the previous findings. Thereby, different persons were observed at different times, also labelled as *non-concurrent multiple baseline across-individuals design* (Watson & Workman, 1981). The AB-plan consists of a baseline phase (A-phase, without intervention) which is immediately followed by an intervention phase (B-phase, with WM sensitive math intervention) (Kazdin, 1993). In the B-phase, students participated in 10 to 14 30-minute intervention sessions, which took place in a 1-to-1 setting. Every student worked with the same instructor from our team for the entire study. At the end of each baseline or intervention session, mathematical competencies were measured with short tests which lasted a maximum of 20 minutes. The A-phase had a minimum of four measurements ($M = 5.5$, $SD = 1.18$). To analyze the effect of the intervention, an intra-individual comparison of the A and B phases is used (Kazdin, 1993).

To ensure treatment fidelity, the instructors participated in three 1.5-hour training sessions in which they were taught the key principles of the intervention. The training topics included the development of early mathematical skills, counting and relational number sense, typical difficulties/mistakes, WM and mathematical learning, and using different representation levels (enactive-iconic-symbolic). During the entire intervention, regular meetings were held between all instructors involved. It was possible to adapt tasks, e.g., to choose a smaller number space.

Table 2. ***Descriptive Statistics for Working Memory***

	Phonological loop				**Visuospatial sketchpad**		**Central Executive**							
	digit span		nonword repetition		matrix span		corsi block span		backward digit		counting span		object span	
	rw	T	rw	T	rw	T	rw	T	rw	T	rw	T	rw	T
Mia	2.00	29	--	--	2.63	29	2.13	29	1.50	29	1.75	29	2.50	42
Marcel	1.88	29	--	--	2.75	37	3.25	42	1.25	29	1.13	29	2.13	40
Lara	3.13	38	17.00	55	3.13	42	1.63	29	1.00	29	1.38	30	2.25	42
Jana	2.25	29	13.00	48	1.75	31	1.38	29	1.13	29	1.25	29	2.00	42
Anne	2.38	30	20.00	64	2.50	34	2.13	29	1.88	33	1.88	38	2.13	40
Paul	3.00	36	15.00	51	3.38	44	1.63	29	1.88	33	1.88	38	1.78	33
Lisa	3.25	40	13.00	46	5.38	58	4.50	59	2.75	46	1.75	36	2.25	42
Anna	2.88	30	13.00	42	2.88	34	3.63	42	2.00	29	2.00	35	1.00	29
Matheo	1.25	29	4.00	32	1.25	29	1.13	29	1.00	29	1.00	29	1.00	29
Robin	2.13	29	7.00	38	2.38	29	2.25	29	1.75	29	1.50	29	1.25	29

Note. rw = raw score, T = T-Scores

Intervention

The intervention sessions were designed based on an unpublished manual and the research subject in Schulze et al. (2020b). The manual consists of different modules and blocks. For our study, we used module *numbers up to 20* (module 1) and *number bindings up to 10* (module 2). Module 1 aims to build a deep understanding of numbers up to 20, and it is structured over three blocks (number word sequence up to 20, numbers as quantities, quasi-simultaneous representation of quantities). Module 2 aims to develop a relational understanding of numbers, especially in the automation of number bonds. Finally, the students understand that part-whole relationships between quantities can be represented with precise number words (part-whole number bonds, e. g. split 10 into 6 and 4). They can also describe exact differences between numbers (e.g. the difference between 5 and 3 is 2). Module 2 is structured over three blocks (number bonds of 5, number bonds of 10, number bonds of all numbers up to 10). In addition, the number bonds are developed at different representation levels (enactive, iconic, symbolic). The twenty frame with small plates (figure 1) serves as the central representation tool. It is divided into quadrants with engraved lines through the middle, which helps to see small plates as groups of five.

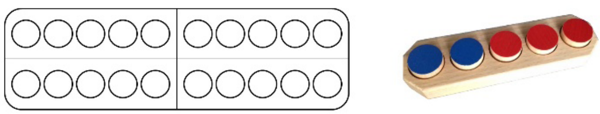

Figure 1. **Twenty Frame With Small Plates**

In turn, each block consists of various tasks and exercises. So, first of all, students need to acquire the exact number word sequence (module 1, block 1). This includes, for example, the number-word sequence forwards and backwards, knowing about predecessors and successors and counting in steps. As stated in the previous work, this 'requires the repetition of single number words but also depends on updating the relevant segment of the number word sequence in working memory for the correct reproduction' (Schulze et al., 2020b, p. 2020). This illustrates the importance of not overloading the WM with irrelevant stimuli during learning. The low-impact design is a main feature of the *WM sensitive math intervention* (see section 1.4).

The second block of the first module (*numbers as quantities*) focuses on developing the quantity-number concept. One goal to reduce the WM load is to build mental images of the twenty frame. These mental images can make it easier to calculate and build math strategies. For example, the students are asked to remember the number of structured small plates. The task is explicitly to memorize the structured small plates so that the students can use their free WM capacities for math learning. This is just one example of the explicit encouragement to use the WM in learning, which is a key principle of the intervention.

Dependent variables and measurement

Quantity-number competencies

Based on the developmental model described above, quantity-number competencies (QNC) at Levels I, II and III were recorded by a standardized German test for assessing early mathematical competencies, the *MBK 1+* (Ennemoser et al., 2017). The test can be used 6 weeks after school entry but is also for older children with special educational needs. The test's quality criteria have been tested by several studies, where it was shown that the retest reliability is satisfied and internal consistencies are good. As in Schulze et al. (2020b), we used the test for an initial assessment of mathematical competencies and for a second time after the B-phase.

Number Line and Relational understanding of numbers

As the present work is a conceptual replication, we have also used Schulze and Kuhl's (2020a, 2020b) number line and number bonds tasks to study the development of early mathematical competencies across the phases. The number line task measures the understanding of the exact number word sequence. The participants are asked to fill in missing numbers on a number line (0 to 10 and 10 to 20). As a dependent variable, we measured the number of errors (out of 11 tasks).

The number bonds task measures the understanding and automation of relations between numbers by using number bonds in the form of the so-called *pyramid notation* (Schulze et al., 2020b). In this task, a number is divided into two parts (e.g. 5 in 3 and 2), with one part missing in the illustration, which has to be added by the children (5 – 3 – ?). To eliminate the need for operation signs (+ and –), the initial number stands at the top and the two parts below the initial number, similar to the format of the number houses. The test consists of two levels, which we have combined in the following so that all bonds of all numbers up to 10 are tested. The number bonds task is a pure symbol level task, but it is possible to do the test with material if it is too difficult for the students. We measured the number of errors (out of 16 tasks) as the dependent variable.

Working memory

According to the model of Baddeley (1986), we assessed WM using the *Working Memory Test Battery for Children Aged Five to Twelve Years* (AGTB 5–12; Hasselhorn et al., 2012). The AGTB is a computer-based and adaptive German test battery with good results for test quality. For test economic reasons, we did not use all the subtests.

We used the digit span to measure the phonological loop, where sequences of two to eight digits are presented acoustically. These have to be reproduced by the participants immediately after the presentation. As a further measure, we used a nonword repetition task. Here, tri- to pentasyllabic nonwords must be repeated immediately after acoustical presentation.

To measure the visuospatial sketchpad, we used the corsi block span and the matrix span. In the corsi block span, the students are asked to remember a sequence of two to eight smileys (the impression is that the smiley moves from one square to another). In the matrix span, students are required to remember a static pattern, so the task operationalizes the storage capacity of the static-visual cache.

Three further tests were used to measure the central executive: *backward digit span*, *counting span* and *object span.* These tasks require not only the storage of information but also the simultaneous processing of information. Similar to the forward digit span, a digit sequence is presented acoustically and has to be reproduced immediately but in the reverse order. In the counting span, a picture with squares and one to nine circles is presented on a screen. The participants have to count the circles. The subjects receive a sequence of two to seven of these pictures, and the number of circles has to be reproduced verbally in the same order. In the object span, subjects are presented with a sequence of two to seven objects. For each object, they have to say if it is edible or not. Afterwards, the participant has to reproduce the objects verbally in the presented order.

Data analysis

The measurements across the baseline (nA ≥ 4) and intervention phase (nB ≥ 10) resulted in 14–21 data points per student (table 1). For data analysis, the R package SCAN by Wilbert and Lüke (2021) was used. In addition to the descriptive analysis of the graphed data, we calculated different overlap and correlation-based effect sizes: the *percentage of all nonoverlapping data* (PAND; Parker et al., 2007), the *standardized mean difference* (SMD; Glass, 1976) and the baseline corrected Tau (Tarlow, 2017), which conceptualizes the homogeneity of phases as effect size after correcting for monotonic baseline trends using Theil-Sen regression. Additionally, a piecewise regression analysis across all cases (level 2) was conducted.

Results

We used two tests to measure the development of basic mathematical skills: The number bond test and the number line test. As the students had different learning starting points, the individual intervention was adapted to their background. This was possible due to the modular intervention. But, that has also led to the result that the number bond test was still too difficult for some students in the B-phase (Paul, Matheo, Robin); there is no effect at all. We reported the results from the number line test for these students, which was too easy for the rest. So, the test presented in Table 3 corresponds to the zone of proximal development.

Most students displayed increased problem-solving accuracy from the baseline condition (figure 2).

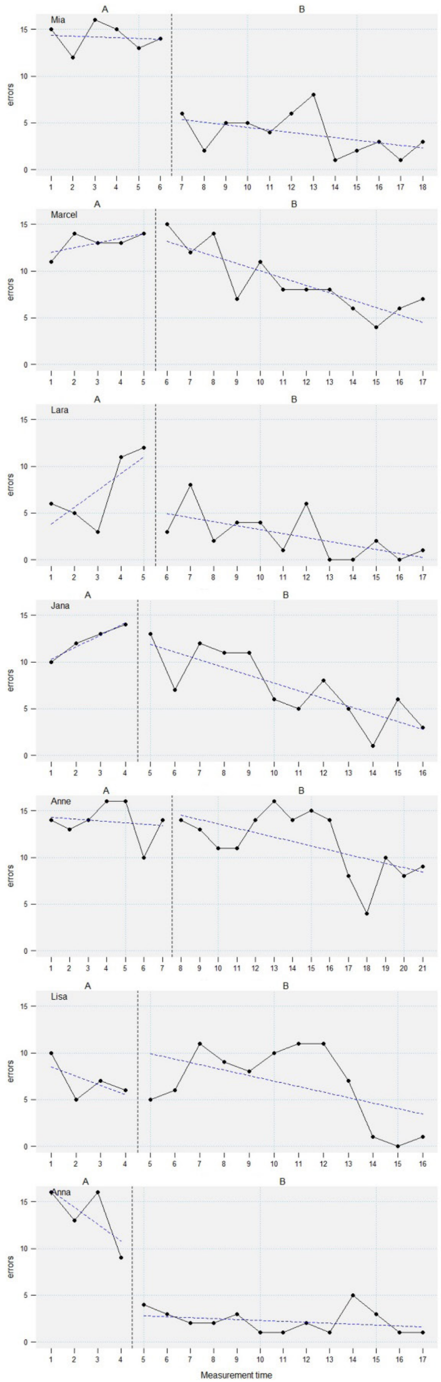

Figure 2. ***Dependent Variable in Phases A and B for Each Participant***

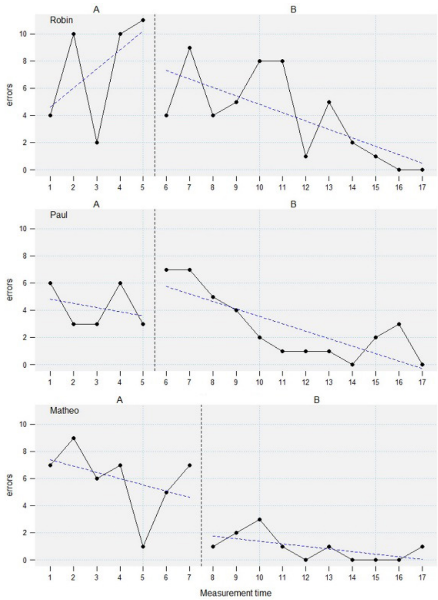

Figure 2 **continued. Dependent Variable in Phases A and B for each participant**

As seen in Table 3, only Lisa shows no change in her error rate agreeable to the phase changes. For Paul, we see a very small change; whether this is due to the phase change is questionable as well. The remaining majority of the students showed small (e.g., Anne) to large reductions in their error rates. The majority of them reduced their average error rate in the intervention phase (number bonds: M_B-M_A: M = -5.46, Min–Max = -0.33 – -11.27; number line: M_B-M_A: M = -3.34, Min–Max = -1.45 – -5.10). The trend towards error reduction remained or even improved (*number bonds:* T_B-T_A: M = -0.58, Min–Max = 1.70 – 2.22; *number line:* T_B-T_A: M = -0.66, Min–Max = -0.25 – -2.02). The error reduction in the number bonds test is more distinct than in the number line test. Except for Lisa, the SMDs also show moderate to strong intervention effects.

The PAND – whose values range between 50 and 100 – suggests a strong intervention effect in the cases of Mia and Anna and a moderate effect in the cases of Marcel, Lara, Jana, Matheo and Robin. According to the PAND, there is no effect for Paul and Lisa.

The Tau value is interpreted as a rank correlation coefficient. Except for Paul and Lisa, it indicates strong (for Mia, Lara, Anna, Matheo) and moderate (for Marcel, Jana, Anne, and Robin) intervention effects.

Table 3. ***Descriptive Statistics and Effect Sizes for Number Bonds (Errors) and Number Line (Errors)***

		A			B			A vs. B				
No	name	***M*** **(*SD*)**	***Md*** **(*MAD*)**	**Trend**	***M*** **(*SD*)**	***Md*** **(*MAD*)**	Trend	M_B-M_A	T_B-T_A	***SMD***	***PAND***	***Tau***
number bonds (errors)												
1	Mia	14.17 (1.47)	14.50 (1.48)	-0.09	3.83 (2.21)	3.50 (2.22)	-0.27	-10.33	-0.19	-7.02	100	-0.70
2	Marcel	13.00 (1.23)	13.00 (1.48)	0.50	8.83 (3.41)	8.00 (2.97)	-0.79	-4.17	-1.29	-3.40	76	-0.45
3	Lara	7.40 (3.91)	6.00 (4.45)	1.80	2.58 (2.54)	2.00 (2.97)	-0.42	-4.82	-2.22	-1.23	76	-0.50
4	Jana	12.25 (1.71)	12.50 (1.48)	1.30	7.33 (3.75)	6.50 (3.71)	-0.83	-4.92	-2.13	-2.88	88	-0.48
5	Anne	13.86 (2.04)	14.00 (1.48)	-0.14	11.50 (2.04)	12.00 (2.97)	-0.47	-2.36	-0.33	-1.16	81	-0.30
7	Lisa	7.00 (2.16)	6.50 (2.16)	-1.00	6.67 (4.12)	7.50 (4.45)	-0.59	-0.33	0.41	-0.15	62	0.05
8	Anna	13.50 (3.32)	14.50 (2.22)	-1.80	2.23 (1.30)	2.00 (1.48)	-0.10	-11.27	1.70	-3.40	100	-0.66
number line (errors)												
6	Paul	4.20 (1.64)	3.00 (0.00)	-0.30	2.75 (2.50)	2.00 (2.23)	-0.55	-1.45	-0.25	-0.88	65	-0.29
9	Matheo	6.00 (2.52)	7.00 (1.48)	-0.46	0.90 (0.99)	1.00 (1.48)	-0.19	-5.10	0.28	-2.03	88	-0.69
10	Robin	7.40 (4.10)	10.00 (1.48)	1.40	3.92 (3.20)	4.00 (1.48)	-0.62	-3.48	-2.02	-0.85	76	-0.38

Table 4 summarizes the results of the piecewise regression analysis across the cases (level 2). In the number bond task, there is a highly significant intercept effect. A highly significant level effect indicates a direct improvement from the start of the intervention. Furthermore, there is a highly significant slope effect concerning the comparison between the two phases. In summary, the participants decreased their errors in the test by 0.775 per intervention session. However, there is no trend effect.

For the number line task, we also see a highly significant intercept effect across all participants. However, neither the trend, level, nor slope effects are significant (tab. 4).

Table 4. ***Piecewise Regression Model for Number Bonds (Errors) and Number Line (Errors) (Level 2 Analysis)***

	B	*SE*	*t*	*p*
	number bonds (errors)			
Intercept	10.683	1.385	7.713	0.00**
Trend	0.303	0.305	0.994	0.32
Level	-3.655	1.221	-2.993	0.00**
Slope	-0.775	0.319	-2.428	0.01**
	number line (errors)			
Intercept	7.157	1.237	5.788	0.00**
Trend	-0.356	0.302	-1.182	0.24
Level	0.214	1.394	0.154	0.88
Slope	-0.111	0.320	-0.347	0.73

*significant at the .05 level, **significant at the .01 level

Discussion

Main findings

In the present study, we investigated the extent to which the WM sensitive math intervention affects the early mathematical competencies of students with LD? We expected a gradual improvement in level as well as slope during the intervention. Our results indicate that the intervention can improve the early mathematical competencies of students with LD. Therefore, our findings are in accordance with the results of a systematic review by Cannella-Malone et al. (2021), which showed that across studies, interventions enabled students with LD to make progress in academic skills across different content areas. Our findings extend previous results in so far as our study focuses on fostering early mathematical competencies. To date, there have only been a few studies in this area, and most of the math interventions relate to the field of addition (Cannella-Malone et al., 2021).

Nevertheless, not all students reduced their errors in both tests; for some, the number bond test was the appropriate measure (Mia, Marcel, Lara, Jana, Anne, Lisa, Anna). For the others, the number line test was appropriate (Paul, Matheo, Robin). Overall, most participants display improvements in measured performance throughout the study. The non-overlap indices and the regression analysis support the descriptive analysis, showing that the intervention positively affected the dependent variables. In the visual analysis, however, we observe outliers in some data graphs. We can see this, for example, in Mia, Lara, Anne, and Anna (figure 2). Robin's data points are also highly variable in the first half of the B-phase. This result is not unusual in our target group, as learning generally takes longer (Brankaer et al., 2011), and what has been learned cannot be recalled with certainty.

However, our results do not indicate any learning developments that we can attribute to the intervention for Paul and Lisa. As in Schulze et al. (2020b), some participants have not responded to the intervention as expected. At first glance, the result in Lisa's case is surprising. Lisa did not have the weakest math skills before the study, compared to her peers, measured using the MBK 1+. Moreover, she has the strongest WM performance compared to her peers. Schulze et al. (2020b) found an interesting pattern regarding WM performance in some nonresponders: Two students had a very poor performance in the so-called Corsi block backward task. The Corsi block backwards task requires the combination of central executive and dynamic visuospatial functions. We can't say whether Lisa – and Paul as well – have difficulties with these special requirements despite her good WM performance because we used other WM tests. Perhaps a particular difficulty lies here, which we did not clarify in our study.

On the other hand, Paul is also well below average in the forward Corsi block test, whereas he is in the average range in the static matrix span task. Nevertheless, it might be that Lisa's relatively weak results are not due to the WM, in particular, and that another variable we did not capture impacted performance (e.g., attention and focus on the learning task). In any case, we suspect that Lisa and Paul would have needed many more intervention sessions. For example, Brankaer et al. (2011) showed that students with LD need more time to acquire the linkage of numbers to quantities and the numerical magnitude representation. However, in our study, increasing the sessions further for organizational reasons was not possible.

Moreover, not all participants for which we conclude effects show the same pattern across the two phases. As such, Mia, Lara, Anna Matheo, and Robin show improvement relatively immediately after entering the B-phase. Even if their performance varies, they gradually improve from the intervention phase. In the case of Marcel and Jana, there is only a gradual improvement after about half of the intervention phase. And for Anne, we first see an increase in performance towards the end of the intervention. Nevertheless, this result is plausible, as our sample is very heterogeneous, and not all students with LD can acquire the same level of mathematical competencies (Browder et al., 2008).

Another interesting finding, also shown by Schulze et al. (2020b), is the improvement in early mathematical skills measured by the MBK 1+. All participants improved, most of them even strongly (MBK 1+ Pre: $M = 22.39$; MBK 1+ Post: $M = 31.05$). Just as Schulze et al. (2020b) have already said, 'Unfortunately, the retest reliability of the test varies between $r = .67$ and $r = .77$; we must consider the possibility that this is an effect of retesting' (p. 233). Nevertheless, we consider our findings to be encouraging. Our sample is very heterogeneous, and some students have multiple special needs areas. For this reason, the results show that the WM sensitive approach is suitable for diverse learning backgrounds.

Limitations

Despite the encouraging results, some limitations should be mentioned. First, we cannot say whether the positive learning development is also stable. It may be that the students need ongoing intensive learning support because of the nature of the intervention. Because of the study's context, we could not extend the intervention phase, so we can only speculate whether more intervention sessions would have been useful for nonresponders like Lisa and Paul. In future studies, introducing follow-up testing might be the best option, e.g. 1 month later.

Second, we did not systematically capture attention, motivation and language proficiency. For attention and motivation, we have only the reports and observations of the instructors.

Finally, as in most of the studies (Canella-Malone et al., 2021), our sample consists of students with mild to moderate intelligence impairment. Thus, studies investigating the efficacy in people with more significant impairments are still outstanding.

Conclusions

According to Schnepel et al. (2020), we assume that mathematics instruction for students with LD has to be very tailored and adaptive because the WM sensitive math interventions by Schulze (2020) meet these characteristics, and our study provides evidence for the effectiveness of this approach in students with LD.

As we were able to replicate the previous results (Schulze et al., 2020a; Schulze et al., 2020b) in a sample of individuals with ID, our results support the hypothesis that the mathematical development of students with LD is similar to typical development, but delayed and slower (Baroody, 1999; Bashash et al., 2003).

It is also particularly positive that the test instructors have not attended any extensive training courses and can work well with the manual. This is an important aspect for the feasibility of the concept. However, the implementation should be investigated in future studies. To sum up, our findings provide further evidence for the effectiveness of the WM sensitive math intervention and its practical relevance. We want to emphasize the importance of teaching early mathematical skills (such as relational understanding of numbers) to students with LD. Our results suggest that the WM sensitive math intervention fits this purpose.

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