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The Effects of a Computer-Based Mathematics Intervention in Primary School Students with and Without Emotional and Behavioral Difficulties

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Abstract

Mathematics difficulties (MD) affect about 20% of the students in German schools. Almost half of them also exhibit emotional and behavioral difficulties (EBD). While a growing number of mathematics interventions target children with MD separately, there is a lack of evidence for the effectiveness of these interventions for children with combined MD and EBD. This study aims to investigate the differential effects of an evidence-based mathematics intervention on children with and without EBD.

This single-case study examined 11 children with internalizing and externalizing EBDs from grades 3 and 4 using a staggered AB-Design. A computer-based mathematics intervention was provided for 5 weeks, during which the mathematical performance of the students was measured using a learning progress assessment in A- and B-phases. Data were analyzed using (a) overlap indices, (b) piecewise linear regression (PLM) models for each student, and (c) a multilevel PLM across all children. The results suggest different effectiveness for children with and without EBD, indicating a small direct influence of the severity of the EBD. Thus, the effectiveness of mathematics interventions might not be generalizable for children with combined EBD and MD. Further research is necessary to better understand the differential effectiveness of mathematics interventions for these children.

Keywords:

Mathematics Difficulties; Single Case Study; Emotional and Behavioral Difficulties; Mathematics Intervention;

Introduction

Several studies have shown that about 20% of students in German schools have severe difficulties with learning mathematics (OECD, 2019; Frey et al., 2010). Typically, children with mathematics difficulties (MD) struggle with the basic operations (Kuhn, 2015), place value understanding (Gebhart et al., 2012; Moeller & Lambert, 2019), and number sense (Kuhn, 2015). This 20% value has remained stable across the recent twenty years in grades 3 to 9. It has to be stressed that the empirically found prevalence is substantially bigger than the expected prevalence based on the definition of developmental dyscalculia (DD) as defined in the ICD-11 (WHO, 2022).This means that there is a large achievement gap and that the actual percentage of students with low mathematical skills is likely to be higher than the ICD-11 definition allows (Ehlert et al., 2012; Schulte-Körne, 2021) which underlines the need for school-based, non-therapeutic interventions.

About half of the German students with MD also exhibit emotional and behavioral difficulties (EBD) in at least one domain (Visser et al., 2020). EBD can basically be differentiated into internalizing (e.g., depression) and externalizing (e.g., attention-deficit/hyperactivity disorder; ADHD) disorders (Achenbach & Edelbrock, 1978). In a synthesis of epidemiological studies conducted by Visser et al. (2020), about 30% of students with MD even exhibited EBD in more than one domain. Students with MD had an especially high vulnerability for ADHD (odds-ratio=3.7), depression (3.25), and anxiety disorder (2.26) compared to students without any learning difficulty. Against the background of the reported prevalence rates, one out of ten students in Germany shows comorbid MD and EBD. Given a typical German class with nearly 30 students, there are statistically about three students with comorbid MD and EBD in every class. Thus, one could conclude that EBDs are typical comorbid disorders for students with MD. Furthermore, math growth trajectories of students with emotional difficulties from ages 7 to 17 were shown to be significantly lower than those of students without comparable problems (Wei et al., 2013). Results from a large-scale study conducted in the US with over 9000 students from kindergarten through grade 8 also indicate that low performance in mathematics (even after statistically controlling for reading proficiency) significantly increases the risk for developing poor interpersonal skills and internalizing behavioral problems (Lin et al., 2013).

At least four hypotheses have been raised to explain the comorbidity of learning and behavior disorders (see Morgan & Sideridis, 2013). First, learning problems might cause behavioral problems because learning problems could lead to disengagement and more disruptive behavior in the classroom. Second, the behavioral problems could interfere with the demands of academic learning situations, such that students' problematic behaviors significantly affect their learning performance. Third, it would be possible that learning and behavioral problems are reciprocally or transactionally related, i.e., learning problems negatively affect behavior, but these behavioral problems in turn negatively affect academic learning. And fourth, the two phenomena may be unrelated and other individual, contextual, or cultural factors could cause the comorbidity of learning and behavioral problems. Regardless of which explanatory model is applied in a specific case, it is important to consider these influencing factors when evaluating and developing evidence-based interventions (Morgan & Sideridis, 2013). Although there are few studies that examine the true underlying causal effects, there is a slight tendency toward viewing behavioral problems in particular as causing learning problems (Kulkarni et al., 2020). For this reason, we focus on these causal hypotheses in this study and further elaborate on related findings for evidence-based practice of comorbid math and behavioral problems.

There is currently a growing number of evidence-based interventions that underpins their positive effect for children with MD (Chodura et al., 2015; Jitendra et al., 2021; Reynvoet et al., 2021; Stevens et al., 2018). Typically, mathematics interventions focus on basic mathematical competencies such as number sense (e.g., subitizing, number line estimation, magnitude comparison), basic operations, or word problems. However, the effectiveness of mathematics interventions in meta-analyses differs substantially. For instance, Chodura et al. (2015) report effect sizes ranging between -2.31 and 5.09, and Jitendra et al. (2018) found effect sizes between −0.92 and 3.04. This highlights the importance of considering differential effectiveness, e.g., for different groups of children with MD. For example, Stevens et al. (2018) found lower average effect sizes for students from secondary schools than Chodura et al. (2015) found for primary school students. This result indicates that younger students with MD may benefit more from mathematics interventions than older students. A possible explanation could be the similarity of the contents between the mathematics interventions and the primary school mathematics curricula.

In recent years, international research on the topic has focused on computer-based interventions for mathematics. With emerging technological possibilities and increasing accessibility even for less privileged children, computer-based interventions promise to play a more and more important role for mathematics intervention in the future (Räsänen et al., 2019). In general, computer-based interventions can successfully support students in learning mathematics (Higgins et al., 2018; Buyn & Juong, 2017; Ran et al., 2021; Räsänen et al., 2009). Focusing on computer-based educational games, Buyn and Juong (2017) found an overall effect size of d=.37 with a range of .01 to 3.17. In another study examining low-performing students in particular, Ran et al. (2021) reported a substantial overall effect size of d=.54 with a range of -1.63 to 2.24. Computer-based interventions were especially effective in primary school, whereas secondary school students benefited less from computer-based interventions. The particular effectiveness in primary school might be the result of the typical contents in computer-based interventions, which are number sense and basic operations (Räsänen et al., 2019).

Recounts of the advantages of computer-based interventions in contrast to traditional approaches often mention the motivational effect of computer-based interventions. However, the empirical basis of this claim is rather tentative, with lower effect sizes for motivation than for mathematics performance (Higgins et al., 2018; Wouters et al., 2013).

In view of the fact that half of the students with MD also have comorbid EBD, this group of students deserves more attention. Peltier et al. (2021) recently presented a meta-analysis of single case studies on mathematics interventions for students with EBD. Of the 19 studies included, the majority (13) had been published before the year 2000. This finding indicates that there is no increase in published intervention studies regarding children with comorbid MD and EBD. In contrast, Reynvoet et al. (2021) found an exponential increase in mathematics interventions studies in general beginning from 2010, showing that while the general interest in mathematics increased drastically, children with EBD did not receive adequate attention in such research.

Peltier et al. (2021) reported positive effects of mathematics interventions for children with comorbid MD and EBD, and investigated intervention, context, and depended variable factors that might influence the effectiveness of interventions. The overall effectiveness of mathematics interventions for students with EBD in terms of Tau-U was 74.4%, which means that nearly three out of four comparisons of measurement points in intervention and baseline phase were improved (Peltier et al., 2021). There were no differences in effectiveness regarding the participants' age and interventionist (e.g., teacher or researcher). No significant differences were found regarding the duration of the intervention. Interventions that were conducted in separate rooms in the schools were significantly more effective than interventions that were conducted in the classroom. Interventions targeting accuracy were significantly more effective than interventions targeting the productivity (number of completed tasks), while the targeted mathematical concept (e.g., fact retrieval) had no impact on the effectiveness.

Peltier et al. (2021) comprehensively reported effectiveness factors regarding context and intervention. Most of their findings are in line with older reviews on children with comorbid MD and EBD (Hodge et al., 2006; Ralson et al., 2013). However, there is a lack of research on the effectiveness of interventions for children with comorbid MD and EBD that focusses on the type and severity of the EBD. Both externalizing and internalizing EBDs can be associated with different typical symptoms, causes, and environmental interactions (e.g., Farmer et al., 2016; Landrum, 2017). Current shifts from a categorical to a dimensional perspective on EBD suggest that it would be advisable to not only include the type, but also the severity (Zimmermann et al., 2019), especially because the dynamic interrelation between both constructs might be causal (e.g., Hinshaw, 1992). For these reasons, the dynamic interactions between learning and behavioral problems should be considered and specifically addressed when evaluating intervention effects (Morgan & Sideridis, 2013). In the following sections, we will describe theory-driven and empirically underpinned explanatory models that explain how the type and severity of one internalizing (math anxiety (MA)) and one externalizing (attention deficit/hyperactivity disorder (ADHD)) EBD might affect mathematical learning. The examples of MA and ADHD were chosen, because there are detailed theories regarding their effects on mathematical learning. In addition, MA and ADHD have substantial comorbidities with MD (Du Paul et al., 2013; Orbach et al., 2019).

Internalizing EBD and Mathematics – Math Anxiety

MA is described as "the feeling of tension and anxiety that interferes with the manipulation of numbers and the solving of mathematical problems in a wide variety of ordinary life and academic situations" (Richardson & Suinn, 1972, p. 551). As MA refers nearly exclusively to arithmetic, everyday situations such as paying the groceries or estimating the time for a bus ride can lead to symptoms that are typical for anxiety disorders. MA symptoms can cover, for example, sweating, nervousness, increased heart rates, and palpitation (perception of the person's own heart beat) (Haase et al., 2019).

MA is associated with lower performance in arithmetic, as shown by a growing body of studies (Namkung et al., 2019; Sorvo et al., 2017; Zhang et al., 2019). Studies report short- and long-term negative effects on mathematics learning outcomes. There are inconsistencies in the literature regarding the question, at what age the association between performance in mathematics and MA emerges. While some studies identified negative effects on mathematics performance in primary school students, other studies did not find a negative association until secondary school (for a more detailed discussion see Orbach et al., 2019). It must be noted that MA does not affect all students negatively. Students with high intelligence seem to be more susceptible to having their mathematics performance inhibited by MA (Ramirez et al., 2016). In addition, many studies report gender differences in MA, indicating that girls are more prone to MA (Haase et al., 2019).

By adapting a common construct from the field of psychotherapy, Orbach et al. (2019) differentiated between state-MA and trait-MA. While state-MA refers to the (more or less uncontrollable) mental and physical reactions in stressful mathematical situations, trait-MA refers to the general self-concept of being math-anxious. This differentiation could explain inconsistencies in MA assessment methods and corresponding prevalence (Orbach et al., 2019). In addition, state-MA and trait-MA might be involved in two different explanations for the negative effect of MA as an internalizing EBD on mathematical learning. Of course, trait-MA and state-MA – and thus the corresponding explanations – do not exclude each other, but can coincide.

First, MA can lead to avoiding situations that entail the need to use mathematics. In school, this mostly refers to mathematics classes. Students with MA that avoid mathematics classes or do not pay attention during class have less opportunities to gain and practice mathematical expertise (Ashcraft & Moore, 2009). As a consequence, students with MA have lower mathematics skills and fail more often in tests. A repeated experience of failure, potentially combined with falling short on teachers' or parents' expectations might even increase MA. As avoidance behavior starts even before entering a mathematical situation, trait-MA appears to be more likely to cause avoidance behavior than state-MA.

Second, stressful situations are likely to draw individuals' attention to the anxiety symptoms. While solving mathematical tasks, students with MA might focus more on their fear and negative thoughts than on processing the tasks. Thus, MA might block working memory resources and paralyze the thoughts of students (Suárez-Pellicioni et al., 2016). Because the working memory impairing effects of MA only occur in mathematical situations, state-MA is more likely to block working memory resources than trait-MA.

Externalizing EBD and Mathematics – ADHD

ADHD is a neurodevelopmental disorder that can be described by three symptoms – attention deficit, impulsivity, and hyperactivity – that affect children's behavior in every-day as well as learning contexts independently from specific situations. As a consequence, children with ADHD symptoms show lower school performance (Arnold et al., 2020). One main cause for ADHD symptoms are lower executive functioning (EF) resources (Willcutt et al., 2005). Executive functions (especially inhibitory control, working memory, and cognitive flexibility) play an important role in school, as they are particularly challenged in numerous demanding situations (e.g., individual periods of quiet work, organization of the work process, examination situations). Among others, EFs are necessary for monitoring complex tasks as well as storing or retrieving information in or from the short-term memory (working memory), flexibly switching between different tasks (shifting), and inhibiting interfering stimuli (inhibition) (Gilmore & Cragg, 2018). EF play a crucial role in children's academic, emotional, and social development; inhibition skills, in particular, are relevant for self-regulation (e.g., in conflict situations) (Bailey & Jones, 2019; Cantor et al., 2019). However, especially in students with ADHD commonly have impaired executive functions (e.g., Barkley, 2015; Pineda-Alhucema et al., 2018). In a conceptual model of the relationship between EF and ADHD, Barkley (1997) shows that problems in inhibition affect working memory, emotional self-regulation, and cognitive flexibility, which in turn can lead to difficulties in behavioral self-regulation and thus ADHD symptom-specific behaviors.

Compared to their non-impaired peers, children with ADHD show lower mathematics performance, especially regarding fact retrieval and calculation (Orbach et al., 2020; Tosto et al., 2015). Against the background of different ADHD subtypes, attention difficulties affect mathematical performance stronger than impulsivity or hyperactivity (Massetti et al., 2008; Tosto et al., 2015). Overall, there are only a few high-quality studies examining the causal relationships between externalizing behavioral problems and learning problems; however, evidence tends to indicate that early externalizing behavior problems causally influences later academic performance (Kulkarni, Sullivan & Kim, 2020). In this context, hyperactive-impulsive behaviors in particular appear to have stronger predictive validity than oppositional-disruptive behaviors (Hand & Lonigan, 2021). Correspondingly, two explanations for lower mathematical performance in children with different ADHD profiles can be postulated.

First, children with attention deficits are prone to missing important information taught in school. Usually, lessons in schools last at least for 45 minutes, which might be longer than some children with ADHD can maintain attention. Over the course of several years in school, the probability of missing important information cumulates and leads to growing delays in mathematical development. This explanation is bolstered by studies showing that inattention is stronger related with low mathematical (and generally academic) performance than other ADHD subtypes (Massetti et al., 2008; Tosto et al., 2015).

Second, some – but not all (Willcutt et al., 2005) – children with ADHD also have low EF resources. The relevance of EF for mathematical performance has been demonstrated in several studies (see Friso-van den Bos et al. (2013) and Peng et al. (2016) for reviews). All three main components of EF are relevant in mathematical contexts: Working memory is particularly involved in retrieving arithmetic facts and monitoring complex calculations; shifting is necessary when different operations are embedded in one task; inhibition is relevant for suppressing solutions to similar tasks (Gilmore & Cragg, 2018).

The given examples for the implications of internalizing and externalizing EBDs for mathematics underpin that the same phenomenon –benefiting less from instruction or cognitive impairments while performing calculations – may be caused by different types of EBDs. As a consequence, internalizing and externalizing EBDs can amplify each other in similar phenomena.

Research Questions

As described above, MD in general and also the comorbidities with EBD in students are very common and particularly challenging in school practice. The development and intercorrelations of the two phenomena are complex, with EBD possibly even causing the development of MD. These mechanisms must be considered when designing and evaluating interventions that can be adaptive and appropriately targeted. So far, however, there are only few studies that address this challenge. Furthermore, the relevance of the type and severity of EBD for mathematical learning raises questions regarding the impact of internalizing and externalizing EBDs on mathematics interventions. Therefore, the current study will investigate the following four research questions:

1. How do mathematical skills develop in students with and without behavioral difficulties in the course of an evidence-based computer-based mathematics intervention?
2. With what pattern (i.e., immediately or continuously after implementation) do potential intervention effects set in?
3. To what extent do developmental trajectories of math skills during intervention differ between students with externalizing, internalizing, and no behavioral disorders?
4. To what extent do the severity of the externalizing and internalizing EBD influence the mathematical skills development during the intervention?

Method

Sample

A total of *N* = 11 students from 3 German primary schools participated in this study. Written consent was obtained from the parents in advance. 5 students were in grade 3 and 6 students were in grade 4. With three exceptions (2 Albanian, 1 Polish), all students spoke German as their first-language. All children showed low performance in a standardized math test (T-score ≤ 43 for all children; T-score < 40 for 8 students). Based on their EBD profile, the students can be categorized as having no or few difficulties (EBD-N, *n* = 4), predominantly internalizing difficulties (EBD-I, *n* = 5), or predominantly externalizing difficulties including attentional difficulties (EBD-E, *n* = 2). Table 1 provides an overview of the participating students including their mathematical performance and EBD profiles.

Instructors

The intervention was conducted by three female university graduates at the end of their bachelor studies. All of them had recently completed a course on intervention strategies for students with learning

Table 1

Overview of the participants

Pseudonym	Age (years; months)	Gender	L1	Grade	Math (T-score)[1]	CBCL	CBCL-Int	CBCL-Ext
EBD-N								
Clara	10;5	female	GER	3	32	12	0	6
Dana	12;0	female	GER	4	41	15	2	1
Emma	11;5	female	GER	4	43	18	3	1
John	11;6	male	GER	3	35	8	0	2
EBD-I								
Aron	10;1	male	GER	4	26	69	21	7
Ben	10;7	male	GER	4	35	47	17	2
Gloria	9;4	female	GER	3	30	37	14	0
Hugo	9;9	male	GER	3	30	39	14	0
Keanu	10;2	male	ALB	3	33	40	14	5
EBD-E								
Fabia	11;10	female	ALB	4	43	39	1	27
Ines	9;1	female	POL	3	39	44	8	13

Note. L1=First language; 1Math scores obtained from HRT 1-4 (Haffner et al., 2005); CBCL= scores from the CBCL (Döpfner et al., 2015); CBCL-Int=subscale "internalizing problems" of the CBCL; CBCL-Ext=subscale "externalizing problems" of the CBCL.

difficulties in mathematics and had also gained teaching experience in internships. They also received additional training on the implementation of all instruments and the intervention itself from scientific staff.

Design

A controlled single-case research design was applied for four reasons: First, this methodological approach allows us to examine the response to an intervention of individual students or smaller groups of students with shared characteristics (Riley-Tilman et al., 2020). Second, single-case research allows to capture important characteristics of individual students that might explain intervention success (Riley-Tilman et al., 2020). Third, the repeated and close-meshed measurements in a baseline and intervention phase allow for a systematic comparison of developmental trajectories without and with intervention, as well as specific patterns of intervention effects, which in turn can be used to develop evidence-based support methods (Huitema & McKean, 2000). Fourth, the approach is highly feasible, especially for studies with small target populations (such as students with special education needs) (Maggin et al., 2018).

This study used a quasi-experimental controlled single case AB-design with multiple baselines across participants. Specifically, this means that several students with different characteristics (in our case, different forms of EBD) participated in the study so that single case trajectories can be compared between baseline rates. The intervention onset was staggered across the individual cases so that potential intervention effects were more likely to be ascribed to the implementation of the intervention. The length of the time series measurement for the baseline phase varied between three and five measurement points across all students. The length of the time series measurement for the intervention phase varied between three and nine measurement points across all students. The different lengths of the A- and B-phases were caused by the school closures during the pandemic, which affected the initial design plans.

Instruments

Math performance: Math performance was assessed with the Heidelberger Rechentest 1-4 (HRT) (Haffner et al., 2005), a standardized math test for German primary school students. The timed test covers the basic operations (addition, subtraction, multiplication, division), complement tasks, and number comparison. The retest reliability of the HRT is sufficient (r_{tt}= .77-.89)

Students' development in math performance was measured by a computer-based progress monitoring Cody-LM (Schwenk et al., 2017) embedded in the intervention program. The Cody-LM covers addition, subtraction, and number ordering tasks in a timed condition. Depending on the reaction time, students gain virtual coins for their correct answers. However, when the students' answers are wrong, coins are withdrawn correspondingly. The psychometric validity of the Cody-LM has been tested empirically and showed good split-half reliability ($r_{split\text{-}half}$ = .87-.93) (Schwenk et al., 2017).

Behavior: Students' emotional and behavioral problems were assessed with the German version of the Child Behavior Checklist – Teacher Report Form (CBCL-TRF) (Döpfner et al., 2015). The CBCL-TRF covers internalizing (anxiety, depression, withdrawal, and somatic complaints), externalizing (breaking rules, aggressive behavior), and attentional problems (inattention, hyperactivity-impulsivity). Students' behavior was assessed using a 3-point Likert scale completed by the classroom teachers. Studies examining the psychometric properties of the German version of the CBCL-TRF suggest good internal consistencies for Externalizing Problems (α = .94 - .96), Internalizing Problems (α = .87), and Attention Problems (α = .93 - .94) (Döpfner et al., 2011; Volpe et al., 2018).

Intervention

Students were trained with the computer-based mathematics intervention Meister Cody (Kasaa Health, 2013). Meister Cody is based on a robust indicators approach: Skills that predict mathematical learning well are trained to provide students with a sound basis for subsequent learning. The robust indicators cover number line estimation, transcoding, fact retrieval, part-whole-tasks, number-set-correspondence, calculations, word problems, and working memory tasks (Kuhn & Holling, 2014). Example screenshots of the intervention formats are shown in Figure 1. After an initial assessment, the training content is individually adapted to the students' mathematical profile. The effectiveness of Meister Cody has been tested in an empirical study (Kuhn & Holling, 2014).

The computer-based intervention was conducted by the instructors on a tablet in a quiet and separate room in school. Training sessions lasted for about 20 minutes each. Due to difficulties in the implementation of the study caused by the COVID-19 pandemic, students only received between 3 and 9 training sessions.

Results

The analysis of the data obtained in the current study was structured into three sections. First, the trajectories of students' mathematical performance were visually analyzed, including descriptive analyses and overlap indices. Second, piecewise regression models were employed for each student individually to test for significant intervention effects. Third, a hierarchical piecewise regression aggregating all students and

Figure 1
Screenshots of the intervention program. Top left: magnitude comparison; Top right: number line estimation; Bottom left: counting; Bottom right: addition.

EBD profile were used to investigate the influence of EBD type and severity. All analyses were conducted using R (R Core Team, 2018) and the package scan (Wilbert & Lüke, 2021).

Visual Analyses and Overlap Indices

Based on the visual analysis and the overlap indices, the intervention had different effects on the different students: While some students benefited well from the training, others showed stagnating or even decreasing performance trajectories. To examine the intervention, we calculated several non-overlap measures. The non-rescaled non-overlap of all pairs (NAP; Parker & Vannest, 2009) is the percentage of all pairwise comparisons across the baseline and intervention phases. According to Parker and Vannest (2009), medium effects are indicated by values of 66% to 92%, and strong effects are indicated by values of 93% to 100%.

The Percentage of All Non-Overlapping Data (PAND) indicates the percentage of data from the baseline and intervention phases that do not overlap. There are no conventions for interpreting the PAND value, but there are certain rules of thumb. For example, a PAND value of 50% or less indicates that the differences between the baseline and intervention phases occurred by chance. A value of 70% or more could indicate a small effect, 80% or more a medium effect, and 90% or more a large effect (Parker et al., 2007).

Percentage Exceeding the Median (PEM; Ma 2006) indicates the percentage of data points from the intervention phase that are above the median of the baseline phase. The PEM can take values between 0 and 100%, with values between 70% and 90% indicating a moderate effect and 90% and above indicating a strong effect (Alresheed et al., 2013).

The Percentage Exceeding the Trend (PET) indicates the percentage of data points from the intervention phase that are above the trend from the baseline phase. It is therefore the trend-based equivalent of the PEM. The PET can take values between 0 and 100%, with values between 70% and 90% indicating a moderate effect and 90% and above indicating a strong effect (Alresheed et al., 2013).

Tau-U analysis allows to examine treatment effects on both between-phase difference and within-phase trend (Parker et al., 2011), and offers at least four different types of Tau-U calculations (Parker et al., 2011). In this study, the Tau-U "non-overlap with phase B trend with baseline trend controlled" (Parker et al., 2011, p. 291) was employed, which is the non-overlap of all pairs between the baseline and intervention phase plus the intervention phase trend minus the baseline phase trend. Although no general recommendation can be made about conventions for interpreting Tau-U values, a value of .20 can be considered as a small change, values from .20 to .60 as moderate changes, values from .60 to .80 as large changes, and values above .80 as large to very large changes (Vannest & Ninci, 2015).

Comparing the trajectories of the three EBD groups, all students with no EBD benefited at least slightly from the intervention (mean Tau-U=.35). In contrast, about half of the students in the EBD-I (mean Tau-U=.16) and EBD-E (mean Tau-U=-.09) groups did not benefit from the intervention at all. However, especially two out of five students from the EBD-I group showed considerable responsivity (Tau-U=.44 and .47, $p < .05$ in both cases). Descriptive statistics and overlap indices of all students are summarized in Table 2.

Besides these differential (average) effects for students with and without EBD, the effects of the intervention are generally low. The training effects are significant in only two cases. The visual analysis of the learning trajectories indicates mostly stable performances in the A- as well as in the B-phases. Moreover, level-related overlap indices such as Percentage Exceeding the Mean (PEM), Non-overlap of All Pairs (NAP), or Percentage of All Non-overlap Data (PAND) are substantially higher than trend-related indices such as Percentage Exceeding the Trend (PET). These findings indicate that predominantly level effects can be assumed, but barely any trend effects: Students might perform better during the intervention, but their development is – at least across the observed time – not accelerated. No to little trend effects of the intervention in all students might also be caused by positive trends in the baseline phase in nine out of eleven cases.

As there are little to no trend effects in the observed B-phases, there is no evidence for continuous intervention effect across time in this study. In contrast, those students who benefited from the intervention immediately showed increased mathematics performance. Only in the EBD-N group did all students show small positive trends in the B phase, which indicates that these students may have also benefited continuously to a small degree.

When investigating the variance in the progression monitoring, students with externalizing EBD in particular showed great variance across time. Compared to students with externalizing EBD, variance was generally lower in the EBD-N and EBD-I group.

Piecewise Regression Models

To investigate the level and slope effects of the intervention in the three EBD groups in more detail, piecewise regression models were run separately for the different groups. Piecewise regression models can bolster assumptions of (a) level effects in terms of an immediate effect of the intervention on mathematical performance and (b) continuous increase in performance over a longer time period. As the visual analysis and the overlap indices indicated that there are little to no trend effects in the B phase, trend effects were excluded from the regression models.

All groups showed higher level parameters than slope parameters. In addition, the regression parameters both for levels and for slopes were bigger in the EBD-I group than in the EBD-E group, and even bigger in the EBD-N group. Especially regarding slopes, regression parameters were close to zero. These findings underpin the results of the visual analyses, which indicated an immediate effect that was strongest in the EBD-N group and weakest in the EBD-E group.

The piecewise regression models employed in this analysis yielded no level or slope effects that were statistically significant. Given the comparably small number of measurement points, we argue that the regression parameters may be of value for practical decision-making in interventions planning, although the hypothesis concerning significant level and slope effects must be rejected. The explained variance supports the notion of small level effects and negligible slope effects in all groups.

Hierarchical Piecewise Regression Models

Finally, a multilevel extension across all cases was calculated with measurements at level 1 nested in subjects at level 2 (Van den Noortgate & Onghena, 2003). In addition to the standard regression model, two interaction effects between intensity of EBD and level and slope were included. This application of regression models allows for inferences about the intervention effects across all students considering the influence of the severity of the specific EBD on the math competence trajectories in the B phase. The overall explained variance of the hierarchical piecewise regression model was R^2=.597. The parameters of the hierarchical piecewise regression model are summarized in Table 4.

The results indicate a significant level effect across all students, meaning that there was an improvement in math skills immediately after the implementation of the intervention. This result is in line with the findings from the previous analyses. None of the other variables had a statistically significant effect. Non-significant effects might be caused by the relatively small number of measurement time points, especially in the B phase (see Table 4), which means that more attention must be paid to the regression coefficients, as these indicate the practical significance of the competence development during the intervention phase. Severity of internalizing EBD was associated with lower intervention effects to a small degree, whereas severity of externalizing – including attentional difficulties – had no considerable effect. In addition, the model shows no substantial interaction effect of level and intensity of EBD.

Figure 2

Trajectories of the mathematical performance of the EBD-N group.

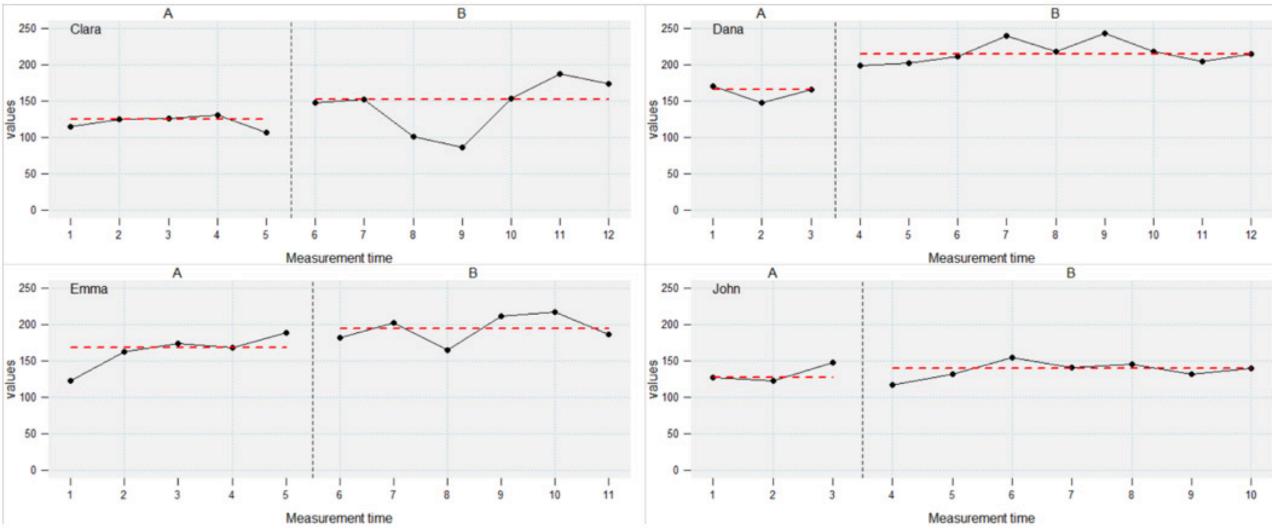

Figure 3

Trajectories of the mathematical performance of the EBD-I group.

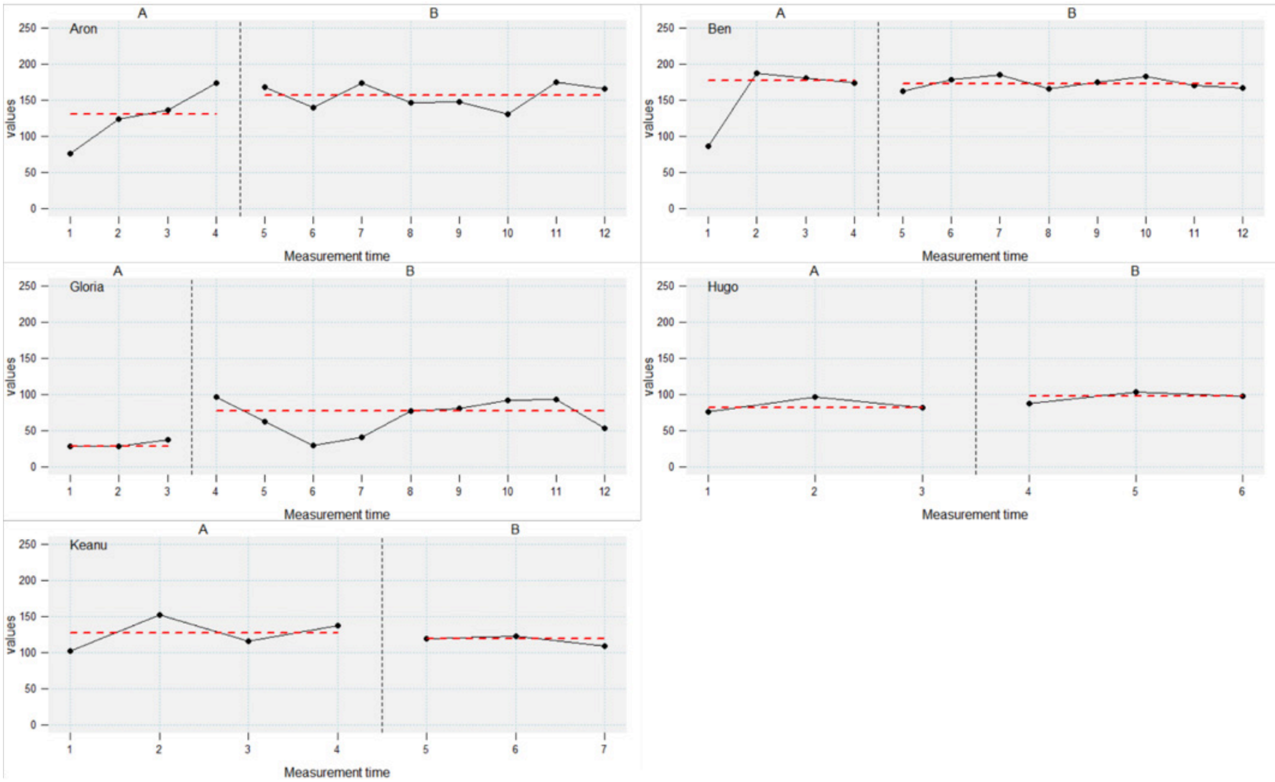

Figure 4

Trajectories of the mathematical performance of the EBD-E group.

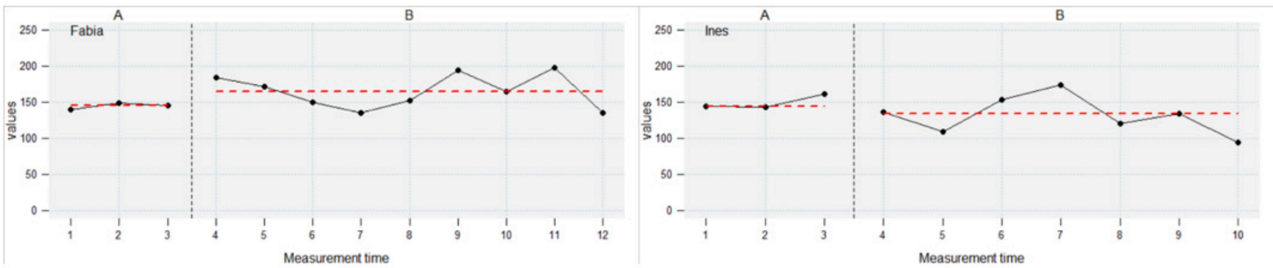

Table 2

Descriptive statistics of the A- and B-phases

Pseudonym	A-Phase					B-Phase					Overlap					
	MP	*M*	*SD*	Md	Trend	MP	*M*	*SD*	Md	Trend	PND	PEM	PET	NAP	PAND	Tau-U
EBD-N																
Clara	5	120.80	9.65	125	-1.00	7	143.00	26.78	152	7.14	71.4	71.4	71.4	71.4	66.7	.33
Dana	3	161.33	11.72	166	-2.00	9	216.44	15.50	214	1.40	100	100**	100**	100**	100**	.59**
Emma	5	162.60	24.65	168	13.80	6	193.50	20.07	194	3.34	50.0	83.3	.00	83.3*	81.8**	.31
John	3	132.67	13.43	127	10.50	7	137.14	11.71	139	2.04	14.3	85.7	.00	61.9	80.0	.18
EBD-I																
Aron	4	127.25	40.03	130	30.30	8	130.00	16.78	157	.50	12.5	100*	.00	76.6	83.3*	.20
Ben	4	156.75	47.46	177	25.70	8	173.25	8.35	172.5	-.02	.00	37.5	.00	43.8	50.0	-.06
Gloria	3	31.33	5.77	28	5.00	9	69.56	24.25	77	1.35	88.9	100**	66.7	96.3*	83.3	.44*
Hugo	3	84.67	10.26	82	3.00	3	96.00	8.19	98	5.50	66.7	100	66.7	88.9	66.7	.47
Keanu	4	126.75	22.14	126.5	6.90	3	117.00	7.21	119	-5.00	.00	.00	.00	41.7	42.9	-.24
EBD-E																
Fabia	3	144.33	5.03	145	3.00	9	164.67	23.60	164	-.52	77.8	77.8	44.4	77.8	66.7	.20
Ines	3	149.33	10.12	144	8.50	7	131.29	26.63	124	-3.89	14.3	28.6	.00	23.8	40.0	-.38

**Note. MP = measurement points; M = mean; SD = standard deviation; Md=median; PND = percentage of nonoverlap data; PET = percentage exceeding the mean; PET = percentage exceeding the trend; NAP = non-overlap of all pairs; PAND=percentage of all non-overlapping data; Tau-U = baseline corrected Kendall-Tau (Tarlow, 2017); *=p < .05; **= p <.01.*

Table 3

Piecewise regression parameters for the three EBD groups.

Parameter	B	SE	t	*p*	ΔR^2
EBD-N					.438
Intercept	144.468	15.192	9.510	<.01	.300
Level	14.338	10.153	1.412	.116	.134
Slope	3.428	1.841	1.862	.07	.004
EBD-I					.464
Intercept	106.040	18.539	5.720	<.01	.355
Level	12.552	10.063	1.247	.219	.105
Slope	1.668	1.829	.912	.367	.003
EBD-E					.454
Intercept	146.833	12.319	11.919	<.01	.158
Level	5.655	16.659	.339	.738	.289
Slope	-.738	2.594	-.284	.779	.007

**Note. B=Unstandardized regression coefficient; SE=standard error; t=value of the t-test; p=significance of t-test; ΔR^2=change in explained variance.*

Table 4.

Hierarchical piecewise regression model across all students.

Parameter	*B*	*SE*	*t*	*p*	ΔR^2
Intercept	109.707	25.077	4.375	<.01	.495
Level	23.969	11.121	2.155	.034	.098
Slope	1.616	1.176	1.374	.172	.001
Internalizing	-1.721	1.534	-1.122	.294	.002
Externalizing	.340	.760	.447	.667	.000
Level x Internalizing	-.265	.614	-.432	.667	.000
Level x Externalizing	-.380	.314	-1.209	.230	.000

**Note. B=Unstandardized regression coefficient; SE=standard error; t=value of the t-test; p=significance of t-test; ΔR^2=change in explained variance.*

Discussion

The aim of this study was to investigate the effects of an evidence-based mathematics intervention in students with and without EBDs. Special attention was given to the onset and development of potential intervention effects, the comparison of effects in students with and without EBD, and the potential influence of externalizing and internalizing EBDs on the intervention effects. In sum, four research questions were examined.

Regarding the first research question addressing students' mathematical development during an intervention, the study found substantial differences in responsivity. While a few students showed significantly better mathematics performance during the B-phase, other students' performance was similar or even lower than in the baseline phase. This finding underscores the importance of examining the individual effectiveness on a single-case basis for interventions that have shown to be effective in randomized control group studies (Riley-Tilman e al., 2020).

The second research question focused on patterns of intervention effects (i.e., immediate or continuous effects after implementation). The effects in those cases that showed positive intervention effects set in closely after the beginning of the B phase, as illustrated in the visual analysis. This interpretation is supported by overlap indices and piecewise regression model parameters that indicate a level effect. However, visual analyses, overlap indices, and piecewise regression models show no slope effects. Where found, performance improved immediately after the beginning of the intervention, but did not accelerate in the course of the intervention.

Third, we examined differences in math development trajectories between students with externalizing, internalizing, and without behavioral problems. Based on the results in the CBCL, students were assigned to three groups. In all analyses, the students without EBD (EBD-N) benefited the most from the intervention. Students with internalizing EBDs (EBD-I) benefited less, while students with externalizing EBDs (EBD-E) showed the lowest intervention effects. The pattern of effects in the three groups was the same for level and slope effects. These findings indicate a differential effectiveness of mathematics interventions in students with and without EBD, with lower effects for externalizing EBDs. Previous studies showed that students with EBD were likely to show lower mean math performance (Graefen et al., 2015; Wei et al., 2013), which is supported by these results. The results also indicate that students with externalizing EBDs such as ADHD are more strongly impaired than students with internalizing EBDs. As pointed out, externalizing EBDs are often associated with low executive functioning resources, which play a crucial role in mathematical learning. Thus, lacking executive capacity can explain these findings.

Fourth, we examined the extent to which the severity of externalizing and internalizing behavioral problems influenced the development of math skills during the intervention. The hierarchical piecewise regression model was employed to test the direct influence of the severity of students' EBD on the intervention effects. Although not significantly, the severity of internalizing EBD had a substantial negative effect on the performance in the B-phase, meaning that lower internalizing behavior problems are associated with stronger gains in math competence. A typical mathematics related internalizing EBD is math anxiety. The results suggest that the severity of anxiety (as one example for an internalizing EBD) has a direct effect on the students' responsivity to a mathematics intervention. A potential explanation could be that students with internalizing EBDs showed more avoidance behavior, even in the training sessions. No comparable effects were found for externalizing EBDs, nor the interaction of severity of internalizing or externalizing EBDs with level. This finding is in line with previous studies that have shown that students with MD are especially vulnerable to internalizing EBDs, such as anxiety or depression (Visser et al., 2020). With respect to practical settings, this could imply the need for modifications to intervention for students with internalizing behavior problems.

In general, the results of the current study should be interpreted with caution due to its limited external and internal validity: First, the size of the effects of the intervention might be limited due to few measurement points and training sessions in a short intervention phase. In particular the cases that showed no significant effects might have just needed more time. Whereas no slope effects were found in a short intervention phase, a longer intervention phase might reveal an acceleration in students' development. Second, the design lacked a withdrawal phase. In a withdrawal design, a second A-phase is added immediately after the B-phase, potentially followed by a subsequent second B-phase. An additional A-phase (and B-phase) would allow for disentangling the intervention effects from random or schooling effects. Thus, the significance of the results would be higher in a withdrawal design.

The investigation of the effect of a computer-based mathematics intervention on students with and without EBD employed a single-case design. Such a design was considered appropriate especially in view of the clearly outlined and specific target sample that does not expect high sample sizes, i.e., students with comorbid MD and EBD. However, it must be noted that results from a single-case study are hard to generalize for the whole population due to low sample sizes (Maggin et al., 2018), though replicating single-case studies does enable generalizability of findings from such studies.

Practical implications

The (tentative) results of the current study provide partial support for the assumption that effectiveness of mathematics interventions cannot be generalized for students with EBDs. Theory-driven explanatory models and empirical findings suggest that students with EBDs benefit less from mathematics interventions. Therefore, specific evidence for the effectiveness of mathematics intervention for students with EBDs as well as insights into the underlying theoretical mechanisms of effectiveness is necessary. The need for evidence-based mathematics interventions for students with EBDs is underpinned by the fact that about half of the students with MD are affected by EBDs, too.

Since externalizing and internalizing EBDs showed different effects on the intervention in this study, the differentiation into externalizing and internalizing EBD seems to be adequate. However, the findings regarding the effects in this study were inconsistent: While students from the EBD-E group showed practically no increase in performance in the visual analyses, overlap indices, and the piecewise regression models, the severity of the internalizing EBDs had a substantial direct influence in the hierarchical piecewise regression models. One reason might be that the students from the EBD-E group also had internalizing EBDs to some (lower) extent and vice versa. This explanation raises the question, how externalizing and internalizing EBDs interact and might amplify each other in students with both EBD subtypes. Future research on mathematics interventions for students with EBD might address this question.

Should future studies find evidence for the assumption of differential effects of mathematics interventions for students with EBD, there would be a need for specific interventions for these students. Based on the results of this study, EBD-sensitive mathematics interventions might focus on internalizing, externalizing, or combined EBDs. The explanatory models presented above suggest such a differentiation. In addition, a thorough review of effect models on mathematical learning for other EBDs that are less researched, such as depression, social problems, or oppositional behavior, might inform specific mathematics interventions for students with EBD.

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