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Zeitschrift für Psychologie 223 (2015) 2, S. 83-92

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https://doi.org/10.25656/01:12728

How IQ–Achievement Discrepancy and Additional Reading and Spelling Difficulties Relate to Working Memory Functioning in Children With Poor Mathematical Skills

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The study was part of the longitudinal research project *Differential Diagnostic Relevance of Working Memory in Children With Learning Disabilities (RAVEN)*, exploring the developmental interplay between working memory and school achievement in children with learning disabilities. This research is part of the research initiative *Developmental Disorders of Scholastic Skills*, funded by the German Federal Ministry of Education and Research (BMBF; grant number: 01GJ1012A-D). The authors thank Dipl.-Psych. Christina Balke-

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Melcher, MSc. Psych. Larissa Bonin, Prof. Dr. Claudia Mähler and Dr. Kirsten Schuchardt of the University of Hildesheim (Germany) as well as M.A. Soz. Claudia Schmidt of the University of Oldenburg (Germany) for their involvement in carrying out this study. Additionally, the authors thank all participating children and their parents.

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Abstract

Previous research on working memory (WM) in children with poor mathematical skills has yielded heterogeneous results possibly due to inconsistent consideration of the IQ–achievement discrepancy and additional reading and spelling difficulties. To examine the impact of both, the WM of 68 average-achieving and 68 low-achieving third-graders in mathematics was assessed. Preliminary analyses showed that poor mathematical skills were associated with poor WM. Afterwards, children with isolated mathematical difficulties were separated from those with additional reading and spelling difficulties. Half of each group fulfilled the IQ–achievement discrepancy, resulting in a 2 (additional reading and spelling difficulties: yes/no) by 2 (IQ–achievement discrepancy: yes/no) factorial design. Analyses revealed that not fulfilling the IQ–achievement discrepancy was associated with poor visual WM, whereas additional reading and spelling difficulties were associated with poor central executive functioning in children fulfilling the IQ–achievement discrepancy. Therefore, WM in children with poor mathematical skills differs according to the IQ–achievement discrepancy and additional reading and spelling difficulties.

Keywords: working memory; mathematical difficulties; reading and spelling difficulties; learning disorders; IQ–achievement discrepancy

Children with unexpected learning difficulties show poor academic skills despite average intellectual ability. For instance, this definition was used in the prevalence study of Fischbach et al. (2013) which revealed that approximately 23% of second- and third-graders in Germany have unexpected learning difficulties in at least one academic domain. While 5% of this sample exhibited isolated poor mathematical skills, 4.2% showed difficulties in mathematics as well as reading and spelling.

Children with unexpected difficulties in mathematics either have a learning disorder (LD) or are poor learners. While the latter do not fulfill a critical IQ–mathematical achievement discrepancy, children with an LD do. According to the research criteria of ICD-10 (WHO, 1993), two *SD*s have to be applied as a critical discrepancy, whereas in educational practice 1.2 to 1.5 *SD*s are considered sufficient (Hasselhorn & Schuchardt, 2006).

Achievement in mathematics relates more closely to working memory (WM) among children with poor mathematical skills than among typical learners (Friso-van den Bos, van der Ven, Kroesbergen, & van Luit, 2013). Therefore, WM deficits are considered to be one possible cause of poor mathematical skills although results of previous empirical studies on WM functioning in children with poor mathematical skills are rather inconsistent (e.g., Schuchardt, Maehler, & Hasselhorn, 2008).

A common theoretical framework in empirical approaches to analyzing WM in children with learning difficulties is Baddeley's (1986) multicomponent WM model, which contains a superior regulatory system called the *central executive* and two subsystems referred to as the *phonological loop* and the *visuospatial sketchpad*. The phonological loop processes verbal information, whereas the sketchpad processes visual and spatial information. The sketchpad comprises a *visual cache* responsible for static-visual information, and an *inner scribe* responsible for dynamic-spatial information (Logie, 1995). The central executive regulates and controls processes in WM by controlling its subsystems and supervising information flow between different parts of the cognitive system. While the subsystems store presented information temporarily, the central executive is responsible for the active manipulation and processing of this information (e.g., Baddeley, 1996).

A number of studies on WM in children with poor mathematical skills revealed that those children exhibit visuospatial WM deficits (cf. Raghubar, Barnes, & Hecht, 2010). However, it is still unresolved as to whether these deficits are related to visual *and* spatial processing (e.g., D`Amico & Guarnera, 2005; Schuchardt et al., 2008) or to spatial processing only (e.g., McLean & Hitch, 1999; Passolunghi & Mammarella, 2012; Swanson & Sachse-Lee, 2001; van der Sluis, van der Leij, A., & de Jong, 2005). There are also studies in which no spatial deficits are observed (e.g., Bull, Johnston, & Roy, 1999; De Weerdt, Desoete, & Roeyers, 2013; Geary, Hamson, & Hoard, 2000; Kyttälä, 2008). Furthermore, previous research yielded inconsistent results regarding peculiarities of the phonological loop and the central executive (cf. Peng, Congying, Beilei, and Sha, 2012). It is still a matter of controversy as to whether deficits in both WM components are global irrespective of the material used in the tasks (cf. Swanson & Jerman, 2006) or whether there are just numerical processing deficits (e.g., Passolunghi & Siegel, 2001 for forward and backward span tasks but not for complex span tasks). In addition, there is empirical evidence for visuospatial central executive deficits (e.g., Rotzer et al., 2009).

One reason for these heterogeneous research findings might be the differing practices in checking for additional reading and spelling difficulties (e.g., Passolunghi, 2006). Knowledge about comorbidity of learning difficulties is still limited (e.g., Büttner & Hasselhorn, 2011). In fact, difficulties in mathematics and in literary language are investigated less when combined than when isolated (e.g., Schuchardt et al., 2008) although there is evidence that combined difficulties occur more often than estimated on the basis of the prevalence rates of isolated difficulties (Dirks, Spyer, van Lieshout, & de Sonneville, 2008). Children with these mixed learning difficulties are categorized either as having a *mixed disorder of scholastic skills* (WHO, 1993; hereinafter referred to as a *mixed LD*) if they fulfill a critical IQ–achievement discrepancy or as *mixed poor learners* if they do not.

In a meta-analysis by Swanson and Jerman (2006) a moderate effect of group (poor mathematical skills with versus without reading and spelling difficulties) was found for the phonological loop when assessed with verbal material and a small effect was found for the central executive when assessed with verbal and visuospatial material: Children with isolated poor mathematical skills outperformed children with additional reading and spelling difficulties. No effect of group was found for phonological loop functioning assessed with digits. Peng et al. (2012) found a similar pattern of results regarding material specificity for the phonological loop and for the central executive. However, material specificity among central executive tasks was observed with inhibition tasks but not with updating and dual-tasks. Schuchardt and Mähler (2010) did not report material specificity. They found poorer phonological WM and a statistical trend of poorer central executive WM in children with a mixed LD than in those with a mathematical LD. In line with the central executive results, van der Sluis et al. (2005) reported a statistical trend of central executive differences between both groups, but only in the backward digit span and not in complex span tasks. No differences were found for phonological or visuospatial WM, which is in accordance with results reported by Landerl, Fussenegger, Moll, and Willburger (2009) as well as by Andersson and Lyxell (2007). However, in the latter study no WM differences were found between both groups.

In summary, there is no evidence of differences in the visuospatial sketchpad between children with isolated poor mathematical skills and those with additional reading and spelling difficulties. However, concerning the phonological loop and the central executive, results are heterogeneous; there is even some evidence of material specificity.

Another possible reason for heterogeneous results in research on WM in children with poor mathematical skills is whether an IQ–achievement discrepancy (hereinafter IQ-discrepancy) criterion is applied. The inclusion of this criterion in the international diagnostic manual of the WHO (1993) implies that children who fulfill the IQ-discrepancy and those who do not differ in cognitive factors, thereby justifying separation of the groups. Correspondingly, Brankaer, Ghesquière, and De Smedt (2014) found better WM functioning in children with poor mathematical skills who fulfilled the IQ-discrepancy than in those who did not. However, there is contrary evidence (Kuhn, Raddatz, Holling, & Dobel, 2013; Maehler & Schuchardt, 2009, 2011) indicating that IQ-discrepancy is not related to WM functioning.

Research Questions and Hypotheses

First, we compared children with poor mathematical skills to typical learners in order to answer the first research question: Do children with poor mathematical skills have WM deficits? In line with most empirical evidence we hypothesized that children with poor mathematical skills would have deficits in the phonological loop, the dynamic-spatial scribe, and the central executive, but not in the visual cache. These analyses would serve as a precondition for the second and main research question: Do WM deficits in children with poor mathematical skills differ as a function of additional reading and spelling difficulties as well as the IQ-discrepancy? For additional reading and spelling difficulties, it was not possible to postulate a specific hypothesis concerning phonological WM functioning due to the heterogeneous results of previous studies. However, to the best of our knowledge, no study has reported differences between both groups in visuospatial sketchpad. Therefore, we hypothesized that children with mixed learning difficulties would not differ in their visuospatial WM functioning from children with isolated poor mathematical skills. As most studies have reported central executive differences between both groups, we hypothesized a negative effect of additional reading and spelling difficulties on central executive WM in children with poor mathematical skills. We abstained from hypothesizing about the IQ-discrepancy due to inconsistent results of previous research.

Method

Sample and Design

Of the 136 third-graders from regular elementary schools in Germany who participated in the study, 34 exhibited isolated poor mathematical skills (mathematics $T < 40$ equates to percentile < 16; reading and spelling $T \geq 40$; discrepancy between mathematics and achievement in reading and spelling ≥ 5 *T*-points), 34 showed mixed learning difficulties (mathematics, reading, and spelling $T < 40$), and 68 did not exhibit learning difficulties (mathematics, reading, and spelling $T \geq 45$) and served as a control group. The participants' IQ was at least average ($IQ \geq 85$). Children were recruited from the sample of an epidemiological study on learning difficulties at the end of Grade 2 and beginning of Grade 3 in which nonverbal intelligence and academic achievement were assessed in groups over two 1.5-hr lessons. Consent of the parents and schools was obtained prior to testing.

Nonverbal intelligence was assessed with the *Culture Fair Intelligence Test* (CFT 1; Cattell, Weiß, & Osterland, 1997). German standardized achievement tests were administered to assess academic skills: Reading was assessed with a reading comprehension test (ELFE 1-6; Lenhard & Schneider, 2006), spelling with a dictation (WRT 2+; Birkel, 2007), and mathematics with arithmetical, word and geometry problems (DEMAT 2+; Krajewski, Liehm, & Schneider, 2004). Internal consistencies of the standardized achievement tests range from .89 to .97 as indicated in the technical manuals.

To address the second research question of whether WM deficits in children with poor mathematical skills differ as a function of additional reading and spelling difficulties as well as the IQ-discrepancy the two groups with learning difficulties were divided into two subsamples. Half of each group showed an IQ-discrepancy of at least 1.2 *SD*s resulting in a 2 (additional reading and spelling difficulties: yes/no) by 2 (IQ-discrepancy: yes/no) factorial design including the following four groups: children with a *mathematical LD* (in terms of ICD-10: F81.2 specific disorder of arithmetical skills), *poor mathematics learners*, children with a *mixed LD* (in terms of ICD-10: F81.3 mixed disorder of scholastic skills), and *mixed poor learners*. Both groups with an LD and those with poor learners were parallelized according to IQ and mathematical skills.

Table 1 shows the characteristics of the group with poor mathematical skills and the control group. For all analyses, α-level was set at .05 if not otherwise specified. Both groups did not differ in terms of age but differed in terms of mathematical, reading, and spelling skills as well as IQ. Sex distribution was balanced within the mathematical learning difficulties group, χ^2 (1) = 3.77, $p = .052$; and within the control group, χ^2 (1) < 1, $p = .808$.

[Please insert Table 1 here]

The characteristics of the four subgroups with poor mathematical skills are presented in Table 2. In line with sample criteria, there were statistically significant main effects of additional reading and spelling difficulties for reading as well as spelling and of IQ-discrepancy for nonverbal IQ: Children with isolated learning difficulties outperformed children with mixed learning difficulties in reading and spelling, whereas children with an LD outperformed poor learners in nonverbal IQ. As expected due to the sampling procedure, no statistically significant effects for age or mathematical achievement were observed.

Sex distribution was not balanced within the mathematical LD group, χ^2 (1) = 9.94, $p = .002$; or within the poor mathematics learners group, χ^2 (1) = 4.77, $p = .029$; however, sex distribution was balanced within the mixed LD group, χ^2 (1) < 1, *p* = .808; and the mixed poor learners group, χ^2 (1) = 2.88, *p* = .090. This is in line with prevalence studies revealing that girls are overrepresented in mathematical difficulties (Fischbach et al., 2013), whereas sex distribution is balanced in children with mixed difficulties in mathematics, reading, and spelling (Landerl & Moll, 2010).

[Please insert Table 2 here]

WM Assessment

WM was assessed using the *Working Memory Test Battery for Children Aged Five to Twelve Years* (AGTB 5-12; Hasselhorn et al., 2012), a computer-based and adaptive German test battery. In a sample of 1,669 children the tripartite structure of WM was established for the AGTB 5-12 by Michalzyk, Malstädt, Worgt, Könen, and Hasselhorn (2013). Internal consistencies of the subtests measured in 9- to 12-year-old children range from .92 to .99 except for nonword repetition (.74; Hasselhorn et al., 2012). In addition to the AGTB 5-12, two further WM tasks were administered: *articulation rate* and *backward word span*. All WM subtests except two (*articulation rate* and *nonword repetition*) include ten trials following an adaptive algorithm. Dependent variables of these span tasks are means of the last eight trials. WM assessment was realized in schools or in university laboratories and was conducted by a trained instructor in two individual sessions lasting 45 minutes each.

Phonological loop.

Articulation rate. Two triplets of monosyllabic nouns are presented acoustically. Each triplet has to be articulated as quickly as possible ten times in a row. The mean articulation time of the four shortest triplets was calculated for each of both trials and averaged as dependent variable.

Digit span. Digit sequences of two to eight digits are presented acoustically and have to be reproduced immediately after presentation.

Nonword repetition. Tri- to pentasyllabic nonwords have to be repeated immediately after acoustical presentation. Half of the 24 nonwords are presented in a modulated way (i.e., with a distorted sound). The number of correct responses was used as dependent variable.

Word span monosyllabic and trisyllabic. Similar to the digit span, word sequences of two to eight mono- or trisyllabic words are presented acoustically and have to be reproduced immediately after presentation.

Visuospatial Sketchpad.

Corsi block span. Nine unsystematically located white squares are presented on a grey screen. A sequence of two to eight smileys appears in the squares, creating the impression that the smiley moves from one square to another. The child has to reproduce the way of the smiley by touching the squares on a touchscreen in the presented order. The length of sequences operationalizes the dynamic-spatial scribe.

Matrix span. A pattern of two to eight black fields are presented in a white 4 x 4 matrix. Immediately after presentation, the pattern has to be reproduced in an empty 4 x 4 matrix by touching the respective fields on the screen. The matrix span operationalizes the storage capacity of the static-visual cache.

Central executive.

Backward digit and word span. Similar to forward digit and word span, a digit or word sequence of two to seven items is presented acoustically and has to be reproduced immediately in the reverse order.

Counting span. A picture with squares and one to nine circles is randomly presented on the screen. The circles have to be counted. A sequence of two to seven of these pictures is presented and the number of circles has to be reproduced verbally in the same order.

Object span. A sequence of two to seven objects is presented on a white screen. After viewing each object the child has to say if the object is edible or not. After the whole sequence the child has to reproduce the objects verbally in the presented order.

Results

Means and *SD*s for all WM subtests are presented as a function of poor mathematical skills (first research question) in Table 3 and as a function of additional reading and spelling difficulties as well as the IQ-discrepancy (second research question) in Table 4.

Do children with poor mathematical skills have WM deficits?

To compare the phonological and central executive WM of the total group of children with poor mathematical skills to that of the typical learners, multivariate analyses of covariance (MANCOVAs) were conducted with group as a fixed factor and IQ as covariate. For visuospatial WM separate univariate analyses of covariance (ANCOVAs) were performed, because different hypotheses were postulated for visual and spatial WM. A statistically significant group effect was revealed for the phonological loop, $F(5, 124) = 4.16$, $p = .002$, $\eta_p^2 = .14$; the dynamic-spatial scribe, $F(1, 133) = 5.11$, $p = .025$, $\eta_p^2 = .04$; and the central executive, $F(4, 129) = 6.90$, $p < .001$, $\eta_p^2 = .18$; but not for the visual cache, $F(1, 133) = 1.01$, $p = .316$. Effects of the covariate IQ are shown in Table 3. Subsequent ANCOVAs showed that typical learners outperformed children with poor mathematical skills in all phonological tasks except the articulation rate and in all central executive tasks except the object span (see Table 3).

[Please insert Table 3 here]

Do WM deficits in children with poor mathematical skills differ as a function of additional reading and spelling difficulties as well as the IQ-discrepancy?

Multivariate analyses of variance (MANOVAs) with fixed factors of additional versus no additional reading and spelling difficulties and fulfilled versus not fulfilled IQ-discrepancy were conducted separately for phonological, visuospatial, and central executive WM tasks.

Regarding the phonological loop, neither the multivariate main effects (reading and spelling difficulties: $F(5, 55) = 1.05$, $p = .398$; IQ-discrepancy: $F(5, 55) = 1.12$, $p = .362$), nor the interaction effect, $F(5, 55) = 2.15$, $p = .073$; reached the specified significance level.

For analysis of the visuospatial tasks α-level was set at .10 because the statistical null hypothesis was tested (cf. Bortz & Schuster, 2010; Cohen, 2013). The MANOVA showed a statistically significant main effect of IQ-discrepancy, $F(2, 63) = 3.43$, $p = .038$, $\eta_p^2 = .10$; whereas neither the main effect of reading and spelling difficulties, $F(2, 63) = 1.94$, $p = .153$; nor the interaction effect, $F(2, 63) = 2.06$, $p = .136$; was statistically significant. Subsequent ANOVAs (see Table 4) indicated that children who fulfilled the IQ-discrepancy outperformed poor learners in the matrix span. However, no statistically significant difference was observed for the corsi block span.

Concerning the central executive, the multivariate main effect of additional reading and spelling difficulties proved to be statistically significant, $F(4, 60) = 3.14$, $p = .021$, $\eta_p^2 = .17$. In subsequent ANOVAs (see Table 4) children with isolated poor mathematical skills outperformed children with additional reading and spelling difficulties on backward word span and object span. No statistically significant multivariate main effect of IQ-discrepancy was observed, $F(4, 60) < 1$, $p = .701$; however, the interaction between both factors proved to be statistically significant, $F(4, 60) = 3.65$, $p = .010$, $\eta_p^2 = .20$. Subsequent ANOVAs showed statistically significant interactions for backward word span and object span. Analyses of simple effects revealed that children with a mathematical LD outperformed children with a mixed LD in backward word span, $F(1, 63) = 16.50$, $p < .001$, $\eta_p^2 = .21$; and object span, $F(1, 63) = 12.06$, $p < .001$, $\eta_p^2 = .16$. Furthermore, children with a mathematical LD outperformed poor mathematics learners in backward word span, $F(1, 63) = 4.43$, $p = .039$, $\eta_p^2 = .07$; whereas mixed poor learners outperformed children with a mixed LD in object span, $F(1, 63) = 7.53$, $p = .008$, $\eta_p^2 = .11$.

[Please insert Table 4 here]

Discussion

Previous research (see e.g., Raghubar et al., 2010 for an overview) on WM in children with poor mathematical skills produced inconsistent results even among studies based on the theoretical framework of WM proposed by Baddeley (1986). A possible reason for this is differences in considering IQ-discrepancy and additional reading and spelling difficulties (e.g., Schuchardt et al., 2008). Therefore, we investigated the impact of both issues on WM in children with poor mathematical skills. First, the WM in the total group of children with poor mathematical skills was compared to that of typical learners to replicate the finding that these children have WM deficits. As this precondition was confirmed, we addressed the second and main research question of whether WM deficits in children with poor mathematical skills differ as a function of additional reading and spelling difficulties as well as the IQ-discrepancy. Thus, children with poor mathematical skills were divided resulting in a 2 (additional reading and spelling difficulties: yes/no) by 2 (IQ-discrepancy: yes/no) factorial design.

Do children with poor mathematical skills have WM deficits?

The hypothesis that children with poor mathematical skills have deficits in the phonological loop, the dynamic-spatial scribe, and the central executive, but not in the visual cache when compared to typical learners was confirmed. Regarding the phonological loop and the central executive, deficits were found for verbal and numerical material, indicating that deficits seem to be global rather than material-specific, which is in line with previous research (e.g., Swanson & Jerman, 2006). In accordance with the findings reported by

Passolunghi and Mammarella (2012), the results of the visuospatial tasks suggest that children with poor mathematical skills exhibit particular deficits in dynamic-spatial WM because they showed impairments in corsi block span only. Their matrix span functioning was not impaired, indicating that they did not show a static-visual WM deficit.

Do WM deficits in children with poor mathematical skills differ as a function of additional reading and spelling difficulties?

First, in line with the results of Andersson and Lyxell (2007), Landerl et al. (2009) and van der Sluis et al. (2005), no differences were observed in the phonological loop between children with and those without additional reading and spelling difficulties. Second, the hypothesis that children with mixed learning difficulties do not differ in visuospatial WM from children with isolated poor mathematical skills was confirmed. This result fits with data reported by Anderson and Lyxell (2007), Landerl et al. (2009), Schuchardt and Mähler (2010) as well as those by van der Sluis et al. (2005). Therefore, previous heterogeneity of results for phonological and visuospatial WM in children with poor mathematical skills does not seem to be the consequence of not considering additional reading and spelling difficulties. Third, the hypothesis that children with mixed learning difficulties show central executive WM deficits when compared to children with isolated poor mathematical skills was only partly confirmed. Specifically, the arithmetical mean pattern of all four central executive tasks and the interaction effect revealed that this is true for children with an LD only; not for poor learners. This is in line with the results of the above-mentioned study by van der Sluis et al. (2005) as well as that of Schuchardt and Mähler (2010), which showed a statistical trend of lower central executive functioning in children with a mixed LD than in children with a mathematical LD. Moreover, subsequent ANOVAs suggested that additional reading and spelling difficulties were not related to facets of the central executive when assessed with counting span and backward digit span, but rather to those facets assessed with object span and backward word span. This pattern of results suggests that additional reading and spelling difficulties are related to additional central executive deficits in processing verbal information, but not in processing numerical information. This kind of material specificity also was found by Passolunghi and Siegel (2001, 2004) for backward span but not complex span tasks and by Peng et al. (2012) for inhibition but not updating and dual-tasks.

In line with the arithmetical mean pattern, deficits in word span backward of children with an LD can be ascribed to additional reading and spelling difficulties. Therefore, it can be hypothesized that children with an isolated mathematical LD have deficits in tasks with numerical material but not in central executive tasks per se. This is one issue that should be addressed in future research. Another issue to be explored is the assessment of central executive WM with visuospatial material, which was not addressed in the present study.

Given the present results it might be assumed that studies, in which additional reading and spelling difficulties were not checked completely, reported global central executive deficits (e.g., Passolunghi & Siegel, 2001 for complex span tasks) because the samples might have included children with a mixed LD. Furthermore, global central executive deficits observed in studies in which additional reading and spelling difficulties were checked (e.g., Chan & Ho, 2010) might be assigned to the fact that only numerical material was used to assess central executive WM.

Do WM deficits in children with poor mathematical skills differ as a function of the IQ-discrepancy?

Our analyses revealed that children with an LD did not differ from poor learners in their phonological but did in their visuospatial WM functioning: Children with an LD outperformed poor learners in matrix span, whereas both groups did not differ in corsi block span. These results indicate that poor learners have more difficulties with visual WM than children with an LD. Regarding the central executive, the question of whether WM deficits in children with poor mathematical skills differ as a function of the IQ-discrepancy cannot be answered without considering additional reading and spelling difficulties because the arithmetical mean pattern of all four central executive tasks and the interaction effect indicated that children with a mathematical LD outperformed poor mathematics learners, whereas mixed poor learners outperformed children with a mixed LD.

The results regarding visual and central executive WM were in accordance with those of Brankaer et al. (2014), who also observed that children with a mathematical LD outperformed poor mathematics learners even though they included children with a below-average IQ and we did not. Yet, this evidence is not completely in line with results reported by Maehler and Schuchardt (2011), who did not observe any WM differences between children with poor mathematical skills who fulfilled the IQ-discrepancy and those who did not. However, Maehler and Schuchardt (2011) reported a group difference in *IQ* of 6.95 points. The two groups in the present study differed in *IQ* by 12.36 points. This might be one reason we found group differences and Maehler and Schuchardt (2011) did not.

Overall, no deficits were found for visual WM in children with poor mathematical skills when compared to typical learners; however, poorer visual WM functioning was observed in children who did not fulfill the IQ-discrepancy than in those who did. In line with the arithmetical mean pattern, these results suggest that the children with a mathematical LD had deficits in dynamic-spatial WM only, which is in line with findings from Passolunghi and Mammarella (2012), whereas poor learners showed additional visual deficits when compared to children with an LD. Accordingly, consideration of the IQ-discrepancy criterion might determine whether deficits are revealed regarding visual WM. Studies in which the IQ-discrepancy is not checked might find general visuospatial deficits (e.g., D`Amico & Guarnera, 2005), whereas studies in which it is checked might find specific dynamic-spatial impairment. In addition, to the best of our knowledge, our results are the first to provide evidence that fulfilling IQ-discrepancy has a positive effect on central executive WM in children with isolated mathematical difficulties, whereas fulfilling IQ-discrepancy has a negative effect on central executive WM in children with mixed learning difficulties. Thus, previous heterogeneity of results for central executive WM in children with poor mathematical skills might be possibly due to inconsistent consideration of IQ-discrepancy as well as additional reading and spelling difficulties.

Limitations and Implications

There are limitations to be considered regarding the external validity of our results. We addressed additional reading and spelling difficulties as well as IQ-discrepancy as possible causes for heterogeneous results in previous research; however, there are a number of other possible causes currently being discussed in the field. Among them are the cut-off criterion used to define poor mathematical skills (10^{th}, 16^{th}, 25^{th} percentile; e.g., Murphy, Mazzocco, Hanich, & Early, 2007; Passolunghi & Mammarella, 2012), the size of the considered IQ-discrepancy (1, 1.2, 1.5, or 2 *SD*s), subtypes of mathematical difficulties (e.g., in terms of arithmetical achievement; e.g., Geary, Hoard, & Hamson, 1999), and WM tasks (e.g., Peng et al., 2012). Considering these aspects should be continued in future research to obtain a better understanding of WM in children with poor mathematical skills.

Overall, our data indicate that the IQ-discrepancy as well as additional reading and spelling difficulties relate to WM in children with poor mathematical skills. This conclusion has important implications for practitioners. First, poor learners, who do not fulfill the IQ-discrepancy, will be seen as having the same phonological and dynamic-spatial WM deficits as children who fulfill the discrepancy, whereas in visual WM poor learners will be seen as having additional deficits. Regarding the central executive, poor mathematics learners might be expected to have poorer WM functioning than children with a mathematical LD, whereas children with a mixed LD might be expected to have poorer WM functioning than mixed poor learners. Second, our results showed that, whereas isolated and mixed poor learners have comparable WM functioning, children with a mixed LD exhibit poorer central executive WM functioning with verbal material than children with a mathematical LD. This result is important for diagnosticians: Mathematical as well as reading and spelling skills should be considered when diagnosing mathematical learning difficulties (cf. Fischbach et al., 2013). These additional central executive deficits in children with a mixed LD cannot be due to lower IQ because LD groups did not differ in IQ. This result is in line with the suggestion that WM functioning might be more important for successful academic learning than intelligence (Alloway & Alloway, 2010).

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Table 1

Descriptive Statistics and ANOVAs for the Mathematical Learning Difficulties Group (MLD) Versus Control Group (CG)

	MLD ($N = 68$)	**CG** ($N = 68$)	**Group Comparison**		
	M (*SD*)	***M*** (*SD*)	F	p	η_p^2
Nonverbal IQ	**95.40** (7.87)	**101.72** (6.95)	24.67	<.001	.16
Mathematics[a]	**34.68** (2.62)	**52.41** (4.30)	844.28	<.001	.86
Reading[a]	**40.53**[b] (8.45)	**52.01** (4.21)	99.53	<.001	.44
Spelling[a]	**39.78** (7.20)	**49.71** (4.31)	95.28	<.001	.43
Age (in month)	**111.37** (5.62)	**109.76** (3.70)	3.86	.052	.03
Sex (m/f)	26/42	35/33			

Note.
[a]*T*-score: $M = 50$, $SD = 10$. [b]Data of four participants are missing.

Table 2

Descriptive Statistics and ANOVAs for Children With Poor Mathematical Skills as a Function of Reading and Spelling Difficulties and IQ-Discrepancy

	Isolated Mathematical Difficulties		Mixed Academic Difficulties		Reading and Spelling Difficulties			IQ-Discrepancy			Interaction		
	LD (*n* = 17)	**PL** (*n* = 17)	**LD** (*n* = 17)	**PL** (*n* = 17)									
	M (*SD*)	***M*** (*SD*)	***M*** (*SD*)	***M*** (*SD*)	***F***	***p***	η_p^2	***F***	***p***	η_p^2	***F***	***p***	η_p^2
Nonverbal IQ	**101.65** (5.26)	**89.29** (2.42)	**101.82** (6.86)	**88.82** (2.86)	**< 1**	**.898**	**< .01**	**123.27**	**< .001**	**.66**	**< 1**	**.778**	**< .01**
Mathematics[a]	**34.35** (3.30)	**34.82** (2.40)	**33.88** (2.37)	**35.65** (2.18)	**< 1**	**.780**	**< .01**	**3.15**	**.081**	**.05**	**1.05**	**.308**	**.02**
Reading[a]	**48.65** (5.30)	**45.94** (4.78)	**32.65** (3.33)	**33.15**[b] (3.16)	**176.40**	**< .001**	**.75**	**1.03**	**.314**	**.02**	**2.20**	**.144**	**.04**
Spelling[a]	**46.65** (3.59)	**45.12** (3.92)	**32.65** (4.64)	**34.71** (2.31)	**183.98**	**< .001**	**.74**	**< 1**	**.770**	**< .01**	**3.98**	**.050**	**.06**
Age (in month)	**108.47** (3.81)	**111.88** (6.43)	**113.18** (5.64)	**111.94** (5.63)	**3.23**	**.077**	**.05**	**< 1**	**.414**	**.01**	**3.08**	**.084**	**.05**
Sex (m/f)	2/15	4/13	8/9	12/5									

Note. LD = learning disorder; PL = poor learners.
[a]*T*-score: *M* = 50, *SD* = 10. [b]Data of four participants are missing.

Table 3

Descriptive Statistics and (M)ANCOVAs for WM in the Mathematical Learning Difficulties Group (MLD) Versus Control Group (CG)

	MLD	CG	Covariate IQ[a]			Group Comparison		
	M (*SD*)	*M* (*SD*)	*F*	*p*	η_p^2	*F*	*p*	η_p^2
Phonological Loop			**1.45**	**.211**	**.06**	**4.16**	**.002**	**.14**
1-syllabic word span	**3.54**[b] (0.71)	**3.84** (0.63)	< 1	.824	< .01	5.15	.025	.04
3-syllabic word span	**2.88**[b] (0.52)	**3.03** (0.38)	1.69	.196	.01	5.12	.025	.04
Articulation rate	**3.12**[b] (0.56)	**3.24** (0.56)	3.07	.082	.02	3.28	.073	.03
Digit span	**4.05**[b] (0.67)	**4.49** (0.64)	< 1	.528	< .01	14.39	<.001	.10
Nonword repetition	**14.83**[b] (3.96)	**17.50** (3.60)	< 1	.713	< .01	12.74	<.001	.09
Visuospatial Sketchpad								
Corsi block span	**3.82** (0.75)	**4.16** (0.74)	< 1	.674	< .01	5.11	.025	.04
Matrix span	**4.16** (1.17)	**4.61** (1.16)	7.66	.006	.05	1.01	.316	.01
Central Executive			**1.26**	**.288**	**.04**	**6.90**	**< .001**	**.18**
Backward digit span	**2.84**[c] (0.41)	**3.23** (0.64)	4.05	.046	.03	10.12	.002	.07
Backward word span	**2.67**[c] (0.39)	**3.05** (0.51)	< 1	.986	< .01	19.55	< .001	.13
Counting span	**2.84**[c] (0.76)	**3.29** (0.74)	< 1	.498	< .01	8.49	.004	.06
Object span	**2.92**[c] (0.62)	**3.03** (0.79)	< 1	.589	< .01	< 1	.522	< .01

Note.

[a] Effects of the covariate IQ. [b] Data of five participants are missing. [c] Data of one participant is missing.

Table 4

Descriptive Statistics and MANOVAs for WM in Children With Poor Mathematical Skills as a Function of Reading and Spelling Difficulties and IQ-Discrepancy

	Isolated Mathematical Difficulties		**Mixed Academic Difficulties**		**Reading and Spelling Difficulties**			**IQ-Discrepancy**			**Interaction**		
	LD	**PL**	**LD**	**PL**									
	M (*SD*)	***M*** (*SD*)	***M*** (*SD*)	***M*** (*SD*)	***F***	***p***	η_p^2	***F***	***p***	η_p^2	***F***	***p***	η_p^2
Phonological Loop					**1.05**	**.398**	**.09**	**1.12**	**.362**	**.09**	**2.15**	**.073**	**.16**
1-syllabic word span	**3.90** (0.64)	**3.41** (0.49)	**3.21**[a] (0.84)	**3.61**[b] (0.70)									
3-syllabic word span	**2.93** (0.39)	**2.87** (0.47)	**2.70**[a] (0.66)	**3.00**[b] (0.55)									
Articulation rate	**3.15** (0.53)	**3.16** (0.64)	**2.85**[a] (0.57)	**3.34**[b] (0.42)									
Digit span	**4.28** (0.54)	**3.99** (0.64)	**3.64**[a] (0.56)	**4.29**[b] (0.77)									
Nonword repetition	**16.00** (4.78)	**15.29** (3.16)	**13.47**[a] (4.39)	**14.29**[b] (3.02)									
Visuospatial Sketchpad					**1.94**	**.153**	**.06**	**3.43**	**.038**	**.10**	**2.06**	**.136**	**.06**
Corsi block span	**3.78** (0.76)	**3.61** (0.88)	**3.91** (0.69)	**3.99** (0.67)				< 1	.811	< .01			
Matrix span	**4.56** (1.30)	**3.34** (1.00)	**4.46** (1.00)	**4.29** (1.00)				6.93	.011	.10			
Central Executive					**3.14**	**.021**	**.17**	**< 1**	**.701**	**.04**	**3.65**	**.010**	**.20**
Backward digit span	**2.99** (0.37)	**2.80** (0.37)	**2.68**[c] (0.43)	**2.86** (0.43)	1.69	.199	.03				3.61	.062	.05
Backward word span	**2.93** (0.39)	**2.67** (0.36)	**2.42**[c] (0.32)	**2.65** (0.35)	8.87	.004	.12				7.90	.007	.11
Counting span	**3.10** (0.87)	**2.68** (0.69)	**2.70**[c] (0.60)	**2.88** (0.83)	< 1	.561	< .01				2.62	.110	.04
Object span	**3.18** (0.62)	**2.96** (0.57)	**2.48**[c] (0.60)	**3.03** (0.52)	4.91	.030	.07				7.48	.008	.11

Note: LD = learning disorder; PL = poor learners. [a]Data of two participants are missing. [b]Data of three participants are missing. [c]Data of one participant is missing.