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Effects of Pre-School Mathematical Disparities on the Development of Mathematical and Verbal Skills in Primary School Children

Nurit Viesel-Nordmeyer
Michael Schurig
Wilfried Bos
Ute Ritterfeld
TU Dortmund University, Germany

Based on longitudinal data (n = 338) from the German National Educational Panel Study (NEPS) competence development (mathematics and language) of three groups with different mathematical preconditions (+/- 1 SD) were compared between age 4 to 10. Groups were composed by first measurement of mathematical achievement in pre-school age (5/6 years). First, further mathematical development of the groups was investigated up to grade 4 of primary school. Second, group differences in grammar and vocabulary between pre-school and primary school children were explored. Results show a consistent development of mathematical competence in all three groups from pre-school age until 4th grade. Children with low mathematical achievement measured in pre-school age were not able to overcome these deficits during primary school. In contrast, vocabulary development of the three groups varies over time: Within the group with low mathematical achievement measured in pre-school age their similarly weak vocabulary skills caught up with the vocabulary achievements of the other two groups during the following school years. For grammar, the small group-related differences in pre-school become even more pronounced in grade 1. The results contribute to a better understanding of the complex dynamic interrelationship between the development of linguistical and mathematical skills in K-4 and are discussed with respect to the importance of early mathematical promotion.

Keywords: **mathematical learning requirements, mathematical low achievers, group differences, mathematical development, language development.**

Introduction

About 10% of students show persistent low achievement in mathematics (MLA) and 7 % receive the diagnosis of a mathematical learning disability (MLD) (Geary, 2011). Apart from brain-based problems, mathematical difficulties are usually discovered during primary school (Lorenz, 2014). However, recent research indicates that the occurring mathematical problems are mostly based on deficits that already emerge in preschool (Viesel-Nordmeyer, Bos, & Ritterfeld, 2018). Difficulties in acquiring so called early mathematical basic skills – like the numeral concept – seem to persist, sometimes even intensify in school and cause a barrier for the acquisition of more advanced mathematical skills (Krajewski, 2014). Consequently, the number of children diagnosed with low mathematical performance increases from primary to

*Please send correspondence to: Nurit Viesel-Nordmeyer, Center for Research on Education and School Development, TU Dortmund University, Vogelpothsweg 78, Dortmund, Northrhine-Westfalia, 44227, Germany, Phone: 0049-231-7555592, Email: nurit.viesel@tu-dortmund.de.

secondary school (National Center for Education Statistics, 2018). Secondary school students with mathematical problems often still display difficulties in their early mathematical skills (National Mathematics Advisory Panel, 2008).

Research also indicates combined weaknesses in mathematics and linguistic skills such as reading or orthography in primary school (Fischbach et al., 2013), which point to a strong relationship in the acquisition of mathematical and linguistic skills. Children's linguistic skills are linked to their mathematical development during school time as well as to early mathematical acquisition (LeFevre, Fast, Skwarchuk, Smith-Chant, & Bisanz, 2010). Krajewski (2014) explained the role of language for the development of early mathematical skills with its close relationship to numerical understanding, counting ability and the even preceding concept of number words. For pre-school age, Negen and Sarnecka (2012) found a positive association for children´s number-concept acquisition and their general vocabulary skills. Focusing on primary school age, van der Walt (2008) also confirmed the importance of vocabulary knowledge for students' mathematical development. However, similar results were also shown for the relationship between grammar and mathematical skills in preschool (Kleemans, Peters, Segers, & Verhoeven, 2012) and (partially) in primary school (Paetsch, 2016). These results questioning the assumption of an association of verbal and mathematical skills are merely based in semantics. Thus, Kleemans et al. (2012) argued for a joint principle of recursion. In primary school, Paetsch (2016) found for both linguistic skills – vocabulary and grammar – close relationships with mathematical specific language, which represent an important linguistic register for mathematical education in school.

The significant role of language in mathematics is particularly evident in children with linguistic limitations either as the result of a specific language impairment (SLI), second language acquisition or a lower socioeconomic background. Children with SLI display an average standard score on the development of early mathematical skills of more than 1 *SD* below the population mean at repeated time points (Durkin, Mok, & Conti-Ramsden, 2013). Studies also revealed an increasing performance degradation in mathematical skills for children with little improvement in language. Similar influences on the ongoing mathematical development were shown for second language learners (Paetsch, 2016). In addition, there is evidence that the degree of early mathematical skills is predicted by the extent and quality of parental speech in number talk (Mix, Sandhofer, Moore, & Russell, 2011). The importance of linguistic input – which is related to the socioeconomic background – was also found relevant for mathematical performance in school (Hoeft, Wendt, & Kasper, 2015).

More specifically, Bonifacci, Tobia, Bernabini and Marzocchi (2016) investigated the contribution of linguistic skills on mathematics in comparing mono- and bilingual children during pre-school age. Bilingual children performed only weaker in mathematical skills with a verbal component like the semantic knowledge of digits in contrast to mathematical skills with a non-verbal component such as quantity comparison.

Learning disability research displays several longitudinal studies which give diverging evidence to further development of children with mathematical learning disabilities or mathematical low achievers. For example, a comparison of children with different mathematical weaknesses (MLA, MLD) from 1st to 5th grade revealed increasing performance differences within both groups and in comparison to their typical achieving peer group (TA) over time (Geary, 2011). Spanning 5 to 7 years, Jordan, Wylie and Mulhern (2015) compared the mathematical development of children with mere mathematical deficiencies and those, who showed additional linguistic deficits. Both groups displayed very similar patterns of development on all measured mathematical tasks. Independently of the linguistic task proximity, the temporal course of their performance distance to their TA varied between steady, rising and diverging. Results of a comparable study of older children in primary school age (2nd to 3rd grade) revealed a different picture (Jordan & Hanich, 2003): Children with only mathematical deficits and those with combined deficits approximated the mathematical level of their typical achieving peers. During this process, children with only mathematical deficits perform also better over time. The reason for such difference in results is not yet fully understood. Some authors point to differences in aging (Jordan et al., 2015). Additional studies including a broader age range could provide further insights into the developmental processes. Moreover, few studies of students with a pre-school history of speech-language impairment (SLI) (Snowling, Adams, Bishop, & Stothard, 2001) indicate a partial catch up of originally underlying weaknesses. At the same time, the authors also controlled for mathematical performances. Despite much better performance in mathematics for several children with resolved SLI than with persistent SLI, children with resolved SLI continued to lag behind their non-SLI peers. For children with mathematical impairment, we are still lacking similar studies addressing the development of both school achievements – linguistics and mathematics. Furthermore, the investigation of 7-year-old children with and without a history of late language emergence at 24 months fundamentally questions general linguistic catch ups (Rice, Taylor, & Zubrick, 2008). Results of this study bear a particular retention of linguistic weaknesses in syntax and morpho-syntax, but not in vocabulary or semantics. This is particularly interesting as semantics are most often associated with mathematics as described above.

With the present study we aim to examine mathematical and linguistic competence development (2nd year of kindergarten till 4th grade of primary school) of children with different levels of mathematical achievement, measured in pre-school age in more detail. Considering linguistic and socioeconomic background, we will investigate how the development of mathematical competencies of children with low mathematical achievements measured in preschool age differs in comparison to the development of children with higher mathematical achievement. In addition, it will be examined, what kind of linguistic development (vocabulary and grammar) children with a low level of mathematical achievement at preschool age show in school-age. For both parts of our research, we propose – based on reported research – influences of linguistic and socioeconomic background. Sex-related effects on mathematics (Samuelsson & Samuelsson, 2016) as well as linguistics (Schlitter & McElvany, 2018) will be controlled.

Method

Participants

The study draws from group 3 of starting cohort 2 (SC2) from the German National Educational Panel Study (NEPS) (Blossfeld, Roßbach, & von Maurice, 2011). This longitudinal data set (n = 359)[1] includes competence data collected annually from age of 4/5 years (starting point: winter 2010/2011) until 4th grade of primary school (9/10 years) (Steinhauer, Zinn, Christoph, & Goßmann, 2016). Data of children with deficits in nonverbal intelligence (-1.5 *SD*) were excluded. A total of 338 children was included in the analyses (female: 53.3 %). Children were categorized in three groups according to their level of mathematical competence measured in preschool age (5/6 years): "mathematical low achievers (MLA; n = 44)" (children who were lower than -1 *SD*), "mathematical average achievers (MAA; n = 251)" (children between -1 and +1 *SD*) and "mathematical high achievers (MHA; n = 43)" (children who were above +1 *SD*).

Measures

Competence tests were conducted in single (preschool) respectively in small group settings (primary school). Data was linked using anchor-item or anchor-group design depending on susceptibility to memory effects (Fischer, Rohm, Gnambs, & Carstensen, 2016). For background information, parents as well as kindergarten/school teacher's questionnaires were used. The indicated internal consistency using Cronbach's alpha (α) refers to the selected sample (n = 338).

Language: Language was measured through listening comprehension at word (vocabulary) and sentence level (grammar). A German research version of the *Peabody Picture Vocabulary Test* (PPVT; Dunn & Dunn, 2007) was used to access the *receptive vocabulary* at three time points (preschool with 4/5 years, 1st and 3rd grade in primary school) (t1: α = .91; t2: α = .85; t3: α = .84). A shortened version of the German version of the *Test for Reception of Grammar* (TROG-D; Fox, 2006) was used to measure *receptive grammatical competence* in kindergarten (4/5 years) and 1st grade of primary school (6/7 years) (t1: α = .87; t2: α = .82). Language scales in NEPS are operationalized as sum scores, except for one case of grammar. These individual sum scores were standardized to display the following figures.

Mathematics: The mathematical testing applied by NEPS based on the idea of *mathematical literacy* (Stacey & Turner, 2015) as well as the curricular standards in STEM (Kultusministerkonferenz, 2003). Measured *mathematical competencies* can be assigned to subareas like arithmetic or geometry. The test with picture-based answer format was applied first in pre-school age (5/6 years) and repeated in 1st, 2nd and 4th grade of primary school (t1: α = .79; t2: α = .77; t3: α = .78; t4: α = .74).

Linguistic competence level: As in the group-variable for mathematics, children of the whole sample (n = 338) were categorized in three groups according to

1 Due to shortage of time, grammar test were interrupted prematurely in 12.9 % of the test group at the first measurement time point (2012) (NEPS, 2014). After subgroup control, the abandonment of the test must be attributed to a systematic problem. Considering those cases with existing indications for the described test failure, the total sample of group 3 (originally N = 431) had to be reduced.

their level of linguistic competencies. The categorization for group-classification was based on the sum of vocabulary and grammar competencies, measured in pre-school age (4/5 years). The *linguistic competence level* variable was coded as 1 = "low linguistic achievement" (linguistic competence level lower than -1 *SD)*, 2 = "average linguistic achievement" (linguistic competence level between ≥ -1 and ≤ 1 *SD*) and 3 = "high linguistic achievement" (linguistic competence level above +1 *SD*).

Background variables: The cohort profile of starting cohort 2 gives information about two of the background variables of interest: *German as main domestic language* (0 = No/1 = Yes) and the sex of children (1 = male/2 = female). Information was summarized from parent and teacher reports. The parents' questionnaire provides indicators of the socioeconomic status represented as the *Highest International Socio-Economic Index of Occupational Status* based on ISEI-08 (Ganzeboom, 2010).

Data Analyses

For a first overview of the group differences, descriptive statistics for each group were calculated in addition to the general statistic of the sample (see Table 1). Univariate analyses of variance (ANOVAs) were computed for group-related differences between the dependent variables as well as the socioeconomic status (SES). Further, tests were performed for group comparisons for utilized covariates. Pearson's correlation analyses were used to uncover relationships between linguistic and mathematical variables (see Table 3). Several repeated measurement ANOVAs (mathematics, vocabulary, grammar) with the three groups (group 1: MLA, group 2: MAA, group 3: MHA) as between-subject factor have been performed. Number of repeated measurements of each ANOVA varied depending on the available data between two to four time points. The covariates linguistic competence level (LING), German as main-domestic-language (GERM), socioeconomic status (SES) and sex were included as within-subject factors. The level of significance was established at $p < .05$.

Results

Table 1 displays means vs. frequencies, standard deviations and comparisons of the used variables included in ANOVAs resp. χ^2-tests. Using ANOVAs, significant group-related differences ($p < .001$) were revealed for the dependent variables of mathematics and linguistics (vocabulary and grammar) between all groups (Tamhane-adjusted). For the effect of socioeconomic background (SES), used as covariate, LSD post-hoc test revealed significant differences for comparison of MLA and MAA (-9.82, 95 % – *CI* [-15.94, -3.70]) as well as MLA and MHA (-8.20, 95 % – *CI* [-16.01, -.40]) testing bared also significant effects for the linguistic covariates GERM ($p < .001$) and LING ($p < .010$). In contrast, the test produced no significant differences ($p > .05$) in group comparison for sex.

Table 1. ***Descriptive statistics per group***

	MLA (n = 44)	MAA (n = 251)	MHA (n = 43)	Total (n = 338)	
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*	*F*
Vocabulary (MTP 1)	0.53 (0.18)	0.69 (0.13)	0.77 (0.06)	0.68 (0.14)	**37.17*****
Vocabulary (MTP 2)	0.51 (0.14)	0.64 (0.13)	0.74 (0.09)	0.64 (0.14)	**21.89*****
Vocabulary (MTP 3)	0.55 (0.14)	0.65 (0.12)	0.72 (0.08)	0.65 (0.12)	**15.91*****
Grammar (MTP 1)	0.58 (0.15)	0.70 (0.12)	0.79 (0.10)	0.69 (0.14)	**19.21*****
Grammar (MTP 2)	0.59 (0.14)	0.74 (0.12)	0.84 (0.09)	0.73 (0.14)	**25.96*****
Mathematics (MTP 1)	-1.18 (0.43)	0.43 (0.56)	2.14 (0.63)	0.43 (1.01)	**384.20*****
Mathematics (MTP 2)	0.58 (0.99)	1.69 (0.97)	2.97 (1.02)	1.71 (1.15)	**63.67*****
Mathematics (MTP 3)	1.27 (0.87)	2.40 (0.98)	3.81 (1.03)	2.43 (1.17)	**73.16*****
Mathematics (MTP 4)	3.58 (0.95)	4.66 (1.00)	5.79 (0.83)	4.66 (1.12)	**54.10*****
SES	44.82 (17.36)	54.64 (18.17)	53.02 (16.16)	53.25 (18.04)	4.98**
	% (n)	% (n)	% (n)	% (n)	χ^2
LING					62.40***
low	47.7 (21)	10.5 (26)	2.3 (1)	14.3 (48)	
average	50.0 (22)	79.4 (197)	67.5 (29)	74.0 (248)	
high	2.3 (1)	10.1 (25)	30.2 (13)	11.6 (39)	
GERM					11.44**
no	15.9 (7)	4.0 (10)	2.3 (1)	5.3 (18)	
yes	84.1 (37)	96.0 (241)	97.7 (42)	94.7 (320)	
Sex					1.39
male	40.9 (18)	46.6 (117)	53.5 (23)	46.7 (158)	
female	59.1 (26)	53.4 (134)	53.3 (180)	53.3 (180)	

Notes. Descriptive statistics with comparison between groups. MTP = Measurement time point. SES = Socioeconomic status; LING = Linguistic competence level; GERM = German as main-domestic language; F = F-Statistics (ANOVA); χ^2 = Chi-square test; * $p < .05$, ** $p < .01$, *** $p < .001$.

Additional Pearson's correlations showed a relationship between the both linguistic covariates GERM and LING (r = .35; p < .01) as well as a clearly lower relationship with the mathematical group variable for GERM (r = .15; p < .01) than for LING (r = .37; p < .01). Table 2 provides a summary of the relationships between the both linguistic covariates. 29.2 % of children with low linguistic competencies also showed a presumptive second language acquisition. The residual 70 % must trace back on further problems. More so, 47.7 % of children with MLA present low linguistic competencies. However, the classification of MLA results in a group composition with 15.9 % of children whose main-domestic language is not German. Further analyses showed that most of them (75 %) were also characterized by a below-average SES. In MLA, 5.3 % with a low linguistic competence level showed only a below-average SES and further 10.4 % is characterized by a below-average SES without linguistic limitations.

Table 2. ***Relationships between the linguistic covariates***

	GERM	
	no (5.4 %)	yes (94.6 %)
Linguistic competence level (LING)	% (n)	% (n)
low (14.3 %)	29.2 (14)	70.8 (34)
average (74 %)	1.6 (4)	98.4 (244)
high (11.6 %)	0.0 (0)	100.0 (39)

Notes. Percentages are specified as row percentages. GERM = German as main domestic language.

Using the whole sample (n = 338), Pearson's correlations were conducted to explore relationships between mathematical and linguistic dependent variables. As can be seen in Table 3, presented correlations point to very robust connections between linguistic and mathematical competencies over time. All linguistic variables (vocabulary and grammar) of the separate measurement time points (MTPs) are closely related to all separate mathematical variables (p < .01) in a range from r = .40 to r = .53 and an average correlation coefficient of r = .47, p < .01.

Table 3. ***Pearson Product-Moment Correlations of linguistic and mathematical measures (n = 338)***

	1	2	3	4	5	6	7	8
1 Vocabulary (MTP 1)								
2 Vocabulary (MTP 2)	.74**							
3 Vocabulary (MTP 3)	.65**	.72**						
4 Grammar (MTP 1)	.66**	.60**	.51**					
5 Grammar (MTP 2)	.57**	.63**	.60**	.57**				
6 Mathematics (MTP 1)	**.51****	**.49****	.45**	.47**	.53**			
7 Mathematics (MTP 2)	**.47****	**.48****	**.49****	**.50****	**.54****	.66**		
8 Mathematics (MTP 3)	**.44****	**.43****	**.42****	**.47****	**.50****	.67**	.71**	
9 Mathematics (MTP 4)	**.38****	**.47****	**.40****	**.42****	**.55****	.66**	.62**	.69**

Notes. MTP = Measurement time point, * $p < .05$, **$p < .01$. Correlations between mathematical and linguistic variables were emphasized.

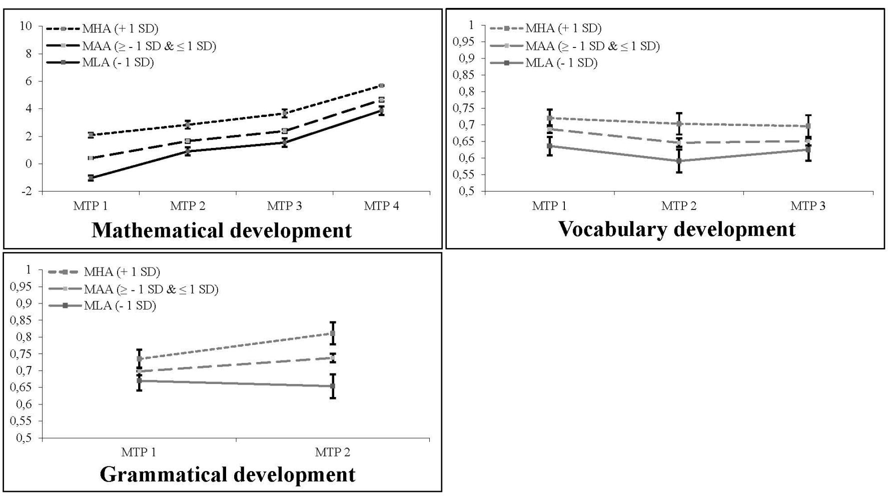

Figure 1. **Comparison of mathematical development (K-4), vocabulary development (K-3), and grammatical development (K-1) between three groups with different mathematical requirements (+/- 1 *SD*) incl. 95% C.I.**

Figure 1 displays a nearly consistent increase of mathematical achievement of all three groups over time. Repeated measurement ANOVAs of mathematical development (see Table 4) demonstrated a persistent main effect of measurement time points (MTPs) during the gradual addition of the proposed covariates (LING, GERM, SES, sex). The effect size in the model ($F(3, 933) = 2357.33$, $p \leq .001$, $\eta_p^2 = .88$) decreased with the addition of LING ($F(2.98, 908.673) = 114.61$, $p \leq .001$, $\eta_p^2 = .27$). This covariate showed a significant main effect ($F(1, 305) = 42.49$, $p \geq .001$, $\eta_p^2 = .12$) in addition to a small interaction effect with MTPs ($F(2.979, 908.673) = 5.28$, Huynh-Feldt-adjusted $p = .001$, $\eta_p^2 = .02$). Furthermore, there was a significant main effect of groups ($F(2, 309) = 142.57$, $p \leq .001$, $\eta_p^2 = .48$) as well as a significant interaction between groups and MTPs which occurred $F(6, 927) = 6.13$, $p \leq .001$, $\eta_p^2 = .04$. Pairwise post-hoc comparisons (LSD-corrected) revealed significant differences ($p < .001$) between all groups (MLA x MAA: -1.21 – *CI* [-1.44, -.98]; MAA x MHA: -1.41 – *CI* [-1.65, -1.17]; MLA x MHA: -2.62 – *CI* [-2.92, -2.31]). SES showed also a significant main effect ($F(1, 287) = 34.34$, $p \leq .001$, $\eta_p^2 = .11$) as well as a small significant interaction with MTPs ($F(2.979, 854.848) = 5.98$, Huynh-Feldt-adjusted $p = .001$, $\eta_p^2 = .02$). The other covariates showed non-significant effects. Additional computed univariate ANOVAs showed influences for SES as well as LING of all MTPs. The effect sizes for SES as well as LING are significantly larger for the MTPs in primary school (SES: t2: $\eta_p^2 = .09^{***}$; t3: $\eta_p^2 = .04^{***}$; t4: $\eta_p^2 = .09^{***}$; LING: t2: $\eta_p^2 = .07^{***}$; t3: $\eta_p^2 = .07^{***}$; t4: $\eta_p^2 = .04^{***}$) than for pre-school-age (SES: t1: $\eta_p^2 = .03^{**}$; LING: t1: $\eta_p^2 = .02^{**}$). With controlled influence of GERM on LING, separate ANOVAs excluding LING as covariate were computed. Repeated measurement ANOVA revealed no significant effect of GERM. Instead of LING, univariate ANOVA for the first MTP of mathematics bore a significant but low effect of GERM ($F(1.313) = 4.704$, $p = .031$, $\eta_p^2 = .02$).

Figure 1 visualizes the development of linguistic competence differences (vocabulary and grammar) between the three groups over time. Since linguistic data was only provided as separate sum scores the development of linguistic competencies should be interpreted by the change of the differences between the groups at each time point.

Table 4. ***Repeated measures ANOVA of the four measurement time points of mathematical competencies (K-4th)***

	$\eta_p^2(F)$	$\eta_p^2(F)$	$\eta_p^2(F)$	$\eta_p^2(F)$	$\eta_p^2(F)$	$\eta_p^2(F)$
Mathematics	**.88 (2357.33***)**	**.81 (1283.66***)**	**.27 (114.61***)**	**.21 (78.92***)**	**.15 (50.72***)**	**.10 (31.99***)**
Mathematics*Group	–	**.04 (6.13***)**	**.05 (7.99***)**	**.05 (7.85***)**	**.05 (7.64***)**	**.05 (7.60***)**
Mathematics*LING	–	–	**.02 (5.28***)**	**.02 (5.64***)**	**.02 (4.46**)**	**.02 (4.55**)**
Mathematics*GERM	–	–	–	.00 (.44)	.01 (1.92)	.01 (1.94)
Mathematics*SES	–	–	–	–	**.02 (5.98***)**	**.02 (5.38***)**
Mathematics*Sex	–	–	–	–	–	.01 (1.80)

Notes. Repeated measures ANOVA with gradual addition of the covariates. LING = Linguistic competence level; GERM = German as main-domestic language; SES = socioeconomic status; $n = 338$; $\eta_p^2(F)$ = partial eta-squared; F = F-Statistics; *= $p \leq .05$, ** = $p \leq .01$, *** = $p \leq .001$.

As can be seen in the figure, vocabulary building pointed to decreasing differences between groups during primary school. The separately computed ANOVAs of the three MTPs for vocabulary (see Table 5) confirmed this assumption (t1 Brown-Forsythe corrected). Furthermore, language played a more prominent role in preschool than in primary school years: In the age of 4/5 years (t1), GERM elicited significant effects ($F(1, 315) = 46.94$, $p \leq .001$, $\eta_p^2 = .13$) besides LING ($F(1, 315) = 237.67$, $p \leq .001$, $\eta_p^2 = .43$). In primary school years (t2 and t3) the effect of LING decreased during a complete loss of the GERM in first school year. Controlling excluded LING showed significant but considerably smaller effects of GERM for all time points (t1: $F(1, 310) = 75.67$, $p \leq .001$, $\eta_p^2 = .20$; t2: $F(1, 313) = 16.25$, $p \leq .001$, $\eta_p^2 = .05$; t3: $F(1, 300) = 18.23$, $p \leq .001$, $\eta_p^2 = .06$). In addition, the general ANOVAs (see Table 5) revealed a small effect of SES in primary school. Furthermore, results of changing differences between the several MTPs based on mean difference tests (Bonferroni corrected) under consideration of the covariates proved visualized tendencies of approach for MLA. In contrast to changes in differences between MAA and MHA (t1: .033; t2: .057; t3: .045), the comparison of vocabulary performance between MLA and MAA (t1: .051; t2: .055; t3: .026) as well as MLA and MHA (t1: .084; t2: .112; t3: .071) pointed to a catch up of the lower vocabulary performance from pre-school age.

Grammar, which was only collected since 1st grade of primary school, shows a different picture (see Figure 1): By having a significant main effect of the models for both MTPs (see Table 5), the computed differences under consideration of the covariates indicated stronger impairment for grammar performance of MLA in comparison to MAA (t1: .028; t2: .084) and MHA (t1: .065; t2: .157) as well as MAA to MHA (t1: .037; t2: .073). As seen in Table 5, univariate ANOVAs showed an increasing main effect of group between 2nd year of Kindergarten (4/5 years) and 1st grade of primary school (6/7 years) (t2 Brown-Forsythe corrected). Language showed a very large significant effect in preschool while supporting a large effect in 1st grade. In this measurement time point, SES as well as sex also revealed significant effects of the comparison of grammar performance.

Discussion

Main objective of the presented study was to examine whether children with weak mathematical pre-school skills are able to catch up within primary school compared to their peers. In addition, the linguistic (vocabulary and grammar) development of these children was studied in comparison to the development of children with higher mathematical performance. In this process, influences of linguistic and socioeconomic background characteristics could be identified. Sex-dependent influences were controlled.

Table 5. ***Linguistic development (vocabulary and grammar) from pre-school age (4/5 years) till 3rd grade of primary school (8/9 years)***

Vocabulary	*MTP 1*	*MTP2*	*MTP3*
Model	**$F(6, 315) = 94.24, p < .001, \eta_p^2 = .65$**	**$F(6, 315) = 42.49, p < .001, \eta_p^2 = .45$**	**$F(6, 303) = 27.88, p < .001, \eta_p^2 = .36$**
Group	**$F(2,315) = 9.10, p < .001, \eta_p^2 = .06$**	**$F(2, 315) = 10.58, p < .001, \eta_p^2 = .06$**	**$F(2, 303) = 5.23, p = .006, \eta_p^2 = .03$**
LING	**$F(1,315) = 237.67, p < .001, \eta_p^2 = .43$**	**$F(1, 315) = 108.65, p < .001, \eta_p^2 = .26$**	***$F(2, 303) = 69.58, p < .001, \eta_p^2 = .19$***
GERM	**$F(1, 315) = 46.94, p < .001, \eta_p^2 = .13$**	$F(1, 315) = 2.53, p = .112, \eta_p^2 = .01$	**$F(1, 303) = 5.46, p = .020, \eta_p^2 = .02$**
SES	$F(1, 315) = 2.89, p = .090, \eta_p^2 = .01$	**$F(1, 315) = 10.92, p < .001, \eta_p^2 = .03$**	**$F(1, 303) = 6.35, p = .012, \eta_p^2 = .02$**
Sex	**$F(1, 315) = 4.00, p = .046, \eta_p^2 = .01$**	$F(1, 315) = 0.02, p = .963, \eta_p^2 = .00$	$F(1,303) = .54, p = .464, \eta_p^2 = .00$
Grammar	*MTP 1*	MTP2	
Model	**$F(6, 315) = 70.85, p < .001, \eta_p^2 = .58$**	**$F(6, 315) = 36.45, p < .001, \eta_p^2 = .41$**	
Group	**$F(2, 315) = 5.20, p = .006, \eta_p^2 = .03$**	**$F(2, 315) = 20.19, p < .001, \eta_p^2 = .12$**	
LING	**$F(1, 315) = 251.68, p < .001, \eta_p^2 = .45$**	**$F(1, 315) = 63.05, p = .010, \eta_p^2 = .17$**	
GERM	**$F(1, 315) = 6.06, p = .014, \eta_p^2 = .02$**	$F(1, 315) = .14, p = .713, \eta_p^2 = .00$	
SES	$F(1, 315) = 1.58, p = .210, \eta_p^2 = .01$	**$F(1, 315) = 18.41, p < .001, \eta_p^2 = .06$**	
Sex	$F(1, 315) = 1.24, p = .267, \eta_p^2 = .00$	**$F(1, 315) = 10.73, p < .001, \eta_p^2 = .03$**	

Notes. Univariate ANOVAs. GERM = German as main-domestic language; LING = Linguistic competence level. $n = 338$; *= $p \leq .05$, ** = $p \leq .01$, *** = $p \leq .001$.

From pre-school age to 4th grade of primary school, data showed a nearly consistent persistence of mathematical differences between mathematical low achieving children and children with higher mathematical achievement. In line with recent research (Geary, 2011), this developmental pattern could be attributed to both, a parallel occurrence of (partial) catch ups and a persistence in mathematical development of low achieving individuals. Both indicate that, in general, pre-school deficits in mathematics are usually not compensated through school instruction. Regarding language development we find a more complex pattern in children with a history of pre-school mathematical limitations with respect to vocabulary and grammar. Children with weak mathematical skills seem able to overcome deficits of pre-school vocabulary weaknesses. For grammatical achievements, however, the gap to their peers appears to widen. These results go along with the above cited study which investigated the development of children with language limitations in early childhood (Rice et al., 2008). The timing of the gap between high and low achievers within the present study (6/7 years) is consistent with the neuropsychological reasoning (CITE). At that age, the window for best obtainment of grammatical abilities starts to narrow (Markowitsch & Weltzer, 2010).

The observation that language is strongly related to mathematical skills was not only confirmed with correlations for the vocabulary and grammar skills at several time points. In agreement with previous studies (Fischbach et al., 2013) half of the children with low mathematical competencies were also characterized by low linguistic competencies. These linguistic skills also had an impact on the mathematical development over time. 23 % of children with low linguistic competencies in MLA showed a low level of German as main domestic language and/or the socioeconomic background simultaneously. Our results point to the importance of the environmental influences like the parental input (Hoeft et al., 2015). Influences of pre-school linguistic competencies on the development of vocabulary and grammar decreased over time while maintaining a high level. Besides, the socioeconomic family background grew more meaningful during school. The influence of this background variable of the access to education in Germany was already shown in large scale student assessments like IGLU or TIMSS (Hoeft et al., 2015). For the presented study, both influences in mathematics, linguistics and socioeconomic background, increased their power over time. In agreement with other studies (Schlitter & McElvany, 2018), grammar skills in school also point to (in this study small) sex-specific influences of academic vocabulary skills.

Although the present investigation is the currently best compromise between approximately representative national panel data and the requirements to answer questions within the mathematical and linguistic development of children with a pre-school history of mathematical impairment in more detail, some issues remain unclear. Due to the fact that the competence scores of the available data (NEPS) were not uniformly anchored throughout, it was not possible to calculate a growth curve model. Additional problems arose from the complexity of the model, so that the sample size was not sufficient for ample model identification. Further analyses based on longitudinal large-scale data with ideally equal groups of mathematical preconditions would make it possible to specifically identify which development patterns at the individual child level underlie the persistent development of mathematical skills.

Although the results reached significance some effect sizes were rather small. Therefore, the level of relevance, particularly of practical relevance, can only be estimated to a limited extent. Also, the available data did not allow controlling for possibly existing differences of patterns through different mathematical task types. In addition, it was not possible to conclusively clarify in which specific skills besides linguistics children with lower mathematical achievement failed solving applied mathematical tasks. Research results of reduced activations in numerical and verbal brain regions by mathematically low achieving children (Berteletti, Prado, & Booth, 2014) as well as a reduced performance of working memory by children characterized by mathematical and/or linguistic weaknesses (Geary, 2011) could contribute to this clarification. Based on the presented study, further research should pay attention to such cognitive abilities.

In summary, the presented study contributes to the identification of relationships between underlying mathematical and linguistic deficits in children moving from preschool through primary education. In line with the current educational debate, special attention should be paid to language in mathematics not only in school but already in kindergarten resp. pre-school years. The solid impact of early mathematical weaknesses on later school achievements demands closer attention on school and especially pre-school promotion of mathematical basic skills. It will be certainly profitable to take approaches into consideration that focus on existing gaps in preschool education (Krajewski, 2014). As the tremendous impact of language – vocabulary and grammar – on mathematical acquisition is recognized we might be able to better address educational inequalities resulting from educational and linguistic backgrounds of children.

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