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Casting the die before the die is cast: the importance of the home numeracy environment for preschool children

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Abstract Mathematical competencies are important not only for academic achievement at school but also for professional success later in life. Although we know a lot about the impact of "Home Literacy Environment" on the development of early linguistic competencies, research on "Home Numeracy Environment" (HNE) and the assessment of its influence on the development of mathematical abilities is in its infancy. We still lack studies analysing this relationship and simultaneously controlling for other variables concerning the individual and the environment. Thus, in this article, we focussed on the development of mathematical competencies in a sample of 609 German children from the end of kindergarten until the end of Grade 1. In particular, we were interested in the role HNE plays in regard to this development while controlling for age, sex, intelligence, rapid naming, number span, linguistic competencies, kindergarten attendance and socioeconomic status. Moreover, HNE was compared between families with or without a history of mathematical disability. HNE was not only an important predictor of mathematical abilities at the end of kindergarten, but it also influenced the further development of mathematical competencies above and beyond its initial impact. Families with a history of dyscalculia provided a more unfavourable HNE than families with no such problems. Results are shown in a structural equation model, which highlights the importance of HNE. The findings indicate that those involved in policy and intervention should focus more on the learning environments in families to improve children's achievement.

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Mathematical competencies play a major role in everyday life, and good numeracy skills facilitate performance on many tasks. Moreover, many professions require certain mathematical abilities. Thus, "mathematics" is an important subject in school, and mathematics in general is of significance for academic and life success (cf. Duncan et al. 2007; Geary 2000).

Accordingly, it is important to support children in the development of their mathematical competencies—even from an early age. Clearly, formal learning of mathematical processes and rules is a major task for teachers in school; however, early mathematical competencies begin developing before the onset of schooling (cf. Butterworth 2005). In the current paper, we investigate whether parents and the learning environment they create at home play a role in the development of early mathematical competencies. We report results of studies analysing the influence of home learning environments on mathematical competence and investigate reasons for differences in specific mathematical learning environments before introducing early mathematical competencies and relevant predictors.

Learning environments and children's development

Although individual characteristics of children predict math achievement fairly well, the influence of learning environments on the development of these competencies needs to be considered. For instance, it has been shown that both kindergarten attendance and the duration of that attendance have an impact on academic achievement (e.g. Sylva et al. 2008; Walston and West 2004). Children who attend kindergarten for a longer time period develop somewhat greater mathematical competencies, compared to children who do not attend kindergarten or do so only for a limited period of time.

In addition to kindergarten education, experiences in the family influence the early development of children. Here, the concept of the so-called "Home Literacy Environment" (HLE) can be differentiated from the concept "Home Numeracy Environment" (HNE). Whereas aspects of HLE predict linguistic competencies (e.g. Hood et al. 2008; Rashid et al. 2005), HNE is more predictive of mathematical competencies (e.g. Dearing et al. 2012; Kleemans et al. 2012; LeFevre et al. 2009).

In comparison to the large number of studies on HLE, research on HNE is relatively scarce. By now, it is well established that HLE, parent reading behaviour, the amount of parent–child reading and the number of books in the household are interrelated with later reading abilities of children even after controlling for intelligence and working memory (cf. Davidse et al. 2011; Niklas and Schneider 2013). Here, HLE acts as a mediator between the more general concept of the socioeconomic status (SES) of the family, often measured by the prestige of parents occupation, and linguistic competencies (Niklas and Schneider 2013).

Although there is plenty of evidence for the importance of HLE for children's linguistic development, its role in regard to mathematical competencies remains unclear. Niklas and Schneider (2010) found a significant correlation between HLE and early knowledge about numbers and quantities. However, when other variables such as age, SES, or intelligence were controlled for, <1 % additional variance in the mathematical precursors was explained by HLE. Other studies also found HLE to be a specific predictor for linguistic skills, but not for mathematical competencies (Christian et al. 1998; Griffin and Morrison 1997).

Melhuish et al. (2008) created a broadly defined construct (i.e. "Home Learning Environment") consisting of mathematical and linguistic activities, such as the frequency of playing with numbers as well as the frequency the children were read to. This construct did significantly predict linguistic as well as mathematical abilities. Presumably, a more specific interrelation between the learning environment in families and mathematical abilities can be expected when learning environments are restricted to mathematical contexts.

The importance of the "Home Numeracy Environment" for children's mathematical competencies was shown by LeFevre et al. (2009). In their study, the frequency of activities indirectly connected to numbers such as playing dice games was weakly but significantly correlated with mathematical competencies at school enrolment (see also Blevins-Knabe and Musun-Miller 1996). More than two decades ago, Resnick (1989) emphasised the finding that the exposure to numbers in daily family life is decisive for the development of mathematical abilities. Children gathering more number experience at home show greater mathematical competencies later in school.

With respect to the conceptualisation of HNE, direct and indirect math-related activities can be differentiated (LeFevre et al. 2009). More specifically, incidents of formal mathematical learning in the family in which parents instruct their children to count or calculate are to be distinguished from indirect mathematical learning, for instance in the case that dice games are played. Both learning contexts seem to support the development of mathematical competencies. However, it is not yet evident which is more important (cf. Huntsinger et al. 2000; LeFevre et al. 2010; LeFevre et al. 2009).

Interestingly, SES played only a minor or indirect role in prediction of early academic achievement in comparison to the home learning environment (Dearing et al. 2012; Krajewski and Schneider 2009; Melhuish et al. 2008; Niklas 2011). For instance, Krajewski and Schneider (2009) demonstrated that SES was important only for later but not for early mathematical abilities. Thus, it seems more important to explore how parents interact with their children than to assess their occupation or educational status.

Differences in home numeracy environments

Recent research showed that differences in HNE influence the mathematical abilities of children (e.g. Kleemans et al. 2012). Therefore, it is also of interest to research why HNE differs between families. For instance, Musun-Miller and Blevins-Knabe (1998) showed that the significance attributed to mathematics by parents correlated with the frequency of mathematics-related activities in the family.

Moreover, parents with a more positive attitude towards mathematics explained more complex mathematical concepts to their children than parents with a negative attitude towards mathematics, thereby promoting the development of their children's mathematical competencies (Skwarchuk 2009). In this context, the experience of parents with mathematics seems to be formative. Hyde et al. (2006) demonstrated that mothers with low mathematics self-confidence and with weaker mathematical competencies performed worse when helping their children with mathematics homework.

Achievement in mathematics is closely associated with the development of mathematical self-concept, with lower math performance corresponding to a lower math self-concept (Marsh et al. 2005). This pattern is also true for individuals with learning disabilities (Möller et al. 2009) such that a mathematical disability often leads to a lower mathematical self-concept and a more negative attitude towards mathematics. Parents with a lower mathematical self-concept are often less engaged in promoting the development of mathematical competencies of their children. Therefore, it is to be expected that families with a history of mathematical disability provide a less favourable HNE.

Early mathematical competencies and their precursors

The foundation of good mathematical skills is laid very early in the school career of children, and mathematical achievement at the beginning of primary school is among the best predictors for later academic achievement in secondary school and early adulthood (cf. Claessens et al. 2009; cf. Stern 2009). In the beginning of primary school, mathematical abilities consist mainly of knowing the Arabic number symbols, calculating small sums, linking numbers to quantities or solving easy geometry tasks (e.g. Krajewski and Schneider 2009).

However, it seems important to note that mathematical learning starts even before school enrolment and that infants aged less than a year already show certain mathematical competencies, such as preverbal counting or differentiation of small quantities (cf. Butterworth 2005; Wynn 1990). Before children enter school, they often are able to name many numbers, count up to about 40 and add and subtract small numbers (Butterworth 2005). This emphasises the important role families play in the early development of mathematical competencies of children as most of these competencies will be acquired in the context of the family.

Recent longitudinal studies have identified informal mathematical knowledge components in kindergarten children predicting later mathematical abilities at the end of primary school. In particular, the early understanding of quantities, numbers, and the relation between quantities and number words seem to be of utmost importance (Geary 2011; Krajewski and Schneider 2009). Children who are able to identify more number symbols, count better and are able to match amounts of objects to numbers earlier in their development than other children also do better in mathematics later in school. Thus, these factors, which are influenced by the home numeracy environment, are very specific predictors of mathematical achievement above and beyond the contribution of more general abilities such as intelligence or working memory (Krajewski and Schneider 2009; Niklas 2011).

However, the role of intelligence and working memory in the development of mathematical competencies cannot be ignored. Although being unspecific, and thus also influencing, for instance, linguistic competencies, these variables show close interrelations with mathematical competencies and have been shown to explain a substantial amount of variance in academic achievement (cf. Gustafsson and Undheim 1996; Passolunghi et al. 2007). For instance, Swanson's analyses (2006) revealed that working memory is an important predictor of mathematical competence. Intelligence was also found to be a reliable predictor for early mathematical competencies and subsequent development of these competencies (e.g. Niklas 2011). However, the amount of variance explained by intelligence and working memory in mathematical achievement might decrease, or even be of no significance when other variables such as early literacy skills or HNE are taken into account (cf. Kleemans et al. 2012).

Besides intelligence and working memory, other variables are important for mathematics as well, such as linguistic abilities and rapid naming. For instance, deficits in rapid naming were found for children with dyscalculia (Willburger et al. 2008), and in longitudinal studies ranging from kindergarten age until the end of primary school, it was a good predictor for later mathematical achievement (Koponen et al. 2007; Krajewski and Schneider 2009). Also for linguistic measures, such as phonological awareness (PA) and thus the ability to identify or work with rhymes or phonemes, or vocabulary close interrelations with mathematical competencies were found (cf. Dearing et al. 2012; Kleemans et al. 2012; Krajewski et al. 2008).

Moreover, early differences in math performance between the sexes can be observed in some countries. In Germany, where this study took place, boys outperform girls in mathematical tasks from the beginning of Grade 1 onwards (cf. Niklas and Schneider 2012; Bonson et al. 2008).

Research questions

To date, research on HNE has been relatively scarce, and there are no generally accepted definitions and operationalisations of the construct "Home Numeracy Environment" in the literature. Given that recent research demonstrates the role the specific learning environment in a family can play in the early development of mathematical competencies, we carried out a study that tried to provide new information about the interrelation between HNE and early mathematical competencies. First, we assumed that a less favourable HNE is provided by families with a history of mathematical learning disabilities. A second assumption was that HNE should be associated with subsequent mathematical competencies. More specifically, children who experienced a more favourable HNE should achieve greater mathematical performance. Third, we tested the hypothesis that HNE not only predicts mathematical competencies in kindergarten but also predicts the further development of these competencies in Grade 1, even after other relevant factors such as intelligence, working memory, linguistic competencies, kindergarten attendance, SES, age and gender have been controlled for.

Method

Sample

Data analyses were carried out in the context of a large-scale longitudinal study in South Germany (Project "The school-prepared child", cf. Hasselhorn et al. 2012). In Germany, most children enter primary school at the age of 6 years. Before school enrolment, almost all German children attend kindergarten for some years. In German kindergartens, almost no formal teaching occurs, even though there are many incidences of informal learning.

The relevant assessments started about 18 months before school enrolment (t1), when the children were about 4;10 years old and attended kindergarten. This first assessment was repeated in kindergarten after 15 months shortly before school enrolment (t2). Further assessments were conducted 1 month after school enrolment (t3) and at the end of Grade 1 (t4).

In total, N=609 children (46.5 % girls and 53.5 % boys) with parental consent were included in the analyses. For these children information about HNE could be obtained at t2. Mean age of the sample at the time of school enrolment was M=77 months (SD=4.5; min=63; max=96). The children attended 63 kindergartens in South Germany and were mainly from urban environments (about 80 %).

All children were tested individually in kindergarten as well as at the beginning of Grade 1, with assessments distributed across several days. At the end of Grade 1, group assessments were carried out. Each individual testing in kindergarten and primary school lasted about 30 min, and the group test in Grade 1 lasted about 40 min.

Some children dropped out due to illness or holidays, and had missing data due to the fact that testing was distributed across several days. As a consequence, complete data of only N=493 children were available for the kindergarten period (t1 and t2). Upon school enrolment, even more children dropped out, as they were now distributed across more than 120 schools. Due to organisational constraints, only 30 schools could be further investigated in the project. Moreover, some of the children were retained from school enrolment, and for others, their parents did not give further consent. Thus, complete data sets from only N=340 children could be obtained in kindergarten as well as in primary school.

Missing data analysis revealed no differences between children who dropped out at t3 and those who were retained in regard to sex, migration background and kindergarten attendance. However, both groups differed regarding their intellectual and mathematical skills, their age, Home Numeracy Environment and SES (p<.05). Children for whom data at t3 and t4 could be obtained were older, had greater intellectual and mathematical competencies and their parents provided a more favourable HNE. Interestingly, parents of children who dropped out had occupations with a higher prestige and thus a higher SES. The impact of these differences on the results of this study will be discussed in the limitations section.

Test instrumentation

Although a large number of test instruments were used in the project "The school-prepared child", only those test instruments relevant for our analyses will be described in the following.

Intelligence

A German version of the Columbia Mental Maturity Scale (CMM; Burgemeister et al. 1972) was used to assess intelligence at both assessments in kindergarten. Children had to identify the odd picture in an array of four or five pictures (e.g. one spoon and three forks). Reliability and prognostic validity of the CMM are adequate, and the test represents a good measure for later school achievement (cf. Esser 2002; split-half reliability ranging between .92 and .96).

Rapid naming

Children's prompt retrieval of information stored in long-term memory was tested by a rapid naming task in kindergarten. Here, the children had to name pictures selected to be of a low difficulty level in random order three times (fish, ball, house, dog, tree, ice). They required in total approximately between 10 and 70 s to name all 18 pictures, with group means of 28.5, and 23.7 s at t1, and t2, respectively.

Number span

Auditive working memory was tested by a number span task in kindergarten. Here, the children had to repeat series of two to six numbers presented by CD. The internal consistency of this task from the Heidelberger auditory screening battery ("Heidelberger Auditives Screening in der Einschulungsuntersuchung"; Schöler and Brunner 2008) is sufficient (Cronbach's α>.70; cf. Schöler and Schäfer 2004).

Phonological awareness

Three tasks measuring PA were administered. At both, t1 and t2, a test was provided that required children to find two rhymes for each of five given words (e.g. house). Additionally, at the first measurement point (t1), the rhyme identification task from the Bielefelder Screening (Jansen et al. 2002) was presented, in which the children had to decide whether two given words were rhymes. This task was substituted by a version of the classic rhyme categorisation task by Bradley and Bryant (1985) at measurement point t2. Here, the children had to decide which of four given words sounded odd and did not rhyme with the other words (e.g. “Saum, Baum, Laut, Raum”). The internal consistency for the PA sum score was sufficient for t1 and t2 (Cronbach's α=.66 and .65).

Vocabulary

Children's active vocabulary was measured by the first part of the revised vocabulary test for 3- to 5-year-old children (“Aktiver Wortschatztest für 3- bis 5-jährige Kinder—Revision”; Kiese-Himmel 2005). Here, children had to name 35 pictures, and the test included nouns as well as verbs. In our sample, the internal consistency for the vocabulary sum score, consisting of naming nouns and verbs, was .86 and .79 for t1 and t2.

Measures of mathematical competencies

In kindergarten (t1 and t2), the precursors of mathematics were assessed using the adaptation of a test battery for young children developed by Krajewski (2005; cf. Krajewski and Schneider 2009). Here, the children had to count up to 21, name numbers, solve easy calculation problems, match numbers to quantities and compare different quantities of black dots. The internal consistency was sufficient (Cronbach's α=.85 and .75).

About 1 month after school enrolment (t3), the children were assessed with the German version of the computerised test battery “Performance Indicators in Primary School” (PIPS; Tymms and Albone 2002). Here, among other competencies (e.g. phonological awareness, early reading), early mathematical competencies were also assessed. The children had to solve easy and difficult addition and subtraction tasks, name two and three digit numbers, calculate with coins, continue rows of numbers in a meaningful way and solve some geometry tasks. The raw data were analysed at the “Centre for Evaluation & Monitoring” in the UK, and we used the provided sum score in our analyses (internal consistency, α=.86).

At the end of Grade 1 (t4), children's mathematical abilities were assessed with the curriculum-based and standardised test “Deutscher Mathematiktest für erste Klassen” (DEMAT 1+; Krajewski et al. 2002). The nine subtests of the DEMAT 1+ required children, for instance, to calculate, to solve written maths problems or to link numbers to quantities. The psychometric characteristics of this test are good (internal consistency α=.89).

Questionnaires

In addition, questionnaires were used to gain further information about the children. For instance, kindergarten teachers were asked about the kindergarten attendance of the children, and the parents were asked about aspects of the family situation relevant for the assessment.

Kindergarten attendance

Information about kindergarten attendance consisted of two variables, that is, daily attendance in hours and years of kindergarten attendance at the beginning of the study (t1). The product “years×hours a day” thus reflects the intensity of the contact with the kindergarten the children had at t1. It was calculated for N=558 children and yielded values between 1 and 31.5 (M=9.8, SD=5.1).

Socioeconomic status

The SES was estimated based on the greatest prestige of both parental occupations (cf. Wegener 1988). The prestige scale ranged from 20 (unskilled labourer) up to 186.8 (physician). Information about occupations of N=551 households was obtained. The average highest prestige score in our sample was M=76.7 (SD=36.8).

Information on "Home Numeracy Environment" and mathematical disabilities in the family

At t2, parents were asked about mathematical activities in the family and experiences with mathematical disabilities. Given that the project "The school-prepared child" was concerned with a variety of research issues, only a few questions on this topic could be presented to the parents. For instance, parents were asked whether someone in their family had experienced a mathematical disability or not. In total, 6.8 % (N=41) of the 600 parents answering this question reported such a disability in their family, a prevalence quite realistic for unselected samples (cf. Shalev et al. 2000).

The HNE was obtained by three questions tapping certain games parents played with their child. The parents were asked how often they played dice games such as "Ludo", counting games such as "Kosmolino: 1,2,3", and calculation games such as "I learn to calculate" together with their child. The items had to be rated with a five step scale ("several times a week", "once a week", "every second or third week", "less frequently", "never"). Afterwards, the answers were assigned values of 4 through 0 and were added up to a sum score. Data were obtained for N=609 families. Observed values ranged from 0 to 12 with a mean of M=7.5 (SD=3.1). The internal consistency of the sum score was sufficient (Cronbach's α=.76). We used this operationalisation as previous studies showed that playing games with a mathematical content appeared to be successful in enhancing mathematical competencies of children (e.g. Ramani and Siegler 2008).

Table 1 shows an overview of all assessed variables.

Analysis overview

In a first step of analysis, descriptive statistics and the results from correlational analyses will be presented. Next, the "Home Numeracy Environment" provided by families with a history

Table 1 Overview of the assessed variables

	Kindergarten		Grade 1	
	t1 (Spring '08)	t2 (Summer '09)	t3 (Autumn '09)	t4 (Summer '10)
Mathematical competencies	Mathematical precursors	Mathematical precursors	PIPS (Mathematics)	DEMAT 1+ (Mathematics)
Control variables	Kindergarten attendance, age; sex; SES;			
	Intelligence	Intelligence		
	Rapid naming	Rapid naming		
	Number span	Number span		
	Phonological awareness	Phonological awareness		
	Vocabulary	Vocabulary		
Mathematical aspects in the family		Questions on HNE & disabilities		

mathematical disabilities will be compared to HNE provided in families with no such disabilities.

In a subsequent step, the development of mathematical competencies and the influence of HNE on this development will be analysed via structural equation modelling (SEM), using the "Full Information Maximum Likelihood" method (cf. Enders 2001; Peugh and Enders 2004). Using this method, the model is specified for all cases, including those cases for which no complete data sets could be obtained. All observed values are taken into account in estimating the model parameters. This statistical method is regarded as one of the best for handling missing data problems (cf. Graham 2009).

As the same mathematical test battery was used at the first two measurement points, correlations of measurement errors for those subtests can be permitted in the SEM. The "Comparative Fit Index" (CFI), the "Incremental Fit Index" (IFI) and the "Tucker Lewis Index" (TLI), the "root mean square error of approximation" (RMSEA) as well as the ratio of chi^2 and degrees of freedom (*df*) are reported as measures of model fit.

As to the specification of the SEM, we expected HNE to be predicted partly by mathematical disabilities in the families. The variance of mathematical abilities at the end of kindergarten (t2) should mainly be explained by the mathematical abilities of the children one and a half year earlier (t1). In addition, we used an exploratory approach to test whether intelligence, rapid naming, number span, phonological awareness, vocabulary, SES, duration of kindergarten attendance, age of the children and HNE also have a direct impact on the mathematical abilities at t2, over and above the earlier mathematical abilities.

Children's initial mathematical competencies at the beginning of Grade 1 (t3) should mainly be predicted by the specific precursors at t2. Contrary to the other measures of mathematical ability, we introduced the PIPS sum score (mathematics t3) as a manifest variable in the model. As sex differences in mathematical competencies may be expected to emerge very early in German primary schools, we included such a path. The assumption was that boys should outperform girls.

Finally, we assumed that mathematical abilities at the end of Grade 1 (t4), assessed with a standardised and curriculum-based test, should mainly be predicted by mathematical competencies at the beginning of Grade 1 (t3). We again used an exploratory approach and allowed paths from all other variables to influence mathematical abilities. This allowed us to test whether HNE has an additional association with the development of competencies in primary school even after other related variables and initial competencies have been controlled for.

Mathematical disabilities in the family, age, sex, SES, kindergarten attendance and mathematics at t3 were included as manifest variables in the model, whereas all other variables were introduced as latent constructs. All insignificant paths were removed in a second step, leading to the final model.

Results

Descriptive statistics and correlational analyses

Table 2 presents the results of the correlational analyses of HNE with the control variables and the mathematical measures as well as the descriptive statistics.

As can be seen from Table 2, there are high interrelations among all mathematics-related measures. We found small but significant correlations between HNE and the mathematical competencies from t2 onwards (HNE was obtained at t2). There were no significant interrelations between HNE and the control variables (also not with control variables at t1,

Table 2 Correlations of "Home Numeracy Environment" with control variables and dependent variables and descriptive statistics

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
(1) HNE		−.08*	.05	−.06	.01	−.17**	.03	−.01	−.04	−.04	−.06	.01	.09*	.12*	.15*
(2) Mathematical disabilities in family[a]			−.07	.00	.01	−.10*	.02	.06	−.14*	−.10*	−.09*	−.09*	−.05	−.08	−.09
(3) Sex[b]				.03	.01	.06	−.06	.00	−.06	−.05	.00	.07	.02	.28**	.13*
(4) Age in months at school enrolment					.08	.01	.13*	−.09*	.01	.06	.02	.33**	.21**	.12*	−.01
(5) Kindergarten attendance						.04	.03	−.04	.05	.08	.08	.14*	.09*	−.04	.08
(6) SES							.10*	−.08	.11*	.31**	.37**	.24**	.19**	.18*	.08
(7) Intelligence t2								−.14*	.14*	.38**	.32**	.40**	.41**	.30**	.24**
(8) Rapid naming in sec. t2									−.19**	−.22**	−.17**	−.30**	−.25**	−.27**	−.07
(9) Number span t2										.38**	.25**	.35**	.32**	.34**	.25**
(10) Phonological awareness t2											.53**	.49**	.45**	.41**	.25**
(11) Vocabulary t2												.40**	.39**	.34**	.32**
(12) Precursors mathematics t1													.62**	.62**	.48**
(13) Precursors mathematics t2														.61**	.47**
(14) Mathematics—beginning of Grade 1															.54**
(15) Mathematics—end of Grade 1															
Means	7.50	.07	.54	77.02	9.84	76.67	52.27	23.72	5.28	13.21	29.81	17.73	25.80	26.59	23.81
SD	3.12	.25	.50	4.51	5.06	36.76	3.95	6.87	1.51	4.65	5.86	7.27	4.00	7.69	7.49

*$p<.05$; **$p<.001$

[a] 0=no disability; 1=mathematical disability

[b] 0=girls; 1=boys

which are not listed in Tab. 2), except for SES. Surprisingly, a higher SES corresponded with a lower HNE, although positive interrelations with mathematical abilities were found for both measures.

In terms of the control variables, intelligence, number span, phonological awareness, and vocabulary showed the highest correlations with the mathematical competencies. For age, kindergarten attendance and rapid naming, significant intercorrelations were only found with the earlier mathematical measures, but not with those obtained at the end of Grade 1. On the contrary, sex interrelated significantly with mathematical competencies only from the beginning of Grade 1 onwards. Finally, there was a significant difference in HNE provided by families with a history of mathematical disability (M=6.58) in comparison to the other families [M=7.59; t (598)=1.99; p<.05; ES=.32].

HNE and competency development

As the correlational analyses were based on a reduced sample due to drop-out problems, in a second step the development of mathematical competencies was examined via structural equation modelling for the whole sample. All insignificant paths and variables were removed from the SEM, and Fig. 1 presents the final model and measures of model fit. The CFI, IFI and the TLI exceeded .90, the RMSEA was below .05, and the ratio of chi^2 and df was below 3, indicating a very good model fit to the data (Weiber and Mühlhaus 2010).

On the right-hand side of Fig. 1, one can see the chronological sequence from top to bottom, starting with the mathematical abilities at the beginning of the study (t1), and ending with academic achievement in math at the end of Grade 1 (t4). As expected, the early precursors of mathematical ability at t1 were the best predictors of mathematical ability at t2. In addition to this latent variable, only intelligence and HNE had a significant influence on math competencies. A small amount of the variance in HNE was explained by mathematical disabilities in some families. Although HNE tended to mediate the relationship between mathematical disabilities in the family and mathematical competencies at t2 and t4, our mediation tests showed no significant mediation for both, t2 and t4 (Goodman test; p<.10, but p>.05).

Mathematical competencies at the beginning of Grade 1 were mainly predicted by earlier maths abilities, although new test instruments were used in Grade 1. In addition, sex differences were observed at t3. As expected, boys outperformed girls. Finally, mathematical abilities at the end of Grade 1 were predicted by the mathematical competencies at t3, intelligence and HNE.

Neither age nor kindergarten attendance, SES, rapid naming, number span, phonological awareness or vocabulary predicted mathematical abilities at t2 significantly when initial mathematical abilities were also included in the model. The same was true for the mathematical competencies at the end of Grade 1. Thus, these variables were excluded from the final model (represented in Fig. 1 with grey dotted lines).

Discussion

It has been suggested for decades that the learning environment that families provide for their children is highly important for the development of children's competencies (e.g. Resnick 1989; cf. Paris et al. 2006). However, although there has been plenty of research on “Home Literacy Environment” and its significance for early linguistic abilities and later reading and spelling (e.g. Aikens and Barbarin 2008; Niklas and Schneider 2013; Scarborough and Dobrich 1994), research on “Home Numeracy Environment” and its relevance for mathematical development is in its infancy. To explore the impact of HNE further, we analysed the interrelation of HNE with

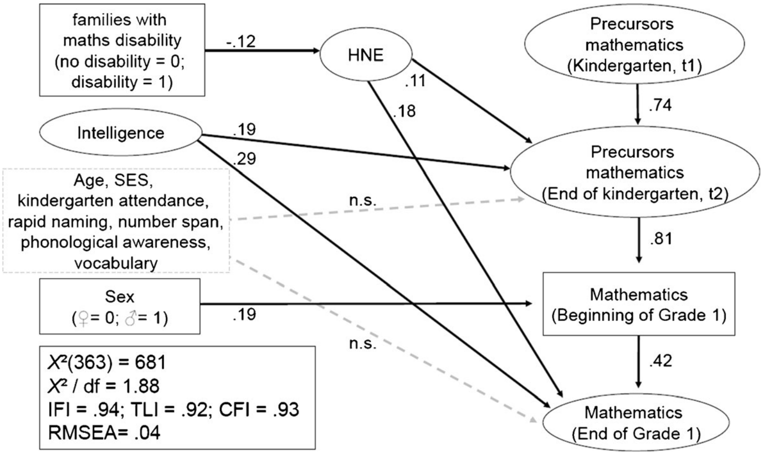

Fig. 1 Structural equation model on the development of mathematical competencies from kindergarten until end of Grade 1

mathematical competencies in German preschool and primary school as well as in relation to mathematical disabilities in the families.

As a main result, HNE was shown to be a reliable albeit moderate predictor of initial mathematical abilities and also predicted further development of mathematical competencies, even after several other variables such as age, sex, SES, intelligence, linguistic variables or working memory were controlled for. Thus, HNE was able to predict early competencies as well as growth in math abilities.

In order to gain better insight in the relationship of HNE and mathematical competencies, we conducted exploratory analyses with the HNE items and mathematical subtests. Of the three HNE items, the frequency of playing dice games showed the closest association with maths abilities. Moreover, we found a positive interrelation between HNE and early number knowledge, as well as a positive relation between HNE and outcomes in the task to compare different amounts of black dots at t2, whereas no significant interrelations between HNE and sums or the matching of numbers to quantities were found. In contrast, HNE was associated with sums and the composition and decomposition of numbers at t4, but not with easy matching of numbers to quantities or number range tasks, in which the children had to visualise numbers on a number line.

Apparently, playing games with a mathematical content helps children with lower competence levels to gain basic number knowledge such as the number names. Later, when children already show certain basic mathematical competencies, playing these games supports the acquisition of more complex knowledge such as how to calculate (cf. Ramani and Siegler 2008; Vandermaas-Peeler et al. 2012). We argue that parents who play these games with their children offer differential support as a function of age and knowledge base of the child. Prior research showed that parents are able to provide sensitive instructions to their children when playing games in a mathematical context, taking into account the competency level of the child (cf. Vandermaas-Peeler et al. 2012). Thus, playing dice or number games in families in everyday life seems to be an easy way of enhancing children's mathematical competencies and prepare them for mathematical instructions in school.

Our correlational analysis showed that the control variables corresponded with the mathematical abilities quite early in the development of mathematical competencies. However, as demonstrated in the SEM analyses, these control variables played only a minor and insignificant role after mathematical competencies at t1 had been included in the structural equation model. Thus, while the control variables were related to mathematical abilities at t1, they did not seem to have an impact above and beyond initial mathematical abilities.

This does not exclude the possibility that they become more important again later on in the development of competencies (cf. Krajewski and Schneider 2009). Moreover, we did not control for the executive system or spatial abilities of the working memory, which may have underestimated the overall effect. Variables tapping these aspects of the working memory explained additional variance in other studies (e.g. Swanson 2006).

Intelligence played an important role in the development of mathematical competencies in our study as it was a good predictor of maths ability. Overall, the evidence in the literature is not consistent. For instance, Passolunghi et al. (2007) found intelligence to be only indirectly linked to mathematical achievement, and as less important as, for example, working memory abilities. In comparison, Ackerman and Lohman (2006) showed that individual differences in intelligence can influence domain knowledge in mathematics directly. More research is needed to identify the significance of intelligence for mathematical competencies in comparison to other variables.

Interestingly, a negative correlation was found between SES and HNE, while both variables were positively related to mathematical abilities. A similar result was also found for the Canadian sample in the analyses by LeFevre et al. (2010). However, no attempt was made by the authors to explain this unexpected result. Ehmke et al. (2006) reported for adolescents from the German PISA sample coming from families with a higher SES also less support in the development of their mathematical competencies by their parents than for adolescents from families with a lower SES. The explanation given by the authors was that children with a higher competence level are less in need of the support by their parents.

Although this explanation seems plausible, we can only speculate about the reasons for this negative relation. It may also be the case that parents with a higher professional status invest less time to interact with their children, and consequently less often play games with a mathematical content. However, available data on the relationship between SES and HLE contradict this assumption (e.g. Niklas and Schneider 2010). That is, parents with a higher SES read more often to their children and visit libraries more often with their children than parents with a lower socioeconomic status. Another explanation could be that parents with a higher SES value linguistic competencies more than mathematical competencies and thus spend only limited time on mathematical activities (cf. Blevins-Knabe et al. 2000; Musun-Miller and Blevins-Knabe 1998; Skwarchuk 2009). Finally, we cannot exclude a possible impact of the way SES was operationalised in our study, namely as the prestige of parental occupation. If other measures such as the income of the household or education of the parents had been used instead, the results might have differed. Future research should analyse the interrelation of different aspects of SES and HNE in more detail.

Although HNE predicted mathematical abilities significantly, the effect sizes were rather small. This was to be expected based on previous research on HLE (e.g. Scarborough and Dobrich 1994). In our view, such small effect sizes could be important because the effects may cumulate over time and because the learning environment features can be more easily changed than, for instance, intelligence.

The same is true for the variable assessing history of mathematical disability in the family. Although the difference in HNE between families without and with such mathematical disability histories does not seem to be very large (small effect sizes), and although HNE did not serve as a mediator, the finding that certain activities occur less often in families with mathematical disabilities is interesting. While in families without such disabilities, dice, counting and calculation games are played about once a week or every second week, in families with a mathematical disability history, such games are played only every second or third week on average. This might be due to lower mathematical self-concepts and interests in those families (see also Hyde et al. 2006; Skwarchuk 2009). The result is even more important if one takes the possibility into account that this difference may cumulate over time. On the other hand, the results have to be interpreted with caution due to our operationalisation of HNE and mathematical disabilities in the families, which consisted of only a few items. Clearly, more research is needed.

Limitations

The present study has some limitations. The main problem is the operationalisation of our central variables HNE and mathematical disabilities in the family. Due to the design of the framework study only a few questions could be posed to the parents on these issues. Given that the assessment of HNE had to be very economic, due to time and space constraints, we decided to obtain HNE data by three questions tapping mainly the frequency with which parents and their child played games in a mathematical context. Those kinds of activities showed to be important aspects of HNE in former studies (cf. LeFevre et al. 2009, 2010). Moreover, the internal consistency of our construct was sufficient, and it proved to be predictive of mathematical competencies. We believe that our items are a good approximation for the overall HNE in a family and that therefore parents playing dice or number games often also support the development of their children's mathematical competencies in other meaningful ways.

Another problem of using a questionnaire is the risk of social desirability. However, previous studies on HLE showed that this assessment procedure often provides reliable data and that there is high concordance with other related measures (cf. Burgess 2002). Furthermore, the prevalence of mathematical disabilities as indicated by the parents was realistic. Nevertheless, our results have to be interpreted with caution due to these operationalisation problems.

We were also not able to analyse the stability of the learning environment over time as the parents could only be asked once about mathematical activities in the family. Thus, the possibility of substantial changes in some families cannot be excluded. However, research on HLE and HNE so far hints at high stability of these measures for at least the time period when children attend preschools and primary schools (Aikens and Barbarin 2008; LeFevre et al. 2009; Niklas 2011). Still, one cannot exclude the possibility that playing these games in families is only important for a certain time period. It is to be expected that the frequency of playing such easy games with a mathematical context does not have much impact after children are taught mathematics formally in the later primary school years and beyond.

Another problem of our study was the rather large drop-out of children upon school enrolment. Here, in particular, data of younger children with lower competence levels could no longer be obtained. This might have led to biased results. In our analyses, however, we used the FIML method and thus one of the best approaches to handle missing data even if the data is not missing completely at random (cf. Graham 2009). Moreover, we assessed several relevant variables that can explain why certain children dropped out (e.g. age and intelligence). Therefore, we argue that our results should on the one hand be interpreted with caution, but on the other hand, we believe that they are reliable and valid.

Strengths

Despite these limitations this study also has several strengths. We were able to analyse data of a comparably large sample (e.g. Huntsinger et al. 2000; LeFevre et al. 2009). Thus, our results seem to be representative at least for German populations. As other studies also show that HNE plays an important role in the development of mathematical competencies, results of former studies with English-speaking samples seem to be generalisable to a German context.

Furthermore, this study is one of the first on HNE in a German context, and there are still only very few studies on HNE in general. Thus, it partly closes the existing gap and might provide useful information for future research on this topic.

Moreover, a wide array of variables was assessed longitudinally in kindergarten and Grade 1. Therefore, we were able to analyse not only the role of HNE in initial mathematical competencies, but also in further development. This influence proved to be important even after various relevant variables had been controlled for.

Finally, the results of this study emphasise the significance of simple games parents might play with their preschool children to promote their mathematical abilities. Ramani and Siegler (2008) showed that playing a simple linear number board for only one hour improved mathematical abilities of children (see also Vandermaas-Peeler et al. 2012). Thus, parents who interact with their children (in comparison to teachers) frequently and for long time periods could have meaningful effects on the early development of mathematical competencies.

Conclusion

This study shows that the "Home Numeracy Environment" provided by a family plays a significant role in the early development of mathematical competencies. HNE predicted mathematical competencies at the end of kindergarten as well as the further development of mathematical abilities until the end of Grade 1. This was also true when the impact of other relevant variables such as intelligence, SES or rapid naming was controlled for. Moreover, families with a history of mathematical disabilities provided a more unfavourable HNE than families with no such history. Needless to say, that the frequency with that those different mathematical activities such as dice games are carried out, can be changed fairly easily, and training effects seem more probable here than for other important factors in the development of mathematical competencies. Thus, we suggest that parents engage more often in direct and indirect mathematical activities with their preschool children. Or to put it in other words: parents should roll the dice more often—so that they shape how the die is cast.

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Current themes of research:

Home learning environments.

Most relevant publications of Frank Niklas in the field of Psychology of Education:

Niklas, F. & Schneider, W. (2013). Home literacy environment and the beginning of reading and spelling. *Contemporary Educational Psychology*, *38*, 40–50.
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Development of memory and metacognition.

Most relevant recent publications of Wolfgang Schneider in the field of Psychology of Education:

Schneider, W. & Berger, N. (2012). Why phonological awareness is causally important in the acquisition of reading and spelling. In S. Suggate & E. Reese (Eds.), *Contemporary debates in early childhood* (pp. 216–226). London: Routledge.

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