Beier and Blossfeld
Large-scale Assessments in Education (2023) 11:7
https://doi.org/10.1186/s40536-023-00153-z

Large-scale Assessments in Education

RESEARCH **Open Access**

How do numerical and literacy stimulations in mother–child interactions relate to early gender differences in mathematical competencies? Empirical results from the NEPS Newborn Cohort study

Loreen Beier[1*] and Hans-Peter Blossfeld[2]

This paper uses data from the National Educational Panel Study (NEPS): Starting Cohort Newborns, https://doi.org/10.5157/NEPS:SC1:7.0.0. From 2008 to 2013, NEPS data was collected as part of the Framework Program for the Promotion of Empirical Educational Research funded by the German Federal Ministry of Education and Research (BMBF). As of 2014, NEPS has been carried out by the Leibniz Institute for Educational Trajectories (LIfBi, Bamberg) in cooperation with a nationwide network

*Correspondence:
loreen.beier@lifbi.de

[1] Leibniz Institute for Educational Trajectories (LIfBi), Wilhelmsplatz 3, 96047 Bamberg, Germany
[2] Graduate Centre, Trimberg Research Academy (TRAc), Otto-Friedrich-Universität Bamberg, Postfach 1549, 96045 Bamberg, Germany

Abstract

While gender differences in mathematical competencies favoring boys are well researched for school and late Kindergarten age, much less is known about their earlier development. Using data from the NEPS Newborn Cohort study, this paper focuses on 4 year-old children and the effects of the numerical and literacy stimulation during mother–child interactions they received at age 2. After controlling for different domain-specific stimulations, structural characteristics of the children's home learning environment, parental views, important child characteristics, and general educational processes between mother and child, empirical analyses showed small but statistically significant gender differences in mathematical competencies favoring girls. Early domain-specific stimulation in mother–child interactions at age 2 did not offer a good explanation for this math advantage of girls over boys at age 4. Nonetheless, even when 2 year-old girls received numerical stimulation quite similar to that of boys, there was some evidence that girls received a higher input in terms of literacy stimulation, and this is related to the small advantage of girls in mathematical competencies at age 4.

Keywords: Gender, Early mother–child interactions, Domain-specific stimulation, Mathematical competencies

Introduction

Many empirical studies demonstrated that boys have better grades and higher competencies in mathematics than girls in elementary school and that these differences are quite stable over the later school career (e.g., Artelt et al., 2001; Blossfeld et al., 2009; Bonsen et al., 2008; Frey et al., 2010; Niklas & Schneider, 2012). Despite the growing body of research on gender-specific differences, it is still unclear when and why they develop in the earlier life course (see also Niklas & Schneider, 2012). Although researchers are increasingly interested in the "when" question, their studies are based largely on children shortly before school entry. This research has shown that boys also have slightly higher mathematical competencies than girls (e.g., Jordan et al., 2006; Lonnemann et al., 2013). Based on the few studies that have analyzed younger ages, most of them found either no early gender differences (e.g., Kersey et al., 2018; Niklas & Schneider, 2012) or small differences even in favor of girls (see Anders et al., 2012). These puzzling results between the studies might be due to small sample sizes, different competency measurements (specific aspects vs. more general mathematical competency measures), different age ranges of children,[1] and/or especially for Germany, specific samples that are not representative for the whole country, but only focus on single federal states or regions. By using the NEPS Newborn Cohort data (Blossfeld & Roßbach, 2019), our analysis not only uses a large representative German-wide sample but is also able to utilize comprehensive mathematical competency measurements at age 4.

Concerning the factors that influence the early emergence of gender differences in mathematical competencies, existing research highlights the importance of early parent-child interactions for children's cognitive development (see, e.g., NICHD Early Child Care Research Network, 1998; Olsen et al., 1984; Pearson et al., 2011). This is in line with the learning environment theory by Kluczniok et al. (2013). According to this theory, mathematical competencies relate more closely to domain-specific educational mathematical stimulation than to more general educational processes between mothers and their children that do not foster domain-specific competencies directly. In line with this view, our analysis concentrates on the numerical and literacy[2] stimulation that boys and girls experience in interactions with their mothers during early childhood.

There have been various studies on differences in parent-child interactions with boys and girls, but their results are contradictory—particularly with respect to domains of stimulation (e.g., sensitivity, motor stimulation, general stimulation, emotionality, strictness) and the child's age (see Maccoby & Jacklin, 1974, for an overview; see also L. F. Halpern et al., 2001; Schoppe-Sullivan et al., 2006). However, the gender differences in mathematical competencies have not been examined with regard to the domain-specific stimulations. Because the NEPS Newborn Cohort (SC1) offers new data on these domain-specific parent-child interactions at age 2, we were able to study whether and to what extent these differences in the domain-specific numerical and literacy stimulation of boys and girls at age 2 are related to gender differences in mathematical competencies at age 4. Thus, based on this database we can analyze the questions when and whereby gender differences in mathematical competencies may emerge.

This article is structured as follows: In a first step, we embed our study within the existing body of theory and empirical research on competence development in the life course and will derive our hypotheses from a more general theoretical model. In a second step, we describe our data and research methods, and then, in a third step, present our empirical results. Finally, we summarize our findings, draw some conclusions, and discuss the limitations of our analysis.

[1] The age range varies for example in Kersey et al. (2018) from 3 to 10 years depending on the certain mathematical tasks, in Niklas and Schneider (2012) from 5.25 to 8 years and in Anders et al. (2012) from 2.8 to 4.75 years.

[2] We include literacy stimulation in our analyses because research shows a strong correlation between mathematical competencies and vocabulary (see section "Theoretical framework and hypotheses").

Theoretical framework and hypotheses

The literature emphasizes two main factors that influence gender-specific differences in mathematical competencies: (1) biological differences in hormones, genes, brain development, and physical maturing; and (2) environmental learning conditions also including parent's gender role expectations that shape the self-concept, interest, and motivation of boys and girls (see D. F. Halpern et al., 2005; Maccoby, 1966; Ruble et al., 2006 for overviews of this discussion). D. F. Halpern (2000) shows, that the answer to the question why early gender related differences emerge cannot be found in separating the influences of 'nature' and 'nurture'. Rather the emergence of gender differences in mathematical competencies has to be viewed as an inherently interdependent and dynamic long-term process in which these environmental influences interact with a child's biological prepositions (see D. F. Halpern, 2000, 2004; Sameroff, 1975). Thus, following the psychobiosocial model by D. F. Halpern (2000), the development of cognitive sex differences can be seen as an interdependent process, where genetic prepositions and hormones influence brain development with the influences of experiences and environment, which in turn effect learning and brain development and so on:

"What people learn influences the structure of their neurons (e.g., their branching and size); brain architectures, in turn, support certain skills and abilities, which may lead people to select additional experiences. […] Learning is both a biological and an environmental variable, and biology and environment are as inseparable as conjoined twins who share a common heart." (D. F. Halpern, 2004, p. 138)

Thus, from a theoretical perspective, we will combine the perspectives of 'nature' with 'nurture' and focus on the *bioecological model of human development* (Bronfenbrenner & Morris, 2006). This approach emphasizes the reciprocal influences between individual development and the surrounding environmental context. In this theory, a child's development is viewed as the result of an interaction between her or his own characteristics and abilities on the one side and the structural characteristics of the learning environment on the other. This interaction is not static, but a continuous stream of activities over the early life course.

Because this theoretical model is still quite abstract, especially with regard to the learning environment of small children, we specify it further for our empirical analyses by using the *framework of the learning environment* (Kluczniok et al., 2013). According to this paradigm, a child's development is seen as the product of the interplay of (1) the structure of the environment, (2) parental educational beliefs, and (3) the nature of parent-child interactions. Parent-child interactions can be separated into general educational processes (all activities that characterize the learning climate in the family and are not associated directly with a specific domain content) and domain-specific educational processes (that relate closely to domain-specific competencies such as mathematics or literacy).

Based on this theoretical framework, we formulated a theoretical development model of mathematical competencies (see Fig. 1; based on Kluczniok et al., 2013, p. 423; Linberg, 2017, p. 54). In this model, the structure of the home learning environment, parental views, and the characteristics of children are interrelated and are assumed to have an indirect effect (via the quality and intensity of parent-child interactions) on mathematical competencies. Additionally, the structure of the home learning environment

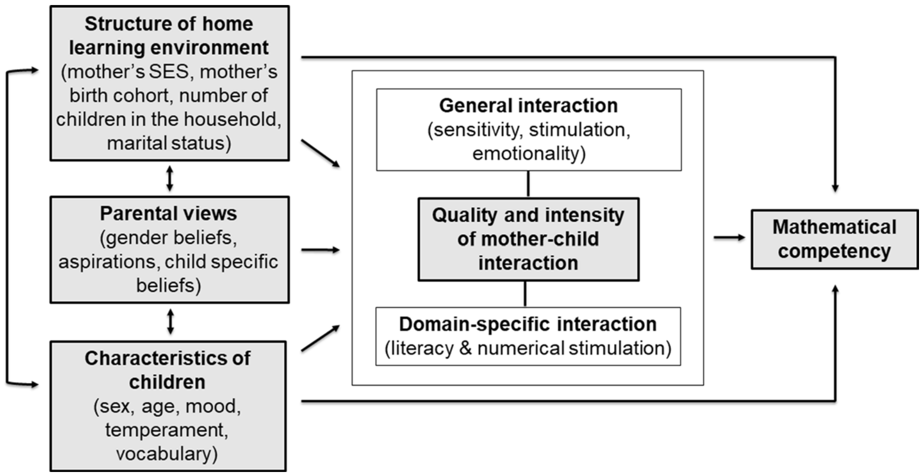

Fig. 1 Bioecological effect model of the development of mathematical competencies (relationships between child characteristics, structure of the home learning environment, parental views, and early mathematical competencies). Source: Own representation based on Linberg (2017, p. 54) and Kluczniok et al., (2013, p. 423)

and the characteristics of children are assumed to have a direct effect on mathematical competencies (see Fig. 1). The quality and intensity of mother-child interactions, divided into general interactions (sensitivity, stimulation, emotionality) as well as domain-specific interactions (literarcy and numerical stimulation), impact directly on mathematical competencies (see Fig. 1).

Several empirical studies support this theoretical model by stressing the close association between child characteristics, the home learning environment, and early numerical skills (see Anders et al., 2012; Kleemans et al., 2012; Weinert et al., 2012). With regard to the learning environment, several studies have demonstrated the central importance of the *quality of early parent-child interactions* for children's cognitive development (see, e.g., NICHD Early Child Care Research Network, 1998; Olsen et al., 1984; Pearson et al., 2011). High quality in parent-child interactions is characterized by all kinds of sensitive and warm reactions as well as stimulating interactions (see Bradley, 2002). According to Ainsworth et al. (1974), "sensitive" behavior means that parents continuously perceive and respond appropriately and promptly to their infant's signals and communications. "Stimulation" in this context can be understood as "guided participation" (Rogoff, 1990) within a learning process that consciously supports the (cognitive) development of the child depending on her or his skills (Rogoff, 1990; Wood et al., 1976). The development of early mathematical competencies as a specific domain of cognitive development (see Weinert et al., 2011) is influenced not only by the general quality of parent-child interactions but also by domain-specific numerical (see Blevins-Knabe & Musun-Miller, 1996) and literacy stimulations (see Anders et al., 2012). Research shows that there is a general positive association between linguistic skills and mathematical competencies. Linguistic skills can even be viewed as a prerequisite for being able to understand and respond to mathematical issues (see D. F. Halpern et al., 2007; Jordan et al., 2002; Kleemans et al., 2012; Koponen et al., 2007; Krajewski & Schneider, 2009). There is empirical evidence that girls acquire language faster than boys (see, e.g., Bornstein et al., 2004; Bornstein &

Haynes, 1998; Bouchard et al., 2009; Maccoby, 1966; Maccoby & Jacklin, 1974). Whether this is due to their differential biological state of development (see, e.g., Gleason & Ely, 2002; Huttenlocher et al., 1991) or to the fact that girls experience greater literacy stimulation (see Leaper, 2002; Leaper et al., 1998; Weinert et al., 2016, for reviews) is a widely discussed topic in the literature.

In our model (see Fig. 1), structural characteristics of the home learning environment and parental views influence the quality of parent-child interactions and therefore the development of mathematical competencies. Numerous studies have documented the effects of family characteristics such as mother's age (see Attig & Weinert, 2018; Berlin et al., 2002) and education as well as her employment status and socioeconomic position (see Attig & Weinert, 2018; Harvey, 1999; Weinert et al., 2010; Weinert et al., 2017) Family composition (see Carlson & Corcoran, 2001; Karwath et al., 2014), parental aspirations for their children, parental gender beliefs, and child-specific beliefs also play an important role (see Eccles et al., 2000; Jacobs & Eccles, 1992) for parent-child interactions and the development of children's (mathematical) competencies.

In addition, child characteristics are also relevant for the parent-child interaction and the development of (mathematical) competencies. Research has demonstrated that children's cognitive development depends on the stage of development associated with their age (see, e.g., Weinert et al., 2011) and also their sex. In line with this, research has shown that girls' cognitive skills develop faster at younger ages (see, e.g., Galsworthy et al., 2000; Toivainen et al., 2017). Moreover, parents show different kinds of interactions toward their children depending on their age (see, e.g., Bornstein et al., 2008). It is also clear that a child's temperament influences the quality of interactions. For example, children who are more "difficult" receive less stimulation, sensitivity, and emotion from their mothers (see Maccoby et al., 1984; van den Bloom & Hoeksma, 1994; Weinert et al., 2016).

In our empirical analysis, we first aim to determine whether the gender differences in mathematical competencies favoring boys at late kindergarten and school age already exist at early kindergarten age. As mentioned above, previous research is inconsistent in this respect. On the one hand, there is empirical evidence that no such gender differences in mathematical competencies exist at this early age (Hypothesis 1; e.g., Kersey et al., 2018; Niklas & Schneider, 2012). On the other hand, studies (see, e.g., Anders et al., 2012) have found that girls have higher mathematical competencies than boys (Hypothesis 2). Second, if we consider domain-specific stimulations as important factors for early gender differences in mathematical competencies (see Fig. 1), we can expect that higher domain-specific stimulation—namely numerical and literacy stimulation—will lead particularly to higher mathematical competencies independent of gender. Thus, if gender differences are to be found in these domain-specific stimulations, we expect that this will lead to gender differences in mathematical competencies (Hypothesis 3). In addition, we expect an indirect effect of maternal socioeconomic status: Because of their biographical experiences, women with a higher socioeconomic status might be more aware of typical female difficulties in the labor market and the importance of equal starting conditions in education than those with lower socioeconomic status. Therefore, we assume that mothers with a higher socioeconomic status will invest more in the competencies of their daughters than their sons, and especially in the numerical competencies (Hypothesis 4).[3] Otherwise, if our analyses fail to confirm that the gender differences in mathematical competencies can be explained by early domain-specific stimulation, they may simply be due to girls maturing faster at younger ages instead of social environmental factors (Hypothesis 5). This would be in line with research on biological explanations of early cognitive gender differences (see above).

Method

Data and sample

Our empirical analyses used data from the Newborn Cohort (release 7.0.0) of the National Educational Panel Study (NEPS; see Blossfeld & Roßbach, 2019). Our sample focused on the first wave of the starting cohort and consisted of 3481 children born in Germany between February and July 2012. We also utilized wave-specific information from the parent interview and added data from parent-child interactions in Wave 3 (2014), mathematical competencies in Wave 5 (2016), and linguistic competencies in Wave 4 (2015). Previous research has shown that there are differences in the style of parent-child interactions between mothers and fathers that are not directly comparable. Because mothers are typically the main caregivers of children in the family, most research concentrates on measurements developed specifically for mothers (see Grossmann et al., 2002). Because NEPS also focuses on mothers,[4] we excluded fathers from our sample.[5]

We also used multivariate imputations via chained equations (MI, m = 50) for the missing values of the independent variables for each of the dependent variables (mathematical competencies in Wave 5 and domain-specific mother-child interactions in Wave 3). Children were excluded from the sample when at least one parent was not born in Germany because we expected specific cultural influences (see Keller, 2014) that were not the focus of this study. Altogether, the sample size for our empirical analysis was 1488 children who had participated in both the competency measurements in Wave 5 (at age 4) and the measurements of literacy and numerical stimulation in Wave 3 (at age 2; 1955 children with data for these measurements).

Dependent and independent variables

The first outcome variable in our analysis is mathematical competencies in Wave 5 when the children were about 4 y old. These were measured with a number puzzle via a tablet (TBT; see Bauer, 2016). The test encompasses different tasks or questions out of five content areas: (a) sets, numbers, and operations, (b) units and measuring, (c) space and shape, (d) change and relationships, and (e) data and chance (NEPS, 2020). For our analyses, we used plausible values (PVs) which were generated with the help of the R package NEPS*scaling* (for an overview see Scharl et al., 2020) in RStudio (Version 1.4.1103; RStudio Team, 2020). Covariates are child's gender, the

[3] To the best of our knowledge there is no other study that would assess the relationship between mothers' SES and their daughters' skills at this young age. For higher age groups e.g. Minello and Blossfeld (2017) show that girls with a high educated mother are more likely to have tertiary education than with a medium educated mother.

[4] In exceptional cases, the direct measures and interviews were obtained from the biological or social father as the legal guardian (Bauer et al., 2013).

[5] We also excluded those cases in which the respondent changed over the waves, because NEPS data do not allow us to reconstruct which parent provided the measurements of parent–child interactions.

domains "literacy stimulation" as well as "numerical stimulation" from Wave 3 when the children were about 2 y old. These data were collected per videotape in a semi-standardized playing situation assessing structure, time, and toys. Trained observers then coded the resulting visual material on 5-point scales ranging from 1 (*not characteristic*) to 5 (*very characteristic*) from a German rating system for assessing parent-child interactions (EKIE; see Sommer & Mann, 2015).

Drawing on our theoretical model, we controlled variables assumed to influence the development of mathematical competencies (see Fig. 1):

(1) Structural characteristics of the home learning environment: Here, we included mother's birth cohort (before 1976, 1976–1980, 1981–1985, 1986 and later), her marital status (single, married, divorced/widowed), the number of persons under age 14 living in the household, mother's employment status (not working vs. working),[6] and the z-standardized mother's socioeconomic status from Wave 1 (ISEI-08; Ganzeboom, 2010; Ganzeboom et al., 1992), because the quality of mother–child interactions is assumed to differ according to these variables (see Weinert et al., 2016).
(2) Parental views: We controlled for the mother's highest idealistic educational aspiration in the German school system for her child: leaving school without a degree, Hauptschule (lower secondary school qualification), Mittlere Reife (middle school qualification), and Abitur (upper secondary school qualification).
(3) Child characteristics: We included the age of the child in months at the date of testing (46–55 months) to control for developmental differences, two temperament items ("angry when not getting what she or he wants," "cries when she or he does not get attention"), and vocabulary competency scores from Wave 4 (sum score) when the children were about 38 months old.
(4) General mother–child interactions: We included the sensitivity under non-distress,[7] global stimulation, and emotionality. All these variables were z-standardized and originally range from 1 (not characteristic) to 5 (very characteristic) according to the EKIE scale (see Sommer & Mann, 2015).

The second block of outcome variables in our analysis are the domain-specific literacy and numerical stimulations in the mother–child interaction from Wave 3 (at age 2). Again, we used the EKIE scale, but this time as a binary variable (less vs. more characteristic for literacy stimulation and not vs. more or less characteristic for numerical stimulation). We took this approach because the shape of the distribution of numerical stimulation did not allow us to treat it as a continuous measure.[8] However, for both domain-specific stimulation variables, we used a 0/1 dummy variable to gain comparable results across both kinds of domain-specific stimulations. The main explanatory variables are the child's gender and the interaction-term child's gender x mother's *z*-standardized socioeconomic status. The control variables again are based on our theoretical model with respect to the different spheres of factors influencing domain-specific stimulation (see Fig. 1 and the description of variables above):

[6] We used the equivalent wave-specific values as well as mother's birth cohort assessed in Wave 1.

[7] Sensitivity under non-distress means "perceiving the child's non-distress signals and reacting to it in a prompt and appropriate manner" (Linberg et al., 2019, p. 5).

[8] Whereas literacy stimulation was more or less normally distributed (but slightly right-skewed), numerical stimulation was rated as not (62%) or rather not characteristic (34%) in 96% of all mothers.

(1) *Structural characteristics of the home learning environment:* mothers' birth cohort, mother's wave-specific marital status, number of children in the household, and mother's employment status.
(2) *Parental views:* mother's highest idealistic educational aspiration for their child
(3) *Child characteristics:* age of the child, two temperament items ("angry when not getting what she or he wants," "cries when she or he does not get attention"), and child's mood during the study observation. Research has shown that not just the mother, but rather both sides of the dyad influence the interaction (see Attig & Weinert, 2018; Lloyd & Masur, 2014; Weinert et al., 2016).

Statistical analyses[9]

After presenting selected descriptive results, we shall first concentrate our analysis on the mathematical competencies of boys and girls (outcome variable 1). We estimated hierarchical multivariate linear models to check the change in the gender difference in mathematical competencies by first including control variables and then the explanatory domains of stimulation and their interactions with the child's sex. This allowed us to control for whether boys or girls just benefited more from higher domain-specific stimulations. In the second step, we used separate hierarchical multivariate binary regression models for numerical and literacy stimulation in Wave 3 including mother's SES. Again, our analysis focused on gender differences and the interaction of gender with the explanatory variables.

Results

We start with a simple comparison of the means of boys and girls and their differences on all the variables in our estimated models (see Table 1). First, we want to stress that there were small but statistically significant gender differences in mathematical competencies in favor of girls at the age of four (see Table 1, $t(1487)$, $p =<.001$), which corresponds to the descriptive findings of the Autorenteam Kompetenzsäule (2020). This result confirmed Hypothesis 2 and contradicted Hypothesis 1. There were no significant mean differences between boys and girls for the covariates literacy stimulation and numerical stimulation. Among the control variables, only child's temperament ("child cries when getting no attention", ($t(2598)$, $p =.0094$) showed significant mean differences—in favor of girls. Looking at the two domains of stimulation (our second outcome variables), we found significant mean differences between boys and girls only in literacy stimulation ($t(2)$, $p =.019$). Girls seemed to experience a higher intensity of literacy stimulation than boys. Numerical stimulation and the other control variables revealed no significant differences between boys and girls. There was only one exception: the mood of the child in the interactions, with girls seeming to be in a better mood ($t(1.580)$, $p =.040$).

[9] All analyses were done with Stata (Version 16.1, StataCorp, 2019). We did not directly includ the weights provided by the NEPS into our models (design-based approach), but variables with significant effects on participation as explanatory variables (model-based approach) as recommended by Würbach et al. (2016) which were already included in our theoretical model (respondents' year of birth, employment status, marital status, number of children in household). Not included were gender of respondents and migration background, because we excluded men and persons with migration background from our sample (see section "Data and sample").

Domain-specific stimulation and mathematical competencies of boys and girls

In the first step of our regression analysis, we test whether there are any significant gender differences in mathematical competencies at age 4. All the estimations in Table 2 are controlled for influences of the structure of the environment, child characteristics, family beliefs, and general aspects of mother-child interactions. Our regression results once more showed a small but significant gender gap in favor of girls (see Model 1 in Table 2). Girls had a 0.124 ($p < 0.001$) higher mathematical competency score than boys. Thus, our regression results again supported Hypothesis 2 but not Hypothesis 1.

In the next step, we analyze whether the gender gap in favor of girls at age 4 could be explained by literacy and numerical stimulation. In Model 2 of Table 2, we first included only literacy stimulation. This model showed that literacy stimulation is (statistically significantly) associated with mathematical competencies ($p = 0.012$). The inclusion of literacy stimulation decreased the gender gap in mathematical competencies by about 2.5%. However, literacy stimulation could not explain the gender gap completely: There was still a statistically significant gender difference in mathematical competencies in Model 2 ($p < 0.001$). Including the interaction effect between gender and literacy stimulation in Model 3 also did not reduce the gender effect on mathematical competencies. In other words, the gender differences in literacy stimulation were not statistically significant.

In Model 4 in Table 2, we included numerical stimulation instead of literacy stimulation. This model showed that the gender gap even increased by about 0.8% and again did not change the significant gender difference in mathematical competencies. Including the interaction term between gender and numerical stimulation in Model 5 of Table 2 also did not reduce the gender effect and showed that the gender differences in numerical stimulation were not statistically significant ($p = 0.970$).

Finally, we included both domain-specific stimulations simultaneously in Model 6 of Table 2. Including both stimulation domains, the results show that only literacy stimulation had a statistically significant association with mathematical competencies ($p = 0.01$; $p = 0.167$ for numerical stimulation) and both types of stimulation only slightly reduced the gender difference in mathematical competencies by about 1.6% (*ns*; Model 6). We conclude that there are small but relatively robust gender differences in mathematical competencies favoring girls, but that these differences cannot be explained by literacy or numerical stimulation, or the control variables included in the model. Thus, based on this evidence, we rejected our hypothesis that the mathematical competencies in favor of girls could be explained by earlier literacy or numerical stimulation (Hypothesis 3). This result is in line with our Hypothesis 5 that girls and boys are in different stages of cognitive development at very young ages: Although we controlled for several kinds of child and family characteristics, girls did better in math at this young age. In general, it seems that boys did experience slightly more numerical stimulation and girls slightly more literacy stimulation.

Do boys and girls benefit from different intensities of literacy and numerical stimulation?

We checked our findings in Table 2 by taking a closer look at the domains of stimulation themselves. Table 3 shows that girls had a higher probability of experiencing greater literacy stimulation than boys, but the difference is statistically not significant ($p = 0.070$;

Table 1 Descriptives (means of variables in the estimated models for girls and boys with standard deviations in parentheses and ranges)

	Means of variables				Girl–boy difference in means	Min	Max
Variables used to estimate outcome variable 1	**Boys (*N* = 743)**		**Girls (*N* = 745)**				
Math competency (WLE; w5)	0.022	(0.027)	0.157	(0.027)	0.14***	− 3.461	3.187
Child's age (in months; w5)	50.04	(0.057)	50.04	(0.056)	− 0.03	46	55
Mother's marital status (w5)	1.84	(0.016)	1.86	(0.015)	0.03	1	3
Mother's employment status (w5)	0.71	(0.017)	0.73	(0.017)	0.01	0	1
Number of children under age 14 in household (w5)	1.93	(0.025)	1.93	(0.026)	0	1	4
Mother–child interaction: sensitivity to non-distress (*z*-standardized; w3)	− 0.03	(0.039)	0.02	(0.041)	0.08	− 3.593	1.576
Mother–child interaction: global stimulation (*z*-standardized; w3)	0.02	(0.041)	− 0.02	(0.039)	− 0.02	− 2.865	2.212
Mother–child interaction: emotionality (z-standardized; w3)	− 0.01	(0.039)	− 0.01	(0.040)	0.01	− 2.968	1.707
Vocabulary (sum score; w4)	58.85	(0.868)	60.34	(0.766)	1.32	12	118
Mother–child interaction: literacy stimulation (*z*-standardized; w3)	− 0.01	(0.040)	0.01	(0.038)	− 0.02	− 3.097	2.099
Mother–child interaction: numerical stimulation (*z*-standardized; w3)	0.020	(0.040)	-0.03	(0.038)	− 0.054	− 0.715	4.247
Variables used to estimate outcome variable 2	**Boys (*N* = 1012)**		**Girls (*N* = 943)**				
Mother–child interaction: literacy stimulation (binary; w3)	0.4	(0.017)	0.45	(0.018)	0.053*	0	1
Mother–child interaction: numerical stimulation (binary; w3)	0.4	(0.017)	0.38	(0.018)	− 0.021	0	1
Child's age (in months; w3)	26.54	(0.039)	26.54	(0.04)	0	24	32
Mother's marital status (w3)	1.78	(0.015)	1.81	(0.014)	0.03	1	3
Mother's employment status (w3)	0.66	(0.015)	0.66	(0.016)	0.007	0	1
Number of persons under age 14 in household (w3)	1.67	(0.022)	1.71	(0.025)	0.04	1	4
Mother–child interaction: child's mood in interaction (w3)	3.20	(0.028)	3.28	(0.029)	0.078*	1	5
Variables used to estimate both outcome variables	**Boys (*N* = 1012)**		**Girls (*N* = 944)**				
Child's temperament: angry, when does not get what it wants (w3)	4.66	(0.038)	4.62	(0.040)	− 0.04	0	6
Child's temperament: cries, when no attention (w3)	2.99	(0.059)	3.20	(0.059)	0.22**	0	6

Table 1 (continued)

Variables used to estimate both outcome variables	**Boys ($N = 1012$)**		**Girls ($N = 944$)**				
Mother's socioeconomic status (ISEI, *z*-standardized; w1)	− 0.03	(0.032)	0	(0.034)	− 0.03	− 2.502	1.550
Mother's birth cohort (w1)	2.73	(0.028)	2.72	(0.031)	− 0.01	1	4
Mother's educational aspirations (w4)	3.82	(0.014)	3.86	(0.013)	0.04	2	4

Source: NEPS, SC1; own calculations; m = 50 imputations; standard errors in parentheses

*$p < 0.05$

**$p < 0.01$

***$p < 0.001$

see Model 1 in Table 3). Including the interaction term of gender with mother's SES in Model 2 did not lead to a change in the probability for girls experiencing higher literacy stimulation than boys ($p = 0.071$). Separated analysis by gender of the child shows no statistically significant changes by mothers' SES for literacy stimulation for girls ($p = 0.088$) or boys ($p = 0.354$; see Model 2). Furthermore, Model 3 in Table 3 indicates that boys had a higher probability of experiencing numerical stimulation than girls, but the difference was once again statistically not significant ($p = 0.433$). Thus, there is evidence that the probability of numerical stimulation increases for girls with increasing mother's SES ($p = 0.500$), whereas the numerical stimulation of boys remains stable across mother's SES ($p = 0.845$). Again, these results were not statistically significant (Model 4). We conclude that our results do not provide support for our hypotheses: We found no significantly higher probability for more literacy or numerical stimulation for girls or boys with increasing SES of the mother. Therefore, maternal socioeconomic status does

Table 2 Mathematical competencies, child's gender, and domains of stimulation (linear regressions)

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
Girl	0.124***	0.121***	0.121***	0.125***	0.125***	0.122***
	(0.0347)	(0.0347)	(0.0347)	(0.0347)	(0.0347)	(0.0346)
Literacy stimulation (w3)		0.0780*	0.0653			0.0797*
		(0.0329)	(0.0377)			(0.0328)
Girl × Literacy stimulation (w3)			0.0272			
			(0.0388)			
Numerical stimulation (w3)				0.0261	0.0278	0.0280
				(0.0200)	(0.0265)	(0.0200)
Girl × Numerical stimulation (w3)					− 0.00342	
					(0.0374)	
Constant	− 6.875***	− 6.654***	− 6.676***	− 6.911***	− 6.911***	− 6.689***
	(0.612)	(0.618)	(0.620)	(0.614)	(0.615)	(0.621)
R^2	0.2100	0.2138	0.2137	0.2108	0.2104	0.2147
N	1488	1488	1488	1488	1488	1488

Source: NEPS, SC1; own calculations; all models control for mother's birth cohort, mother's employment status, child's age, child's temperament, mother's marital status, number of children in the household, mother's educational aspirations, mother's SES, mother's sensitivity, mother's global stimulation, mother's emotionality, and child's vocabulary; m = 50 imputations; variance inflation factor 1/VIF >0.1 for all independent variables; standard errors in parentheses

*$p < 0.05$

**$p < 0.01$

***$p < 0.001$

Table 3 Literacy and numerical stimulation, child's gender, and mother's SES (logistic regressions; average marginal effects)

AME:	Literacy stimulation Model 1	Literacy stimulation Model 2	Numerical stimulation Model 3	Numerical stimulation Model 4
Girl	0.0443	0.0441	− 0.0193	− 0.0193
	(0.0244)	(0.0244)	(0.0246)	(0.0245)
Boy × Mother's SES		0.0170		− 0.0035
		(0.0183)		(0.0179)
Girl × Mother's SES		0.0333		0.0125
		(0.0195)		(0.0188)
R^2	0.0443	0.0461	0.0139	0.0139
N	1955	1955	1955	1955

Source: NEPS, SC1; own calculations; all models control for mother's birth cohort, mother's employment status, child's age, child's temperament, mother's marital status, number of children in the household, mother's educational aspirations, and child's positive mood; m = 50 imputations; variance inflation factor 1/VIF >0.1 for all independent variables; standard errors in parentheses

*$p < 0.05$

**$p < 0.01$

***$p < 0.001$

not explain the differences between boys and girls and we have to reject Hypothesis 4. Hence, we conclude that girls gain a similar amount or quality of literacy and numerical stimulation regardless of the mother's SES.

Discussion

Women are still underrepresented in STEM-oriented occupations, although their level of education is increasingly converging with that of men across cohorts, and younger women even have slightly surpassed young men at the level of university degrees (Helbig, 2010). One explanation for the stability of subject-specific gender differences in the process of educational expansion is, that school girls seem to have lower competencies in mathematics (and science) than school boys (Niklas & Schneider, 2012) and therefore feel less interested in these school subjects and then in STEM-oriented occupational fields (Lörz & Schindler, 2011; Weinhardt, 2017). Since early childhood is a decisive developmental period that sets the stage for later life course outcomes, and early educational experiences create developmental foundations often translating into long-term path dependencies in educational and occupational careers (DiPrete & Eirich, 2006), it is important to study the origins of these gender differences very early in life.

The aim of our study was therefore to determine whether gender differences in mathematical competencies are already evident before school entry in early kindergarten age. In addition, we wanted to investigate whether and to what extent such gender differences are related to maternal numeracy and literacy stimulation.

Linking Bronfenbrenner's bioecological model of human development (Bronfenbrenner & Morris, 2006) with the framework of learning environment (Kluczniok et al., 2013) allowed us to formulate a bioecological model with hypotheses about direct and indirect effects of child and family characteristics, parental beliefs, general mother-child interactions, and the effects of domain-specific stimulations on children's mathematical competencies. Using unique data from the NEPS Newborn Cohort (SC1), we showed that at age 4, girls with German parents have indeed slightly higher mathematical competencies than boys. This result confirms the empirical results of Anders et al. (2012) but contradicts those of Kersey et al. (2018) or Niklas and Schneider (2012) who found no gender differences between boys and girls at early ages. One reason for these results could be that the age groups of our analyses and the analyses by Anders et al. (2012) are very similar, whereas the children in the analyses from Kersey et al. (2018) had a wider age range, or were younger, respectively older, than the age group in Niklas and Schneider (2012). We know from other research like PISA that these advantages turn in favor of boys at later years (see, e.g., OECD, 2019).

Based on our theoretical model, we expected that this gender gap favoring girls would be due to differences in the quality of numerical and literacy stimulation experienced at an early age. However, our empirical analyses demonstrated that the gender gap cannot be explained by domain-specific stimulations in mother-child interactions: Although we controlled for relevant kinds of child and family characteristics, a relatively stable gender difference remained at age 4. Thus, our results supported the hypothesis that the differences favoring girls at this early age are mainly due to gender-specific differentials in development. It seems that girls start earlier in terms of competency development, but as Anders et al. (2012) have shown for Germany, boys have a higher growth rate in mathematical competencies than girls until the age of 6 and then go on to outperform girls in mathematics during the school career.

We have to emphasize that our empirical analyses could only address the relationship between the child and the proximate learning environment in the family (i.e., the primary socialization processes). We abstracted from other influences such as Kindergarten (see Heckman's (2006) Perry Preschool Study which established the lasting value of early childhood education) and peers (secondary socialization processes). There is empirical evidence from the literature that preschool teachers often behave differently with regard to a child's sex (e.g., Brandes et al., 2015; van Polanen et al., 2017). Thus, a closer analysis of the effects of preschool teachers' interactions with children might help to answer the two questions: (1) Why do girls outperform boys in mathematical competencies at early ages, and (2) Why does the female advantage turn around shortly before school entry.

In our models we find insignificant changes in the gender gap across age: Literacy stimulation slightly decreases the gender gap in mathematics (i.e., girls seem to receive more stimulation in linguistic fields), while boys seem to experience slightly more mathematical stimulation. Based on this result, we checked whether there are gender differences in numerical and literacy stimulation itself. We expected that a gender difference could be explained by the mother's socioeconomic status because mothers with a high status are expected to pay more attention to gender-related starting conditions and therefore invest more in their daughters' early competencies. Our analysis found no statistically significantly higher probability that girls or boys would experience such higher input in form of literacy or numerical stimulation.

Limitations

Our study has several limitations: First, due to data restrictions, we had to largely ignore the influences of gender-specific parental values in our theoretical model. Unfortunately, in the NEPS Newborn Cohort, parental assessments of mathematical and linguistic competencies are available only from Wave 5 onward, and parental gender beliefs are not included at all in the NEPS Newborn Cohort (SC1) study. In future analyses, it would be important to include these factors into the data collection of panel waves, because parents shape boys' and girls' self-perception, interests, and competency beliefs. In addition, we know from other studies that structural factors such as parental education or occupation shape the values and beliefs of parents including (1) their gender stereotypes, (2) their child-rearing attitudes, and (3) their child-specific beliefs. Parental views also include the assessments of their child's abilities, and thus the assessment of abilities is connected to parental gender beliefs and stereotypes (Eccles Parsons et al., 1982, 1983). Because mathematics is traditionally viewed as a male domain (Brown & Josephs, 1999), we would expect parents to shape their children's self-concept with gender-specific competency expectations (Eccles Parsons et al., 1982; Jacobs et al., 2005).

Second, from a methodological point of view, our findings could also result from the following data limitations: First, the observed spheres of mother-child interaction were represented in terms of their quantity (the amount) but less in terms of their quality (the complexity). Second, gender variations in the maternal numerical stimulation were quite small in the dataset, because only a few mothers showed no interaction at all. Third, the measurements of mother-child interactions were just one-point observations made under specific conditions. These observations might be an unsatisfactory representation of the typical daily interactions including gender-specific toys provided at home (which tend to foster gender-specific competencies; see, e.g., Eccles et al., 1990; Jacobs et al., 2005). Data from future NEPS panel waves might allow us to study to which extent there are differences between the observed measurements in the NEPS and the real activities at home.

Appendix

See Tables 4, 5, 6.

Table 4 Mathematical competencies, child's gender, domains of stimulation, and control variables (linear regressions)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Age child (w5)	0.113*** (0.0115)	0.112*** (0.0114)	0.108*** (0.0115)	0.108*** (0.0115)	0.113*** (0.0114)	0.113*** (0.0114)	0.109*** (0.0115)
Temperament child: angry (w3)	0.0129 (0.0159)	0.0154 (0.0159)	0.0154 (0.0158)	0.0159 (0.0159)	0.0154 (0.0159)	0.0154 (0.0159)	0.0154 (0.0158)
Temperament child: cries (w3)	− 0.0185 (0.0106)	− 0.0213* (0.0106)	− 0.0204 (0.0106)	− 0.0209 (0.0107)	− 0.0210* (0.0106)	− 0.0210* (0.0106)	− 0.0201 (0.0106)
Marital status mother (ref: single)							
Married	0.0605 (0.0485)	0.0551 (0.0483)	0.0547 (0.0482)	0.055 (0.0482)	0.0544 (0.0483)	0.0544 (0.0483)	0.0540 (0.0482)
Divorced/ widowed	− 0.0790 (0.122)	− 0.0860 (0.121)	− 0.0903 (0.121)	− 0.0922 (0.121)	− 0.0896 (0.121)	− 0.0897 (0.121)	− 0.0942 (0.121)
Employment status mother (w5; ref: not working)	− 0.0606 (0.0416)	− 0.0644 (0.0414)	− 0.0649 (0.0413)	− 0.065 (0.0412)	− 0.0625 (0.0414)	− 0.0624 (0.0414)	− 0.0629 (0.0413)
Number of children in household (w5)	0.00381 (0.0280)	0.00429 (0.0279)	0.00260 (0.0277)	0.00168 (0.0278)	0.00493 (0.0279)	0.00502 (0.0280)	0.00325 (0.0278)
Birth cohort mother	0.0440* (0.0213)	0.0450* (0.0212)	0.0454* (0.0212)	0.0456* (0.0212)	0.0447* (0.0212)	0.0447* (0.0212)	0.00325 (0.0278)
Educational aspirations towards child (w4)	0.146** (0.0524)	0.141** (0.0522)	0.137** (0.0520)	0.136** (0.0520)	0.143** (0.0523)	0.143** (0.0523)	0.139** (0.0521)
SES mother	0.119*** (0.0202)	0.118*** (0.0202)	0.118*** (0.0201)	0.118*** (0.0201)	0.119*** (0.0202)	0.119*** (0.0202)	0.119*** (0.0201)
Vocabulary child (w4)	0.0102*** (0.00114)	0.0102*** (0.00114)	0.0102*** (0.00112)	0.0101*** (0.00112)	0.0101*** (0.00114)	0.0101*** (0.00114)	0.0101*** (0.00113)
Sensitivity to non-distress (w3)	0.0522* (0.0208)	0.0508* (0.0207)	0.0462* (0.0206)	0.0457* (0.0206)	0.0518* (0.0207)	0.0518* (0.0207)	0.0471* (0.0206)
General stimulation (w3)	0.0222 (0.0229)	0.0234 (0.0228)	− 0.0321 (0.0316)	− 0.0322 (0.0316)	0.0167 (0.0237)	0.0167 (0.0237)	− 0.0404 (0.0325)
Emotionality (w3)	− 0.0211 (0.0244)	− 0.0206 (0.0243)	− 0.0344 (0.0247)	− 0.0349 (0.0247)	− 0.0215 (0.0242)	− 0.0215 (0.0242)	− 0.0356 (0.0247)
Girl		0.124*** (0.0347)	0.121*** (0.0347)	0.121*** (0.0347)	0.125*** (0.0347)	0.125*** (0.0347)	0.122*** (0.0346)
Literacy stimulation (w3)			0.0780* (0.0329)	0.0653 (0.0377)			(0.0328)
Girl × Literacy stimulation (w3)				0.0272 (0.0388)			
Numerical stimulation (w3)					0.0261 (0.0200)	0.0278 (0.0265)	0.0280 (0.0200)

Table 4 (continued)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Girl × Numerical stimulation (w3)						-0.00342 (0.0374)	
Constant	− 6.853*** (0.617)	− 6.875*** (0.612)	− 6.654*** (0.618)	− 6.676*** (0.620)	− 6.911*** (0.614)	− 6.911*** (0.615)	− 6.689*** (0.621)
R^2	0.2064	0.2100	0.2138	0.2137	0.2108	0.2104	0.2147
N	1488	1488	1488	1488	1488	1488	1488

Source: NEPS, SC1; own calculations; m = 50 imputations; variance inflation factor 1/VIF >0.1 for all independent variables; standard errors in parentheses

*$p < 0.05$,

**$p < 0.01$

***$p < 0.001$

Table 5 Literacy stimulation, child's gender, mother's SES, and control variables (logistic regressions)

	Model 1	Model 2	Model 3	Model 4
Age child (w3)	0.0479 (0.06052)	0.0484 (0.0607)	0.0473 (0.0607)	0.0478 (0.0608)
Temperament child: angry (w3)	− 0.1164* (0.0477)	− 0.1134* (0.0479)	− 0.1113* (0.0479)	− 0.1111* (0.0479)
Temperament child: cries (w3)	− 0.0302 (0.0300)	− 0.0345 (0.0302)	− 0.0325 (0.0303)	− 0.0329 (0.0303)
Marital status mother (w3; ref: single)				
Married	0.1270 (0.1283)	0.1180 (0.1286)	0.0933 (0.1300)	0.0936 (0.1300)
Divorced/widowed	0.2222 (0.4007)	0.2290 (0.4023)	0.2540 (0.4034)	0.2312 (0.4051)
Employment status mother (w3; ref: not working)	0.1020 (0.1132)	0.1035 (0.1134)	0.0671 (0.1157)	0.0669 (0.1157)
Number of children in household (w3)	0.00792 (0.0787)	0.0049 (0.0788)	0.00421 (0.0790)	0.00376 (0.0790)
Birth cohort mother	0.1410* (0.0635)	0.1418* (0.0636)	0.1172 (0.0642)	0.1191 (0.0643)
Educational aspirations towards child (w4)	0.3172* (0.1460)	0.3044* (0.1464)	0.2538 (0.1489)	0.2546 (0.1490)
Positive mood child (w3)	0.4949*** (0.0710)	0.4898*** (0.0710)	0.4857*** (0.0711)	0.4841*** (0.0711)
Girl		0.1883 (0.1070)	0.1890 (0.1071)	0.1876 (0.1073)
SES mother			0.1002 (0.0585)	0.0590 (0.0776)
Girl × SES mother				0.0825 (0.1065)
Constant	− 4.3389* (1.7540)	− 4.3693* (1.7576)	− 4.0394* (1.7680)	− 4.0536* (1.7687)
R^2	0.0419	0.0443	0.0457	0.0461
N	1.955	1955	1955	1955

Source: NEPS, SC1; own calculations; m = 50 imputations; variance inflation factor 1/VIF >0.1 for all independent variables; standard errors in parentheses

* $p < 0.05$

** $p < 0.01$

*** $p < 0.001$.

Table 6 Numerical stimulation, child's gender, mother's SES, and control variables (logistic regressions)

	Model 1	**Model 2**	**Model 3**	**Model 4**
Age child (w3)	0.0187 (0.0535)	0.0185 (0.0535)	0.0183 (0.0536)	0.0188 (0.0536)
Temperament child: angry (w3)	− 0.0113 (0.0470)	− 0.0128 (0.0471)	− 0.0123 (0.0472)	− 0.0121 (0.0472)
Temperament child: cries (w3)	− 0.0729* (0.0308)	− 0.0711* (0.0309)	− 0.0707* (0.0308)	− 0.0711* (0.0309)
Marital status mother (w3; ref: single)				
Married	− 0.1177 (0.1267)	− 0.11365 (0.1267)	− 0.1183 (0.1285)	− 0.1180 (0.1286)
Divorced/widowed	0.00559 (0.3922)	0.00559 (0.3922)	0.0101 (0.3925)	-0.0098 (0.3936)
Employment status mother (w3; ref: not working)	− 0.1177 (0.1127)	− 0.1184 (0.1128)	− 0.1252 (0.1150)	− 0.1255 (0.1150)
Number of children in house-hold (w3)	− 0.04482 (0.0758)	− 0.0433 (0.0759)	− 0.04358 (0.0759)	− 0.0439 (0.0760)
Birth cohort mother	0.1214* (0.0615)	0.1211* (0.0615)	0.1166 (0.0626)	0.1183 (0.0627)
Educational aspirations towards child (w4)	− 0.0374 (0.1412)	− 0.0314 (0.1415)	− 0.0407 (0.1446)	− 0.0398 (0.1447)
Positive mood child (w3)	0.1550* (0.0657)	0.1578* (0.0658)	0.1568* (0.0658)	0.1550* (0.0657)
Girl		− 0.0858 (0.1058)	− 0.0856 (0.1058)	− 0.0853 (0.1058)
SES mother			0.01835 (0.05939)	− 0.0171 (0.0780)
Girl × SES mother				0.0728 (0.1028)
Constant	− 1.1448 (1.5159)	− 1.1342 (1.5171)	− 1.0732 (1.5363)	− 1.0876 (1.5375)
R^2	0.0104	0.0139	0.0136	0.0139
N	1.955	1955	1955	1955

Source: NEPS, SC1; own calculations; m = 50 imputations; variance inflation factor 1/VIF >0.1 for all independent variables; standard errors in parentheses

* $p < 0.05$

** $p < 0.01$

*** $p < 0.001$

Acknowledgements
Not applicable.

Author contributions
Both authors conceptualized the research idea. LB conducted the literature review, carried out the analyses, drafted and edited the manuscript. HPB revised the manuscript and supervised the research. All authors read and approved the final manuscript.

Funding
The research was funded by the DFG as part of the DFG Priority Programme 1646 "Education as a Lifelong Process".

Availabilty of data and materials
The data that support the findings of this study are available from the Leibnitz Institute for Educational Trajectories (LIfBi) but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available.

Declarations

Ethics approval and consent to participate
Ethical standards were approved by the National Educational Panel Study (NEPS).

Consent for publication
We provide our consent to publish this manuscript upon acceptance for publication in the Springer open journal 'Large Scale Assessments in Education'.

Competing interests
The authors declare that they have no competing interests.

Received: 14 July 2021 Accepted: 19 January 2023
Published online: 06 March 2023

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