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Yulia V. Kuzmina, Diana N. Kaiky,
Alina E. Ivanova

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Yulia V. Kuzmina[1], *Diana N. Kaiky*[2],

Alina E. Ivanova[3]

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Math achievement is affected by social factors such as socioeconomic status (SES) and domain-general cognitive factors such as phonological ability. Little is known how the effects of cognitive factors change depending on social factors during development. This study focuses on the estimation of the effect of phonological ability on math achievement during the first year of schooling and testing the hypothesis that this effect varied depending on students SES. To achieve our aims we used two-wave longitudinal study which was conducted on large sample of first-graders (N= 2,948) in the Tatar Republic (Russia). Participants were assessed twice, at the beginning and at the end of the first grade (mean age was 7.3 years at Time 1). The item response theory (IRT) scaling procedure was used to estimate individual scores in math, number identification, phonology and reading. In order to estimate the effect of phonological ability and SES on math performance, mixed-effect longitudinal models were applied. The results revealed that phonological ability had a significant positive effect on math achievement even when reading achievement, number identification and SES were controlled for. Among SES dimensions only maternal education had an effect on math achievement and its improvement. The effect of phonological ability was higher for students with a larger number of books at home and who used more than one language at home.

Keywords: iPIPS; math achievement; phonological ability; socioeconomic status; moderators

JEL Classification: Z

[1] Center of Education Quality Monitoring, Institute of Education, National Research University Higher School of Economics, Research Fellow, e-mail (jkuzmina@hse.ru)
[2] Center of Education Quality Monitoring, Institute of Education, National Research University Higher School of Economics, Research Assistant, e-mail (dkaiky@hse.ru)
[3] Center of Education Quality Monitoring, Institute of Education, National Research University Higher School of Economics, Research Fellow, e-mail (aeivaniva@hse.ru)

Many factors contribute to individual differences in math achievement. Both the cognitive and social predictors of math development have been extensively discussed in the literature. Sociologists and policymakers mostly focused on the relationship between math achievement and socioeconomic status (SES), whereas cognitive and educational psychologists focused on the cognitive predictors of math achievement. To optimize mathematical, educational and instructional practices, it is necessary to understand how these factors relate to and interact with each other during development.

SES is supposed to be one of the strongest predictors of academic achievement, both in reading and math (e.g. OECD, 2010; Sirin, 2005). The advantages of children from families with high SES emerge before the start of schooling; these differences might remain or expand through school years (Bradley & Corwyn, 2002; Caro, McDonald, & Willms, 2009). There is plenty of evidence that SES is predictive for multiple components of reading skills and development, including decoding, print knowledge, and comprehension (Bowey, 1995; Hecht et al., 2000; Noble et al., 2006; Molfese, Modglin, & Molfese, 2003). SES also affected early precursors of math achievement such as number sense and number competence (e.g. Jordan et al., 2006; Jordan & Levine, 2009).

One possible mechanism explaining this is that SES may affect cognitive functions that correlate with later academic achievement. There is plenty of evidence that low family SES impairs working memory capacity, executive function, intelligence and phonological ability (e.g., Ardila et al., 2005; Farah et al., 2006; Engel et al., 2008; Hackman et al., 2015). That may lead to a further decrease in academic achievement. Particularly, it was demonstrated that the effect of SES on math achievement might be mediated by Approximate Number Sense (ANS) and time detection capacity (Valle-Lisboa et al., 2016). The effect of SES on reading achievement was also mediated by phonological abilities (Bowey, 1995; Zhang et al., 2013).

There is evidence that phonological ability also has a significant effect on math achievement. Phonological ability refers to the sensitivity for the sounds of their language and the capacity to use these sounds to decode linguistic information, the ability to process and understand the sound structure of oral language (Wagner & Torgesen, 1987). The effect of phonological ability on math was more prominent for math performance that involved fact retrieval strategies (De Smedt et al., 2010; Pospoel et al., 2017).

Neuroimaging studies have also confirmed a close relationship between phonological processing and arithmetic fact retrieval (Prado et al., 2011; Simon, Mangin, Cohen, Le Bihan, & Dehaene, 2002). In particular, it was shown that arithmetic problem solving involved brain regions associated with language processing (Arsalidou & Taylor, 2011; Pollack & Ashby, 2018; Prado et al., 2014). Earlier studies demonstrated the significant activation of the brain areas involved in language processing during single-digit multiplication and addition operations compared to subtraction problems (Simon et al., 2002; Prado et al., 2011).

Some studies have demonstrated that a deficit of phonological ability can be one of the factors of dyscalculia (DeSmedt & Boets, 2010; Vukovic & Siegel, 2010). Vanbinst, Ghesquière and De Smedt (2014) demonstrated that children with dyscalculia, who also showed persistent difficulties in arithmetic fact retrieval, performed significantly worse on all dimensions of phonological processing, and these differences were significant even after intelligence, working memory capacity or reading abilities were controlled for. Although it is unlikely that a phonological deficit is the core deficit for children with dyscalculia (e.g., Landerl, Bevan, & Butterworth, 2004), the phonological deficit could be an additional risk factor for developmental math difficulties (De Smedt, 2018).

On the other hand, some studies failed to find a significant relations between phonological and math ability (e.g., de Jong & van der Leij, 1999; Passolunghi, Vercelloni, & Schadee, 2007). In particular, studies have shown that children with both math and reading difficulties usually demonstrated a deficit in phonological processing, while children with only math difficulties often did not show phonological impairments (e.g., Geary, 1993; Moll, Gobel, & Snowling, 2015; Rourke & Conway, 1997). In line with these results, phonological abilities were found to be unique predictors of reading performance but not of math performance (Bradley & Bryant, 1983; Passolunghi, Vercelloni, & Schadee, 2007).

SES can modulate relations between certain types of cognitive predictors and academic achievement (e.g. Demir, Prado, & Booth, 2015; Noble, Farah, &McCandliss, 2006). Particularly, it has been demonstrated that SES moderates the relation between phonological ability and decoding skills for reading (Noble, Farah, & McCandliss, 2006). It has also been shown that SES moderates the relation between math gains and brain activation in regions related to verbal numerical representations and spatial representations. Activity in the brain regions associated with verbal activity during math problem solving was higher for participants with higher SES whereas activation of regions associated with spatial representations was higher for low SES participants (Demir, Prado, & Booth, 2015; Demir-Lira, Prado, & Booth, 2016). This means that children from high SES families rely more on verbal processing during math activities and that SES-related differences in mathematics are larger for the verbal aspects of mathematics (Jordan & Levine, 2009).

Despite a large body of research regarding the relationship between phonological ability and math, and the effect of SES on math achievement, little is known about how SES modulates the effect of phonological ability on math achievement and math progress. Previous studies did not focus on how the effect of phonological ability varies for children with different SES. Meanwhile, this issue might be important for planning remedial programs for children with mathematical difficulties or for the design of developmental programs for children from low SES families.

Current study

The current study has three main goals. The first goal is to estimate the effect of phonological ability on math performance, controlling for reading achievement and number identification skills in the first year of schooling. Although numerous studies investigated the relationship between phonological ability and math, they had several limitations. First of all, most studies were conducted on small samples, which could lead to biased estimations of the effects. Another restriction is related to the cross-sectional design of previous studies which limited their capacity to estimate the effect of phonological ability on progress in math. Our study overcomes these restrictions by using a large sample size and longitudinal two-wave design. We used mixed-effect analysis in order to estimate the effect of phonological ability on math achievement and math progress.

The second goal of our study is to estimate the effect of different SES measures on math achievement and improvement during the first year of schooling. We used two indicators of family SES: maternal education and the number of books at home. Previous studies demonstrated that different indicators of SES had different effects on academic achievement and it is necessary to take into account potential variation in these effects (Sirin, 2005).

Previous studies demonstrated that parental education was a powerful predictor of academic achievement (Sirin, 2005) and that its effect was independent of the effects of family income. Several studies also showed that the number of books at home was a reliable indicator of family cultural and educational status which also reflected parental investment in child development (Brunello, Weber, & Weiss, 2016). The number of books at home had a positive effect on students achievement even when parental education and income were controlled for (Brunello, Weber, & Weiss, 2016; Evans et al., 2010).

We also include language at home as a potential predictor of math achievement. As we obtained data for our study in the Tatar Republic in Russia, some participants used two languages at home (Tatar and Russian) or only Tatar whereas instruction in elementary school was in Russian for our sample. That allowed us to estimate the effect of using other languages at home on academic achievement. Language at home was supposed to be a significant predictor of academic achievement although in some cases this effect might be explained by SES differences (Chiu & Xihua, 2008; Kennedy & Park, 1994).

The third goal of our study is to estimate whether the effect of phonological ability is modulated by student SES and language at home. We hypothesize that children from high SES families tend to more actively involve verbal processing during math problem solving, hence the effect of phonological ability is larger for children with high SES.

We have several research questions regarding our aims:

1) Does the phonological ability affect math achievement during the first year of schooling?
2) Do children with high phonological ability demonstrate better progress in math during the first year of schooling?
3) Does the progress in math during the first year of schooling vary for students depending on their SES and language at home?
4) Does the effect of phonological ability vary for students with different SES?

Method

Participants

This study was conducted in Russia (in the Tatar Republic) during the 2017-2018 academic year. The initial sample of 3,450 first-graders was assessed in October 2017, at the beginning of the first year of schooling (Time 1), and the second stage of the assessment was conducted in May 2018, at the end the first school year (Time 2). In the resulting sample for analysis only children who participated in both waves and whose parents gave information about SES were used. The final sample consisted of 2,948 first-graders (49% were girls). The mean age was 7.3 years at the beginning of the school year and 7.8 years at the end.

The parents of the respondents gave their informed consent before the survey. The data were collected anonymously. The Institutional Review Board at the Higher School of Economics approved the study, and the data were collected according to the guidelines and principles for human research subjects.

Instruments and procedure

In order to estimate math and reading performance, and phonological ability the Russian version of iPIPS (the international Performance Indicators in Primary Schools) was used. iPIPS is based on the Performance Indicators in Primary Schools (PIPS) monitoring system, developed by the Centre for Education and Monitoring at Durham University in the UK (Tymms, 1999; Tymms, Merrell, & Wildy, 2015). The Russian version of the iPIPS assessment was developed from 2013 to 2015 (Ivanova et al., 2016).

Children were assessed on a one-on-one basis by trained testers using computer-assisted software. The assessment, which lasted approximately 15 to 20 minutes, occurred at school and in a separate, quiet room. Each child sat with a tester in front of a computer.

The computerized software-guided test employed a dynamic adaptation algorithm, that is, a sequence of items with stopping rules. The items within each section were arranged in order of increasing difficulty, children started with easy items and moved on to progressively more difficult ones. When the child made three consecutive or four cumulative errors in a section, the assessment of that section stopped and the child proceeded to the next section.

Measures

During two assessment cycles, the same sample of children were presented with the same set of items. In order to examine the achievement level of students over time, we applied the IRT technique, specifically, anchor item equating, using the dichotomous Rasch model (Kolen, Brennan, 2004). Thus, the items were equated such that a continuous scale was used to assess student development from Time 1 to Time 2.

Outcomes

Math performance

For the estimation of math achievement a total of 19 tasks were presented. These tasks included word-based problem-solving tasks and two-digit arithmetic tasks. The scale was unidimensional, with items highly correlated, and test reliability (Cronbach's alpha) varied from 0.8 to 0.9 for Time 1 and Time 2.

Predictors

Phonological ability

We used two types of tasks to assess phonological abilities: rhyming tasks and word/pseudo-word repetition tasks. For the rhyming task, the child had to select the word that rhymed with a target word from three options. In total, five target words were presented. As incorporated in the software, each word was illustrated with a picture and pronounced by a professional narrator. In the word/pseudo-word repetition task, the child was asked to repeat a word or pseudo-word (for example, "frigliyaga" (pseudoword) and "stop" (word)) immediately after hearing it pronounced by the assessment software. There were five items for word repetition and three items for pseudo-word repetition. The reliability was 0.7 at Time 1 and 0.9 at Time 2 assessment.

Number identification

The number-identification tasks included single-, two- and three-digit numbers. The child was asked to name numbers that were presented visually. A total of nine numbers were presented. The scale was unidimensional, with items highly correlated, and test reliability (Cronbach's alpha) varied from 0.8 to 0.9 for Time 1 and Time 2.

Reading performance

The reading performance scale was constructed based on tasks that included letter recognition, word decoding and reading comprehension. First, for letter recognition estimation, children were asked to name letters presented on the screen, eight letters in total. Tasks for the estimation of word decoding skills included fluent printed word recognition and the reading aloud of a short simple story. The words were of high frequency. For the words and the story, each word recognized and read correctly was counted as a correct answer. In the story reading task, the child had to read a short story of 34 words divided into three parts accompanied by related pictures. If the child was able to read half of the words in each part correctly, the item was scored as correct.

The reading comprehension task included two more difficult texts where the child was required to read a passage and, at certain points, to select one word from a choice of three that fit the story best (in total, 36 choices were scored). The reliability of the reading scale was higher than 0.9 for both Time 1 and Time 2.

SES measures

The information about family SES was obtained from parental questionnaires. We used two indicators of family SES: maternal education (1 – mother has higher education; 0 – mother has no higher education); number of books at home (1 – family has more than 100 books at home; 0 – family has less than 100 books at home). We also included variable "language at home" (1 – family uses only Russian language at home; 0 – family uses both Russian and another language at home).

Statistical approach

In order to answer our research questions, we used mixed-effect models in which Time 1 and Time 2 measures were considered as nested in individuals. These models allow us to estimate the effect of predictors on outcomes and time changes in outcomes. Mixed-effect models also estimate between-individuals and within-individual variance (random effect). Using mixed-effect models enabled us to estimate the effects of both time-varying and time-invariant predictors, so we were able to estimate both the effect of phonological ability on math achievement and the effect of SES.

We tested several mixed-effect regression models for math achievement as the outcome:

1) Model 1. In this model a time variable was included. The coefficient of the time variable demonstrated the time changes of math achievement from Time 1 to Time 2.
2) Model 2. In this model some time-variant and time-invariant predictors were added. In order to estimate the effect of phonological ability we added phonological ability as a predictor. The coefficient of this variable reflected how math achievement changed when phonological ability increased by 1 logit. We also added reading achievement and number identification as predictors in order to get more reliable estimations of the effect of phonological ability. We also added SES measures and gender (1 = female) as a predictors.
3) Model 3. In order to estimate the effect of phonological ability on progress in math, we added interaction between the time variable and phonological ability. The coefficient of the interaction term reflected the differences in progress in math progress for students with different phonological abilities.
4) Models 4–6. In order to estimate how math progress varied for students with different SES backgrounds, we included interaction terms between different dimensions of SES, language at home and the time variable. The significance of these terms indicated that time changes significantly varied for students with different SES. Model 4 included interaction between maternal education and the time variable. Model 5 included interaction between the number of books at home and the time variable and Model 6 included interaction between language at home and time.
5) Models 7–9. In order to estimate how the effect of phonological ability varied depending on SES and language at home, we included interaction terms in consecutive models: interaction between maternal education and phonological ability (Model 7), interaction between the number of books at home and phonological ability (Model 8), interaction between language at home and phonological ability (Model 9). The significance of interaction terms can be interpreted as the significance of the differences in effect of phonological ability for students with different SES or language at home.

We compared the models with interaction with the model without interaction (Model 2) using the likelihood ratio test (LR test). This test indicated that the model with interactions fitted the data better than the model without interaction.

Results

Descriptive statistics

We examined math and reading achievement, phonological ability and number identification at Time 1 and Time 2.

Table 1

Descriptive statistics for math and reading achievement, phonological ability and number identification

Variables	Mean (in logits)	SD	Min	Max
Math achievement at Time 1	-1.32	2.22	-6.08	5.91
Math achievement at Time 2	0.91	2.13	-5.03	5.92
Phonological ability at Time 1	0.82	1.46	-5.24	4.36
Phonological ability at Time 2	1.97	1.79	-5.22	4.36
Reading achievement at Time 1	0.04	2.58	-7.01	6.89
Reading achievement at Time 2	2.47	2.13	-7.20	6.91
Number identification at Time 1	2.08	4.79	-9.08	8.34
Number identification at Time 2	5.19	3.72	-6.27	8.35

Descriptive statistics revealed that all measures increased from Time 1 to Time 2.

Descriptive statistics for SES measures are presented at Table 2.

Table 2

Descriptive statistics for SES measures

Variables	Values	%
Mother's education	0 – no higher education	48%
	1 – higher education	52%
Number of books at home	0 – less than 100 books at home	88%
	1 – more than 100 books at home	12%
Language at home	0 – not only Russian language at home	16%
	1 – Russian language at home	84%

The results of the mixed-effect analysis

The results of the mixed-effect analysis are shown in Table 3.

Table 3

The results of mixed-effect analysis for math achievement as outcome

Variables	Model 1	Model 2	Model 3
Constant	-1.32*** (0.04)	-1.85*** (0.07)	-1.90*** (0.08)
Time	2.23*** (0.04)	1.04*** (0.04)	1.17*** (0.06)
Phonological ability		0.19*** (0.02)	0.25*** (0.02)
Reading achievement		0.16*** (0.01)	0.15*** (0.01)
Number identification		0.19*** (0.01)	0.19*** (0.01)

Mother has higher education		0.30*** (0.05)	0.31*** (0.05)
Number of books at home		0.12 (0.08)	0.11 (0.08)
Only Russian language at home		-0.06 (0.07)	-0.06 (0.07)
Gender (girl = 1)		-0.33*** (0.05)	-0.33*** (0.05)
Phonology*Time			-0.10*** (0.02)
Between-individuals variance	2.76	0.78	0.77
Within-individuals variance	1.99	2.00	2.00
Log-likelihood	-12349.43	-11263.05	-11255.167
LR test (Δdf)			15.76*** (1)

*** $p < .001$, ** $p < .01$, * $p < .05$

The results revealed that phonological ability had a positive effect on math achievement. The effect was significant even controlling for reading achievement and number identification. There was a significant difference in math achievement regarding maternal education: the students from families where the mother had higher education had higher math achievement. The number of books at home and language at home had no effect on math achievement.

In Model 3, the interaction between phonological ability and the time variable was significant and negative. This indicated that time changes in math achievement were higher for children with low phonological ability. Math achievement at Time 1 was higher for students with high phonological ability, so difference in math achievements for students with high and low phonological ability reduced at Time 2 (Figure 1).

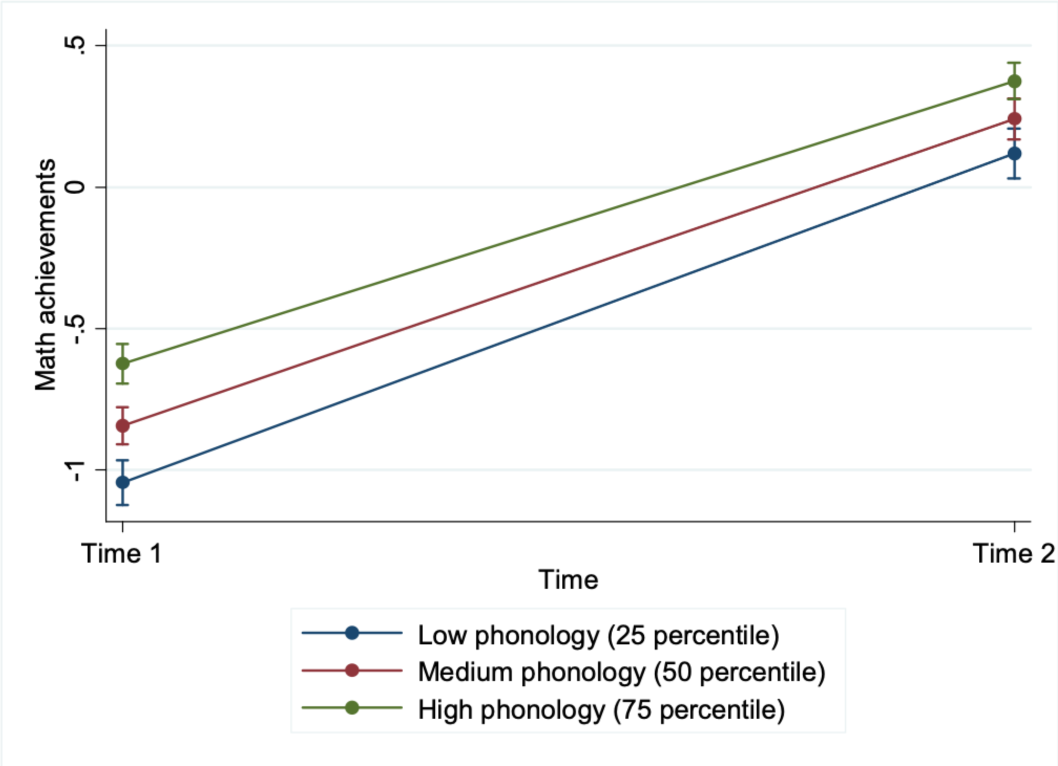

Figure 1. *Time changes in math achievement for students with different phonological ability*

Further analysis revealed that time changes in math achievement significantly varied for students with different SES background (Table 4).

Table 4

The results of mixed-effect analysis for math achievement as outcome and interaction with SES

Variables	Model 4	Model 5	Model 6
Constant	-1.79*** (0.08)	-1.85*** (0.07)	-1.76*** (0.09)
Time	0.92*** (0.06)	1.04*** (0.05)	0.86*** (0.10)
Phonological ability	0.19*** (0.02)	0.19*** (0.02)	0.19*** (0.02)
Reading achievement	0.16*** (0.01)	0.16*** (0.01)	0.16*** (0.01)
Number identification	0.19*** (0.01)	0.19*** (0.01)	0.19*** (0.01)

Mother has higher education	0.19** (0.06)	0.30*** (0.05)	0.30*** (0.05)
Number of books at home	0.11 (0.08)	0.14 (0.10)	0.11 (0.08)
Only Russian language at home	-0.06 (0.07)	-0.06 (0.07)	-0.16 (0.08)
Gender (girl = 1)	-0.33*** (0.05)	-0.33*** (0.05)	-0.33*** (0.05)
Interaction effect			
Mother's education*Time	0.22** (0.07)		
Book at home*Time		-0.05 (0.11)	
Language at home*Time			0.21* (0.10)
Random effect			
Between-individuals variance	0.78	0.78	0.78
Within-individuals variance	1.99	2.00	2.00
Log-likelihood	-11258.65	-11262.93	-11260.83
LR test (Δdf)	8.80** (1)	0.23 (1)	4.44* (1)

*** $p < .001$, ** $p < .01$, * $p < .05$

These results demonstrated that progress in math was greater for pupils with more highly educated mothers. Education-related differences in math achievement increased from the beginning to the end of the first grade (Figure 2).

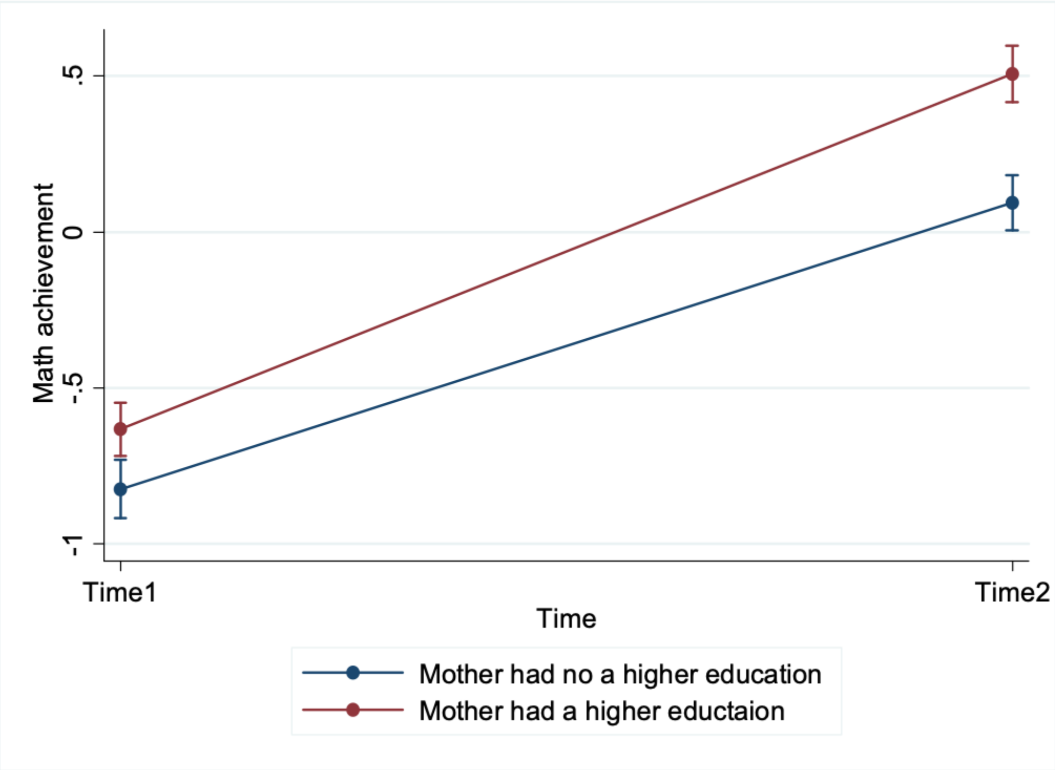

Figure 2. *Time changes in math achievement for students with different levels of mother's education*

The number of books at home had no effect on math achievement or development in math.

There was no significant difference between students at the beginning and at the end of the first grade depending on language at home, although time changes in math were larger for students who used only Russian at home (Figure 3).

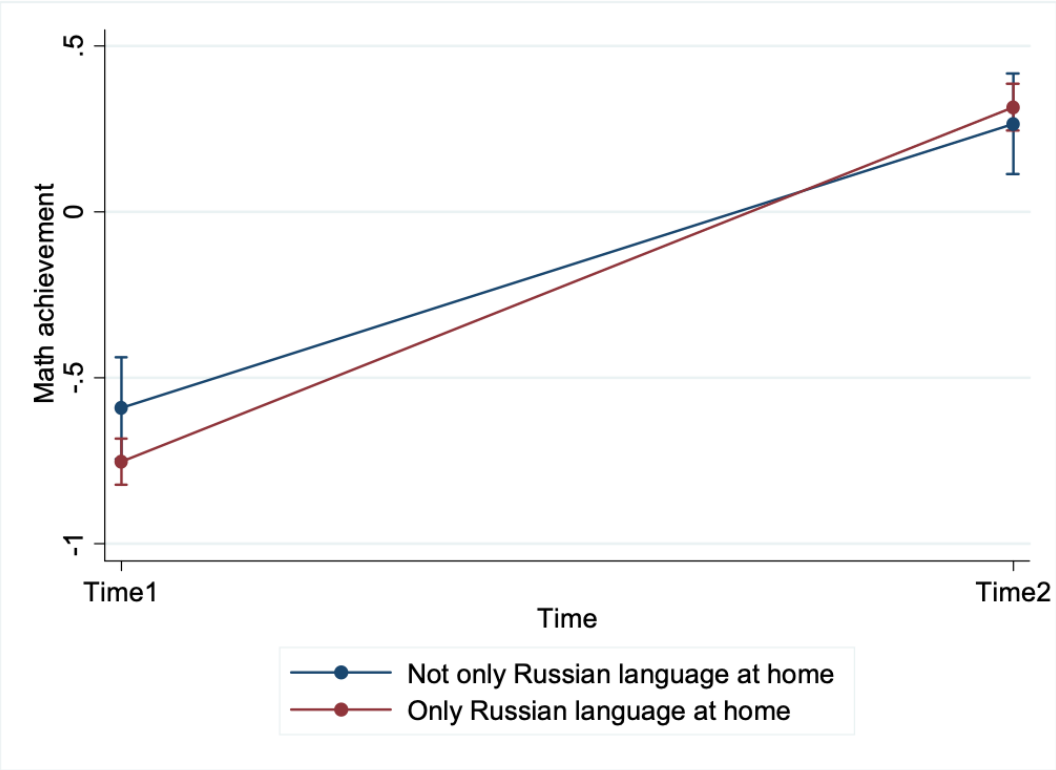

Figure 3. *Time changes in math achievement for students with different language background*

Table 5 shows the estimation of the effect of phonological ability for students with different SES.

Table 5

The results of mixed-effect analysis for math achievement as outcome and interaction with SES

Variables	Model 7	Model 8	Model 9
Constant	-1.85*** (0.08)	-1.83*** (0.07)	-1.95*** (0.08)
Time	1.04*** (0.04)	1.03*** (0.04)	1.03*** (0.04)
Phonological ability	0.19*** (0.02)	0.18*** (0.02)	0.27*** (0.03)
Reading achievement	0.16*** (0.01)	0.16*** (0.01)	0.16*** (0.01)
Number identification	0.19*** (0.01)	0.19*** (0.01)	0.19*** (0.01)

Mother has higher education	0.30*** (0.05)	0.30*** (0.05)	0.30*** (0.05)
Number of books at home	0.11 (0.08)	-0.04 (0.10)	0.12 (0.07)
Only Russian language at home	-0.06 (0.07)	-0.06 (0.07)	0.06 (0.08)
Gender (girl = 1)	-0.33*** (0.05)	-0.33*** (0.05)	-0.33*** (0.05)
Interaction effect			
Mother's education* Phonology	0.002 (0.03)		
Book at home*Phonology		0.09* (0.04)	
Language at home* Phonology			-0.09* (0.04)
Random effect			
Between-individuals variance	0.78	0.78	0.78
Within-individuals variance	2.00	2.00	2.00
Log-likelihood	-11263.04	-11259.79	-11259.99
LR test (Δdf)	0.01 (1)	6.51* (1)	6.13* (1)

*** $p < .001$, ** $p < .01$, * $p < .05$

Models with interaction revealed that maternal education did not moderate the effect of phonological ability on math achievement. The number of books at home significantly moderated the effect of phonological ability on math. A simple slope analysis revealed that the effect was higher for children with more than 100 books at home (Table 6). The interaction between phonological ability and language at home was significant and negative. This indicated that the effect of phonological ability was lower for children from families that used only Russian at home compared to children from families using another language at home (Table 6).

Table 6.

The effect of phonological ability on math achievement for students with different number of books and language at home

Indicators of SES	The effect of phonological ability	95% CI
Less than 100 books at home	0.18*** (0.02)	0.15; 0.21
More than 100 books at home	0.27*** (0.04)	0.20; 0.34
Not only Russian language at home	0.27*** (0.03)	0.20; 0.34
Only Russian language at home	0.18*** (0.02)	0.15; 0.21

*** $p < .001$

These results revealed that phonological ability had an effect on math achievement but the effect depended on SES. On the other hand, there were no differences in math achievement for children depending on the number of books at home for low and medium levels of phonological ability whereas children with more than 100 books at home outperformed children with a small number of books at home at high levels of phonological ability (Figure 4).

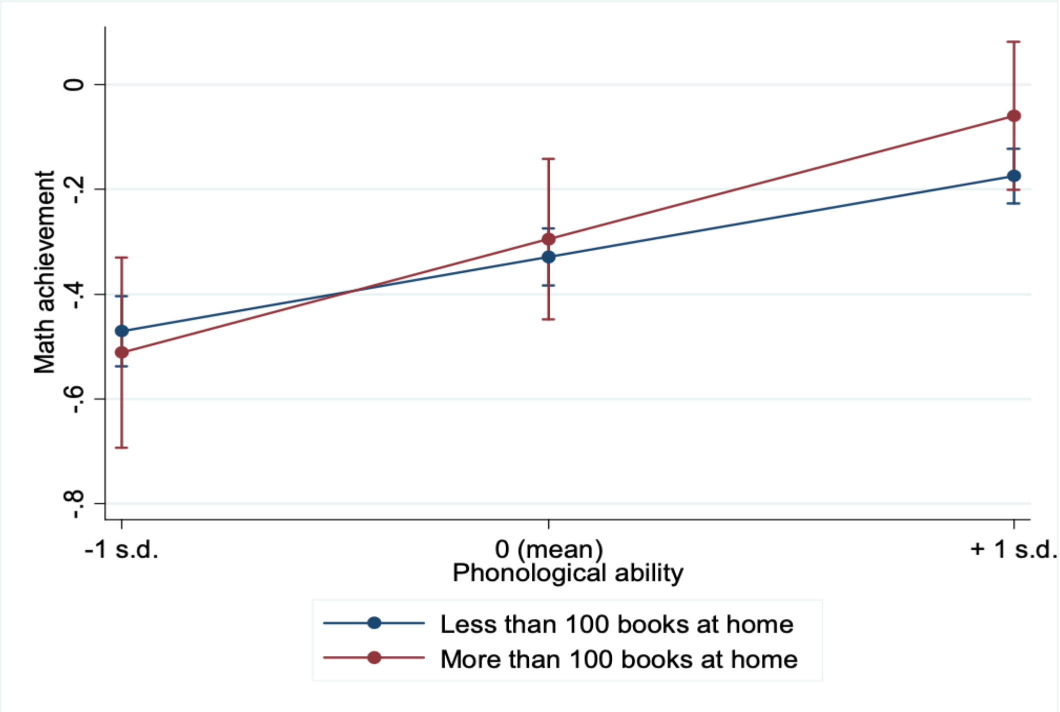

Figure 4. *The effect of phonological ability on math achievement for children with different number of books at home*

At high levels of phonological ability, children with another language at home outperform children who used only Russian at home (Figures 5).

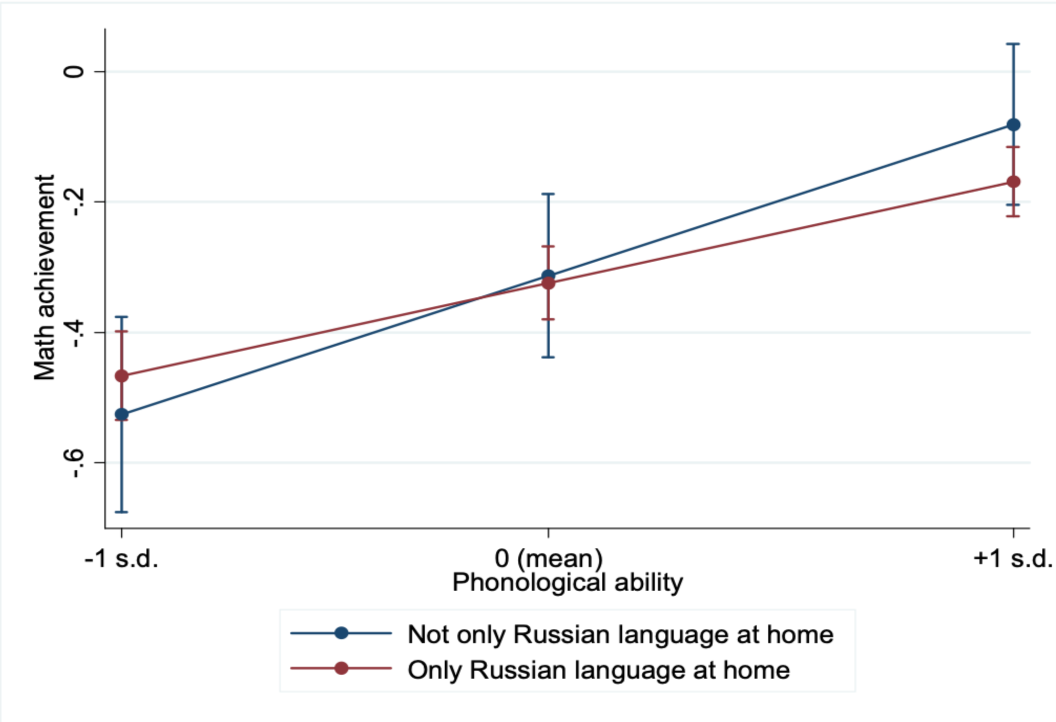

Figure 5. *The effect of phonological ability on math achievement for children with different language background*

Discussion

Previous studies show contradictory results regarding the effect of phonological ability on math achievement. Although some psychophysiological studies revealed that SES modulated the relationship between the activation of language brain areas and math problem solving, there are no studies that demonstrate that the effect of phonological ability varies for students from different SES backgrounds. Our study filled that gap.

We used a large sample of first-graders who participated in iPIPS and were tested twice: at the beginning and at the end of the first grade. The two-wave longitudinal design allowed us to estimate if the changes in phonological ability related to changes in math achievement using mixed-effect models. We also controlled for SES which was measured by maternal education, the number of books at home and language at home.

Our study had three main findings. First, we found that phonological ability affected math achievement even when reading achievement and early precursors of math achievement such as number identification skills were controlled for. Several studies demonstrated that phonological ability did not directly predict math achievement. They show that phonological ability uniquely predict reading achievement and, in turn, poor reading skills might be related to low math achievement (Bradley & Bryant, 1983; Passolunghi, Vercelloni & Schadee, 2007). Our results revealed that both phonological ability and reading achievement predicted math achievement.

Our results also demonstrated that improvement in math achievement during the first year of schooling was higher for children with low levels of phonological ability. These results might be unexpected but it should be taken into account that children with high phonological ability had a significantly higher math achievement at the start of schooling. This smaller progress might be explained by high achievement at the start and the ceiling effect at the end of the school year.

Second, we found that some indicators of SES affect math achievement and math growth. Previous studies demonstrated that maternal education was a powerful predictor of academic achievement (Hoff, 2006; Hoff, Laursen, & Bridges, 2012). Our analysis revealed that children with a more educated mother had higher math achievement and larger improvement in math. Parental education affects academic performance in different ways. First, more educated parents can directly provide resources at home for more successful education, both material and non-material (Bradley & Corwyn, 2002). Secondly, parents with a lower level of education may pay less attention to academic achievement and have lower educational expectations which may lead to lower performance and less progress (e.g. Davis-Kean, 2005; Englund et al., 2004; Zady & Portes, 2001).

Third, although the number of books at home and language at home did not affect math achievement directly, they might modulate the relationship between phonological ability and math. Particularly, phonological ability had a larger effect on math achievement for children with a larger number of books at home. The number of books at home might be considered an indicator of family cultural capital (Brunello, Weber, & Weiss, 2016) and be related to the amount of verbal interaction within the family, frequencies of reading or other verbal activity (Hart & Risley, 1995; Weigel, Martin, & Bennett, 2006). During their development children from families with higher cultural capital might learn to better manipulate verbal representations in general and the verbal representation of numbers specifically (comparing to lower SES children. As a consequence, high SES students may more often recruit phonological processing during math problem solving.

Sixteen percent of participants in our study used another language at home, predominantly Tatar. Although instruction at school was in Russian, some pupils used Tatar at home, so these students were bilingual. There were contradictory results regarding the differences in academic achievement and phonological ability in bilingual children (Bialystok, Majumder, & Martin, 2003; Chen et al., 2004; Mouw &Xie, 1999). Some studies demonstrate that bilingual students have a higher level of phonological ability (Kang, 2012; Loizou & Stuart, 2003). Our study demonstrated that bilingual first-graders did not have significantly lower math achievement at the start and at the end of the first grade. Additional analysis revealed that students did not differ in phonological ability depending on language background. The effect of phonological ability was greater for bilingual students. Probably, bilingual students also recruit phonological resources more often during math problem solving.

It should be noted that phonological ability was measured for the Russian language although for bilingual students phonological ability might be measured for both languages. Previously, it was demonstrated that the consistency between spelling and sounds in a language might affect children's phonological skills and the relationship between phonological and reading skills (Landerl & Wimmer, 2008). As an example, languages with more inconsistent spelling-sound correspondence, such as English, show a longer and larger effect of phonological ability on reading (e.g., Torgesen, Wagner, Rashotte, & Burgess, 1997). A similar effect could likely be observed regarding math performance. In our study, we use the Russian language, which represents a group of Slavic languages and uses the Cyrillic alphabet. Russian phonology has several specific characteristics, which include non-systematic stress patterns, some forms of vowel reduction and consonant assimilation, complex syllable structure. In other words, Russian has been suggested to be in the middle of the continuum, between more regularly spelled languages, for example, Finnish, and English (Laurinavichyute et al., 2018; Seymour et al., 2003). Results may change for bilingual children if phonological ability is measured in both languages.

Our study has some limitations. First, we were able to use only a two-wave longitudinal design. However, it would no doubt be better to have three or more waves in the study in order to more precisely estimate the relationships between our key variables. Another important limitation was the nature of the indicators we used as phonological ability constructs. Phonological ability is represented in this study mostly by one dimension instead of the possible three. Future studies would benefit from having more items measuring lexical access, phonological awareness and memory. Using mixed-effect models did not solve the problems of omitted variables. We estimated the effect of both time-variant and time-invariant variables but we did not control for a large number of possible predictors of math achievement that potentially may explain the correlation between phonological ability and math achievement such as intelligence or executive functions. Future studies are necessary to disentangle the effect of phonological ability from the effect of other cognitive functions.

The results of our study have several practical implications. First, to improve mathematics achievement, some interventions or remedial instruction in the first grade of schooling could be considered. Our results demonstrate that phonological skills should be taken into account when planning interventions to improve mathematical achievement. Second, parental mathematical activities at home should not only focus on promoting children’s basic mathematics skills such as digit knowledge or basic arithmetic but also be accompanied by some sort of phonological activities. Third, the effect of phonological ability varies depending on family SES, meaning that children with low SES were less likely to recruit phonological resources for math problem solving. Therefore, in planning the training programs for low SES children it could be beneficial to use less verbal instructions and more graphical, visual representations of math concepts and tasks. The presentation of math tasks in different formats, verbal and visual, could reduce SES-related difference in math, at least, in elementary school.

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Yulia V. Kuzmina

Center of Education Quality Monitoring, Institute of Education, National Research University Higher School of Economics, research fellow, e-mail (jkuzmina@hse.ru)

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