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## Fluid Intelligence Test Scores Across the Schooling: Evidence of Nonlinear Changes in Girls and Boys

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### ABSTRACT

The results of the analyses of the changes of fluid intelligence scores measured by the Standard Progressive Matrices test across all school years were presented. Sex differences in fluid intelligence scores for each year of schooling as well as in fluid intelligence changes across schooling were analyzed. A total of 1581 participants (51.1% boys) aged 6.8 to 19.1 years from one public school were involved in this cross-sectional study, of whom 871 were primary schoolchildren (mean age = 9.23; range 6.8–11.6), 507 were secondary schoolchildren (mean age = 14.06; range 10.8–18.0), and 203 were high schoolchildren (mean age = 17.25; range 15.3–19.1). To examine the changes in fluid intelligence both correlation analysis and polynomial regression of the total, boys' and girls' samples were performed. Linear, quadratic, and cubic regression models were fitted to the data. To explore sex differences in fluid intelligence in each year of schooling, the series

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of ANOVA were carried out. The results revealed that the school-age change in fluid intelligence is nonlinear for both girls and boys. The changes for girls during the schooling are best described by a quadratic relationship while those for boys are best reflected by a cubic relationship.

#### **KEYWORDS**

fluid intelligence, school-age years, education, development, cross-sectional study, sex differences, polynomial regression

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## **Introduction**

Numerous studies show that intelligence underlies current and future individual achievements in education and professional success and is closely related to mental and physical well-being throughout life (Aichele et al., 2019; Brouwers et al., 2009; Deary et al., 2007; Nisbett et al., 2012; Tikhomirova et al., 2019a; Tikhomirova et al., 2020). Meta-analyses revealed that intelligence is a significant predictor of educational achievement in all school subjects (Brouwers et al., 2009; Deary et al., 2007). The results of large-scale longitudinal studies investigating the causal relationships between intelligence and academic success support this hypothesis (Deary et al., 2007). Certain works report that the more a person learns, the higher his level of intelligence is (Baltes & Reinert, 1969).

Moreover, intelligence is sensitive to characteristics of the sociocultural environment and first to the educational conditions of a particular class, school, region, or national education system (Nisbett et al., 2012; Tikhomirova et al., 2019a). For example, studies of schoolchildren from countries with different educational conditions have shown a decrease in cross-cultural differences in intelligence with school attendance, which is explained by the influence of the learning process on the cognitive development of students (Tikhomirova et al., 2019a; Tucker-Drob & Briley, 2014; von Stumm & Plomin, 2015). This sensitivity requires the study of patterns of change in intelligence occurring throughout the course of schooling in certain educational conditions.

Despite the fact that numerous studies have shown a relationship between intelligence and academic achievement, some differences in approaches to measuring intelligence can be found in these studies. Most of these studies are based on the Cattell-Horn model of fluid and crystallized intelligence (Cattell, 1963; Horn & Cattell, 1966). In accordance with this model, crystallized intelligence is defined as

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the ability to solve problems that are directly related to knowledge acquired during the learning process, from personal experiences and from previously formed skills. Fluid intelligence is defined as the ability to think abstractly and solve problems unrelated to previous experiences, personal knowledge or learning. Nevertheless, the development of fluid intelligence determines the effectiveness of new knowledge and skill acquisition during schooling (Barbey, 2018; Brown, 2016). Fluid intelligence is measured by tests with nonverbal stimuli not related to the sociocultural context. In the school setting, fluid intelligence is often measured using the Standard Progressive Matrices test, which lacks a specific cultural context in that it does not give one social group an advantage over another (Raven, 2003).

Age-related changes in fluid intelligence raise questions surrounding the role of the biological age of respondents and the number of years of schooling in these changes (Brinch & Galloway, 2012; Cahan & Cohen, 1989; Nisbett et al., 2012; Ritchie et al., 2015; etc.). Studies of children starting formal schooling at different ages (Cahan & Cohen, 1989), studies of groups of children not attending school in certain periods of life or receiving an additional year of schooling (Brinch & Galloway, 2012; Nisbett et al., 2012), and studies of older people with biological and educational ages correlated with current cognitive indicators (Schneeweis et al., 2014) allow us to assess the effects of these two factors. In these studies, it is concluded that education, school age in particular, has a more significant effect on the growth of intelligence test values throughout a person's life. Nevertheless, both biological and educational age are equally considered in the analysis of cognitive changes, and either the specificity of their influence on certain cognitive traits is taken into account or they are treated as factors identical in meaning.

The comparison of effects of biological age and years of schooling is especially relevant for studies of schoolchildren from Russia, where children can enter the first grade of school starting from 6.6 and to 8 years of age. This is due to the Federal Law No. 273-FZ *Ob obrazovanii v Rossiiskoi Federatsii* [On Education in the Russian Federation], which defines the age interval (6.6–8 years) from which parents can determine when children should start school (*Ob obrazovanii v Rossiiskoi Federatsii*, 2012). Thus, in one study of Russian primary school students, the range of age variability for grade 1 is 2.4 years—from 6.4 to 8.8 years of age (Tikhomirova et al., 2019a). Such a wide range of variability in the biological age of students in one year of schooling creates an opportunity to analyze the joint and independent influences of this factor on the development of intelligence during schooling.

Fluid intelligence scores change over time. This has been demonstrated by cross-sectional studies reporting changes in mean values (Desjardins & Warnke, 2012; Hartshorne & Germine, 2015; Kievit et al., 2016) and by longitudinal studies that calculate developmental trajectories over a certain time interval (Ghisletta et al., 2012; Tikhomirova et al., 2019a; Tikhomirova et al., 2019b; von Stumm & Plomin, 2015).

These studies show that life-long changes in fluid intelligence are characterized by rapid growth during childhood and adolescence, reaching a peak in early adulthood (30–40 years) and a gradual decline in old age. This pattern of changes in fluid intelligence confirms its role in age-sensitive cognitive ability (Hartshorne &

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Germine, 2015). Fluid intelligence develops unevenly from infancy to adolescence at a significant rate for some children and a less intensive rate for others (Tucker-Drob & Briley, 2014; von Stumm & Plomin, 2015;). It has been reported that individual differences in the development of intelligence in childhood are associated, among other factors, with the socioeconomic characteristics of the microenvironment—familial development experiences (von Stumm & Plomin, 2015). The significance of the socioeconomic conditions of one's family is shown both for the "starting" level of intelligence at 2 years of age and for the growth of intelligence from 2 to 16 years of age (von Stumm & Plomin, 2015).

According to the results of a longitudinal study, in the primary school age period from 7 to 11 years, there is an increase in fluid intelligence scores (Tikhomirova et al., 2019a; Tikhomirova et al., 2019b). At the same time, the most intensive growth occurs between ages 7 and 8 (grades 1–2 of primary school), and then up to age 10 (grades 2–4 of primary school), their scores on the Standard Progressive Matrices test statistically significantly improve.

In general, most researchers agree that the school aged period is characterized, on the one hand, by the most intensive growth of fluid intelligence and, on the other hand, increased sensitivity to sociocultural conditions, primarily educational (Brouwers et al., 2009; Tikhomirova et al., 2019a; von Stumm & Plomin, 2015). This duality is reflected in the problem of the causal relationship between intelligence and education, which leads to a need to control various characteristics of the educational environment when studying temporal changes in intelligence (Deary & Johnson, 2010). At the same time, the question of the nature of changes in test scores of fluid intelligence throughout the entire period of formal schooling, a time interval of 11 years, including childhood, adolescence and early youth, remains unaddressed.

Studies report both the existence of sex differences in intelligence and their absence (e.g., Flynn & Rossi-Casé, 2011). These contradictions are explained by differences in methods used to measure fluid intelligence, the age characteristics of study participants, and macroenvironmental conditions (see Nisbett et al., 2012).

However, most researchers agree that sex differences in intelligence are observed before the age of 16, when the growth rates of girls and boys differ (von Stumm & Plomin, 2015). According to the theory of sex differences in the development of intelligence, this pattern is based in differences in the rates of maturation found between girls and boys: in girls, intensive development begins at the age of approximately 9 years and remains more intense than in boys up to 14–15 years. At 15–16 years of age, growth in girls slows while boys continue to develop.

One study of intellectual development found that at the age of 16, intelligence scores do not differ in girls and boys, but at the same time, there are sex differences in the development of intelligence from infancy to adolescence, confirming the hypothesis of a relationship between uneven maturation and individual indicators of intelligence tests (von Stumm & Plomin, 2015).

Studies have demonstrated the age specificity of differences in intelligence between girls and boys during schooling (Colom & Lynn, 2004). In particular, it has been shown that at 12–13 years of age, girls perform better on intellectual test

tasks than boys of 12–13 years and girls of 14–15 years. Girls of 14–15 years show better results on intelligence tests than boys of 14–15 years and girls of 16–18 years (Colom & Lynn, 2004). At the same time, at the age of 18, the test results of boys are superior to those of girls, and the effect of sex on IQ depends on the type of test task considered. As a rule, sex differences in intelligence, as for other cognitive functions, are explained using sociocultural (gender specificity of education) and neurophysiological (postnatal hormones) paradigms (Frenken et al., 2016; Miller & Halpern, 2014; Shanguan & Shi, 2009; Zilles et al., 2016).

This specificity in the cognitive development of girls and boys can determine differences in changes in fluid intelligence throughout school age. In addition, the results of studies on the sex characteristics of changes in fluid intelligence show different, sometimes diametrically opposing results due to, among other factors, the short time intervals of particular studies (for example, studies examining only adolescents or primary school students). The use of longer study periods covering various periods of life in the analysis of changes in fluid intelligence will make it possible to identify periods of growth, assess their intensity levels, and determine stages of stabilization in boys and girls.

## The Present Study

This cross-sectional study aimed to examine changes in fluid intelligence test scores over all years of schooling from grades 1 to 11. Additionally, sex differences in fluid intelligence test scores for each year of schooling as well as in fluid intelligence changes across schooling were analyzed. Finally, relationships between the year of schooling and schoolchildren's ages and corresponding independent and joint influences on changes in fluid intelligence were investigated.

School education in the Russian Federation covers the periods of childhood, adolescence and youth, creating an opportunity to examine changes in fluid intelligence over a long time interval covering those 6.6 to 19.1 years of age. Additionally, studying schoolchildren from a single public school affords us more control over the educational environment.

## Materials and Methods

### *Participants*

A total of 1581 participants aged 6.8 to 19.1 years from one public school were involved in the study, 51.1% boys.

The primary school-age sample (grades 1–4) included 871 schoolchildren with a mean age of 9.23 (range 6.8–11.6), 51.5% boys. The secondary school-age sample (grades 5–9) included 507 schoolchildren with a mean age of 14.06 (range 10.8–18.0), 55.5% boys. The high school-age sample (grades 10–11) included 203 schoolchildren with a mean age 17.25 (range 15.3–19.1), 40.2% boys.

Table 1 provides a description of the sample by year of schooling, covering Grades 1–11.

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The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of the Psychological Institute of the Russian Academy of Education (Project identification code 2016/2–12). Prior to data collection, all subjects gave their informed consent for inclusion to the study. Written parental informed consent was obtained for all participants. Data collection was carried out at the school in strict accordance with the developed protocols and under the supervision of the researcher.

## Measures

The fluid intelligence was measured using the paper-and-pencil version of the Standard Progressive Matrices test (Raven, 2003). The test consists of 5 sets with 12 items within each set. The item is a matrix, where the participant must select one missing element from 6 or 8 proposed options.

The matrices become progressively more difficult with each consecutive set and test. No discontinuity rules were applied, and the participants performed all of the tasks. The sum of correct responds was calculated.

### **Statistical Approach**

In the first phase, the variability in the participants' ages for each year of schooling was analyzed. A correlation analysis of the participants' ages and years of schooling was carried out. Then, to compare the performance of age and grade as predictors for fluid intelligence, a multiple linear regression was used.

In the second phase, the means and ranges of fluid intelligence test scores for the samples of girls and boys for each year of schooling were calculated. To examine the sex differences and their effect sizes for fluid intelligence for each year of schooling, a one-way analysis of variance (ANOVA) was performed.

In the third phase, to examine changes in fluid intelligence, a correlation analysis of grade and fluid intelligence test scores and polynomial regression of the total, male, and female samples were performed. Various regression models, both linear and nonlinear (quadratic and cubic), were fitted to the data. A polynomial regression was carried out on a total sample and on the female and male samples to analyze sex differences in age-related changes in fluid intelligence. Parameter estimation was performed with the least squares estimator.

## Results

In this study, the age-related changes of fluid intelligence measured as Standard Progressive Matrices test scores were analyzed for the whole schooling period.

### **Age, Grade, and their Impact on Fluid Intelligence Scores Changes**

In the first phase variability in the participants' age for each year of schooling was examined. The mean and range of the participants' ages, sample sizes, and the number of boys in each grade are presented in Table 1.

**Table 1**  
*Sample Description*

Level	Grade	N	Average age (min – max)	N <sub>boys</sub> (%)
Primary	1	146	7.86 (6.8–9.0)	51.4
	2	297	8.89 (7.6–10.3)	55.0
	3	333	9.83 (7.7–10.9)	52.5
	4	95	10.85 (10.1–11.6)	46.9
Secondary	5	102	11.82 (10.8–13.0)	63.7
	6	114	12.81 (11.7–14.2)	55.8
	7	98	13.78 (12.7–15.2)	53.4
	8	99	14.81 (13.6–16.2)	59.4
	9	94	15.77 (14.3–18.0)	45.3
High	10	100	16.72 (15.3–17.8)	35.6
	11	103	17.77 (16.3–19.1)	44.7
Total	1–11	1581	12.31 (6.8–19.1)	51.1

Table 1 demonstrates the average age for students in each school grade. According to the data, students' average age increases with school education by one year from 7.86 in Grade 1 to 17.77 in Grade 11. In other words, the difference in average age between school grades is one year.

At the same time, a wide range of age variability within one year of schooling was obtained.

Therefore, with one year of schooling, the range of students' age may be more than two years. For example, in Grade 1, 6.8 years as a minimum and 9.0 as a maximum were observed. For the final year of schooling, Grade 11, these values are even higher: with an average age of 17.77 years, both sixteen- and nineteen-year-old students can study in this grade. Such a wide range of students' ages in a single grade is first associated with the early or late admission of children to school based on their parents' decisions (6.5 or 7.5 years old). Additionally, a significant overlap in students' age throughout years of schooling was found. Therefore, according to Table 1, students aged 7.7 can be enrolled in Grade 1, 2, or 3.

Given the considerable variance in the ages of students in each year of schooling, the interaction between ages and grades and their independent effects on fluid intelligence scores were examined. First, a correlation analysis of students' ages and years of schooling was carried out. Then, a multiple linear regression with age and years of schooling as predictors of fluid intelligence to the data was fit.

The correlation analysis reveals very strong interrelationships between students' ages and their grades ( $r = 0.98$ ;  $p < 0.01$ ). However, despite such a strong correlation, age and years of schooling can have unique effects on a child's cognitive development (Nisbett et al., 2012; Pica et al., 2004; Schneeweis et al., 2014; Tikhomirova et al., 2019a).

According to the multiple regression analysis, 31% of the variance in fluid intelligence scores is explained by years of schooling ( $\text{adj. } R^2 = 0.305$ ,  $F = 649.01$ ,  $p = 0.000$ ) and 24% is explored by age ( $\text{adj. } R^2 = 0.242$ ,  $F = 400.2$ ,  $p = 0.000$ ). When both predictors are fitted into one regression model, years of schooling are a statistically significant predictor of fluid intelligence ( $\beta = 0.77$ ;  $p = 0.000$ ), but student age ceases to be a statistically significant predictor ( $p > 0.05$ ). This finding points towards school education being a more important factor than age in the development of intelligence and falls in line with published results (Nisbett et al., 2012; Pica et al., 2004; Schneeweis et al., 2014). We thus decided to proceed in using the grade level as the single predictor for fluid intelligence test scores.

**Sex Differences in Fluid Intelligence Scores Across the Schooling**

Table 2 presents the mean and range of values (in parentheses) of fluid intelligence for each grade.

Table 2 demonstrates the mean values and the range of fluid intelligence test scores for the samples of boys and girls for each year of school education. The maximum score of the Standard Progressive Matrices test is 60, and the minimum score is 0.

As shown in Table 2, at the primary and secondary levels of school education (from Grade 1 to Grade 9), slightly higher mean values of fluid intelligence are observed for girls than for boys. On the other hand, for high school education (Grades 10 & 11), the mean values of fluid intelligence for the group of boys are slightly higher than those for the group of girls.

To examine these sex differences and their effects on fluid intelligence in each year of schooling, a one-way analysis of variance (ANOVA) was performed. Statistically significant sex differences in fluid intelligence scores, with girls scoring higher, were obtained for Grade 9 only ( $F = 12.2$ ;  $p < 0.001$ ;  $\eta^2 = 0.16$ ).

**Table 2**  
*Descriptive Statistics for Fluid Intelligence Scores for Grades 1–11*

Level	Grade	Girls	Boys
Primary	1	32.34 (9–48)	30.99 (9–50)
	2	37.32 (10–52)	36.93 (13–56)
	3	40.75 (18–53)	40.36 (11–56)
	4	43.67 (26–54)	42.70 (8–58)
Secondary	5	45.65 (29–53)	43.69 (22–56)
	6	46.02 (34–57)	43.08 (22–57)
	7	48.56 (33–56)	46.26 (13–58)
	8	47.57 (36–59)	46.27 (28–60)
	9	51.43 (29–60)	48.07 (32–58)
High	10	49.18 (40–57)	51.17 (32–59)
	11	52.42 (44–60)	53.68 (47–59)
Total	1–11	42.36 (9–60)	41.32 (8–60)

The observed changes in mean values of fluid intelligence test scores differ for the male and female samples. Particularly, for the female sample, a stronger improvement was observed from Grade 1 to Grade 5, and then a slight improvement in fluid intelligence was found up to Grade 11. For the male sample, Grades 1 to 5 were also marked by intensive improvements in mean values of fluid intelligence, but from Grades 6 to 9, a stabilization of fluid intelligence was found, and then from Grades 10 to 11, intensive improvement was observed again.

### **Changes of Fluid Intelligence Scores Across the Schooling**

Correlation analysis between the year of schooling and fluid intelligence on the both total and boys' and girls' samples was performed. Spearman's correlation coefficient was recorded as 0.58 ( $p < 0.01$ ) for the total sample. This result suggests the not too close interrelationships between the year of schooling and fluid intelligence scores. Sex differences were also found. Thus, higher correlation coefficient was found for girls' sample ( $r = 0.63$ ;  $p < 0.01$ ) than for boys' sample ( $r = 0.49$ ;  $p < 0.01$ ). This result may be associated with sex differences in changes in fluid intelligence during the schooling period. In addition, not a very high correlation coefficient may be a consequence of the nonlinear relationship between grade and fluid intelligence for this period (e.g., von Stumm & Plomin, 2015).

To examine linear and nonlinear relationships, a polynomial regression of the total sample and of samples of girls and boys was performed. Linear, quadratic, and cubic regression models were fitted to the data. The sum of correct responses of the Standard Progressive Matrices test was used as a dependent variable. Parameter estimation was performed with the least squares estimator.

Table 3 presents the results of the series of polynomial regressions of the total sample (T) and of the samples of girls (F) and boys (M).

As shown in Table 3, all regression models had acceptable fit to the data.

**Table 3**

#### *Results of Polynomial Regression of Fluid Intelligence Test Scores*

Type of regression model	Model Summary					Parameter Estimates				
	R <sup>2</sup>	F	df1	df2	$p$	Const.	b1	b2	b3	
Linear	T	0.31	649.0	1	1477	0.00	33.39	1.86		
	F	0.36	397.7	1	690	0.00	33.62	1.89		
	M	0.26	273.3	1	785	0.00	33.24	1.81		
Quadratic	T	0.32	345.3	2	1476	0.00	30.16	3.53	-0.15	
	F	<b>0.39</b>	<b>220.4</b>	<b>2</b>	<b>689</b>	<b>0.00</b>	<b>29.37</b>	<b>4.09</b>	<b>-0.19</b>	
	M	0.27	141.9	2	784	0.00	30.74	3.11	-0.12	
Cubic	T	<b>0.33</b>	<b>240.7</b>	<b>3</b>	<b>1475</b>	<b>0.00</b>	<b>25.66</b>	<b>7.21</b>	<b>-0.92</b>	<b>0.05</b>
	F	0.39	148.2	3	688	0.00	27.31	5.79	-0.55	0.05
	M	<b>0.29</b>	<b>104.5</b>	<b>3</b>	<b>783</b>	<b>0.00</b>	<b>24.07</b>	<b>8.54</b>	<b>-1.25</b>	<b>0.07</b>

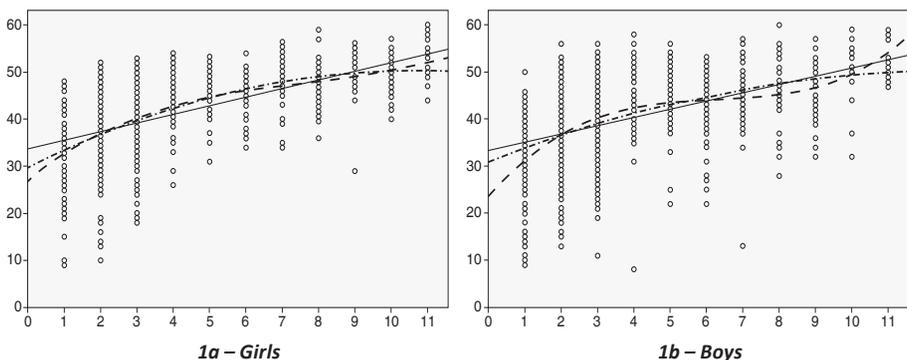
*Note.* The indices of the models that best fit the data are highlighted in bold.

The linear model explained no more than 31% of the variance in fluid intelligence scores for the total sample, 36% of the variance for the sample of girls, and 26% of the variance for the sample of boys. The results reveal that the nonlinear regression models explain more of the variance in the fluid intelligence scores than the linear model for all groups of schoolchildren (see Table 3). Thus, for the total sample, both the quadratic and cubic models better fit the data ( $R^2 = 0.32$  and  $R^2 = 0.33$  respectively,  $p < 0.001$ ), which suggests that the relationships are nonlinear rather than cubic. For the group of girls, both the quadratic and cubic models explain 39% of the variance in fluid intelligence scores, but the quadratic model uses the fewest parameters. Therefore, the quadratic model shows the best fit to the data for the school-aged girls. For the male sample, the largest percentage of the variance in fluid intelligence is explained by the cubic model ( $R^2 = 0.29$ ,  $p < 0.001$ ). Therefore, of the three tested regression models, this model shows the best fit to the data for the school-aged boys.

Thus, the changes in fluid intelligence with years of schooling are nonlinear for both girls and boys. At the same time, quadratic relationships are best applicable to changes in fluid intelligence found for the school-aged girls, and cubic relationships best describe the changes found for the male sample. In particular, the most intensive improvements in fluid intelligence scores were found for Grades 1 to 5, and a slight improvement up to Grade 11 was observed for the group of school-aged girls. For the sample of boys, the most intensive improvements in fluid intelligence scores were observed twice from Grades 1 to 5 and from Grade 10 to 11. Between Grades 6 and 9, the stabilization of fluid intelligence was fixed in boys. These different patterns of school-age changes in fluid intelligence are presented in Figure 1.

In Figure 1, Grades 1 to 11 are measured on the X axis and Standard Progressive Matrices test scores of 0 to 60 are measured on the Y axis. Fluid intelligence scores for each grade obtained from the linear regression (solid line), quadratic model (dashed line), and cubic model (dash-dot line) are illustrated.

**Figure 1**  
*Fluid Intelligence Test Scores for Each Grade Across the Schooling. The Distribution of Fluid Intelligence for Girls (a) and (b) Boys*



Note. Source: Authors.

Figure 1 demonstrates that a nonlinear graph fits the distribution of fluid intelligence quite well for both girls (Figure 1a) and boys (Figure 1b). For the sample of girls, the quadratic model and cubic model explain the most variance in fluid intelligence scores; however, the quadratic model uses the fewest parameters. Therefore, the quadratic model best fits the data for the female sample. As shown in Figure 1a, a great improvement in fluid intelligence was found from Grades 1 to 5 followed by a slight gradual improvement to Grade 11 for the group of school-aged girls. These changes are best described by a quadratic function, a parabola.

For the sample of boys, the cubic model explains the most variance and shows the best fit to the data. Figure 1b shows two significant improvements in fluid intelligence test scores in boys from Grades 1 to 5 and from Grades 10 to 11 with stabilization occurring between Grades 6 and 9. This pattern of change is best described by a cubic function, a cubic parabola.

## Discussion

This cross-sectional study aimed to estimate the changes of fluid intelligence scores measured by the Standard Progressive Matrices test for girls and boys throughout the schooling period. Moreover, sex differences in fluid intelligence scores at each year of schooling were analyzed.

The analysis reveals that despite a strong correlation between grade and schoolchildren age, grade is a more important factor in shaping changes in fluid intelligence during schooling. Therefore, when both predictors were fitted into a single regression model, grade was found to be a statistically significant predictor of fluid intelligence, whereas age was not. This finding points towards the significant importance of school education for children's cognitive development (Brinch & Galloway, 2012; Nisbett et al., 2012; Schneeweis et al., 2014). Moreover, formal education is very important for further cognitive functioning (Ritchie et al., 2015). In particular, the association between the duration of formal education and cognitive abilities measured at age 70 has a direct relationship after controlling for general intelligence factor *g*. The present analysis was carried out with school grade used as a single predictor for fluid intelligence test score changes.

This study shows that girls perform better than boys on fluid intelligence test tasks in each grade throughout primary and secondary school (from Grades 1 to 9). In contrast, during high school (Grades 10 and 11), the mean values of fluid intelligence test scores for the sample of boys were slightly higher than those of the sample of girls. However, statistically significant sex differences in fluid intelligence scores were obtained for Grade 9 only and age 15.7 with the girls having an advantage. An effect size of 16% was found, which is in line with Colom and Lynn (2004) who found that girls aged 12–15 achieve higher scores on intelligence test tasks than their male peers. In general, it was shown that there are no statistically significant sex differences in fluid intelligence test scores from Grades 1 to 8 and from Grades 10 to 11. This result corresponds with data on the lifelong absence of sex differences in fluid intelligence (e.g., Flynn & Rossi-Casé, 2011; Irwing & Lynn, 2005). According to a meta-analysis,

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there are no sex differences in means of fluid intelligence, but the range of test scores is wider for males than for females (Irwing & Lynn, 2005).

Sex differences in relationships between grade and fluid intelligence test scores were also revealed. A stronger correlation was observed in the sample of girls than in boys' sample. These results may be associated with nonlinear changes in fluid intelligence during school years as well as with sex differences (e.g., von Stumm & Plomin, 2015). It was shown that for girls, intensive development in intelligence begins at 9 years of age and continues up to 15 years of age. Then, after age 15, intensive development of intelligence in girls is slow, whereas boys demonstrate more intensive growth in intelligence than girls (von Stumm & Plomin, 2015). Thus, improvements in intelligence test scores show nonlinear patterns across childhood and adolescence.

Indeed, the results of polynomial regression reveal that nonlinear regression models explain more variance in fluid intelligence scores than a linear model for both girls and boys. Nevertheless, different nonlinear models fit to the data of our samples of school-aged girls and boys. The quadratic relationship was found to be the best fit to the pattern of change in fluid intelligence for our female sample. According to the results found for our female sample, the most intensive improvements in fluid intelligence test scores were observed from Grades 1 to 5 with slight improvements occurring up to Grade 11.

Changes observed in the sample of boys are best described by cubic dependency. For the male sample, the most intensive improvements in fluid intelligence test scores were observed twice from Grades 1 to 5 and from Grade 10 to 11 with stabilization occurring between Grades 6 and 9. These different changes in fluid intelligence are best described by a parabolic function for girls and by a cubic function for boys. These results are consistent with findings of previous studies (e.g., Colom & Lynn, 2004; Shangguan & Shi, 2009). In particular, it was shown that only for 10-year-old boys is there a positive correlation between levels of testosterone and success on fluid intelligence tests; at 12 years of age, there is a negative correlation, and at 8 years of age, there are no statistically significant relationships at all (Shangguan & Shi, 2009). These fluctuations in the influence of sex hormones on cognitive functioning may lead to a relative stabilization ("plateau") of fluid intelligence in boys from 6 to 9 years of schooling (aged 12 to 15) as shown in this study.

At the same time, the second intensive increase in fluid intelligence found for our sample of boys aged 16–17 may be related to the selection for continued school education Grades 10 and 11. In the Russian educational system, schooling from Grades 1 to 9 is compulsory, after which a student can continue academic studies at school or attend college for vocational training. As a rule, schooling in Grades 10–11 is chosen by students with good or excellent academic performance. According to the latest data, sex differences are found during schooling in Grades 10–11: the majority of girls continue to the senior grades as do boys, who have higher academic test results (Jackson et al., 2020). Therefore, the improvement in fluid intelligence test scores recorded in our study can be explained by a stronger "filter" for continuing education in high school for the sample of boys.

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Nevertheless, some studies have suggested the age-related specificity in fluid intelligence between girls and boys at school years periods (e.g., Colom & Lynn, 2004). In particular, sex differences in intelligence were found only from 12 to 15 years of age, with girls having an advantage in performance on intelligence tests (Colom & Lynn, 2004). At the same time, it was shown that at the age of 18, the test results of boys are superior to those of girls. In the present study, no statistically significant sex differences were found for senior school ages, although mean fluid intelligence test values were found to be slightly higher in boys.

To sum up, performance on fluid intelligence test scores improves nonlinearly with grade level, demonstrating sex differences after Grade 5.

Sex differences in the results of polynomial regression are also associated with a large percentage of the variance in fluid intelligence of girls explained by the number of years of schooling relative to boys. Within the frameworks of both linear and nonlinear models, the value of the coefficient of multiple determination  $R^2$  for girls varies from 0.36 to 0.39 while that for boys ranges from 0.26–0.29 ( $p < 0.001$ ). These data indicate more dependence of changes in fluid intelligence on the year of schooling for girls than for boys, confirming the relationship between behavioral levels and the specificities of sexual maturation (Miller & Halpern, 2014; Shangquan & Shi, 2009).

At the same time, the larger percentage of the explained dispersion in the variability of intelligence found in girls by “educational” age can also be explained within the context of the sociocultural paradigm (Frenken et al., 2016; Miller & Halpern, 2014; von Stumm & Plomin, 2015). Previously, it was shown that socialization processes, such as the sex specificity of education and parental stereotypes in the upbringing and education of boys and girls, can affect success on cognitive test tasks (Frenken et al., 2016; Miller & Halpern, 2014). It is generally accepted that girls, in demonstrating socially desirable behavior to teachers, complete tasks more thoroughly and accurately, study harder and, as a result, have more experience in training and operating with educational material, including nonverbal material. The gradual improvement in fluid intelligence indicators found in this study from 6 to 11 years of schooling for a group of girls may indicate a greater sensitivity to the effects of formal education. However, more research is needed to test biological and sociocultural effects on sex differences in the cognitive functioning of schoolchildren.

## Conclusion

The results revealed that the school-age change in fluid intelligence is nonlinear for both girls and boys. At the same time quadratic relationships are most applicable to change in fluid intelligence for school-age girls, and cubic relationships are best describing it in a group of boys. It is important to note, the study organized by cross-sectional design with appropriate limitations. Longitudinal studies are needed to examine the developmental trajectories of fluid intelligence.

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