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Relationship between the Development Rate of Executive Functions within a Year and Screen Time in 5—6 year Old Children from three Regions of Russia

Aleksander N. Veraksa
Lomonosov Moscow State University, Moscow, Russia, Psychological Institute,
Russian Academy of Education, Moscow, Russia
ORCID: https://orcid.org/0000-0002-7187-6080, e-mail: veraksa@yandex.ru

Margarita N. Gavrilova
Lomonosov Moscow State University, Moscow, Russia, Psychological Institute,
Russian Academy of Education, Moscow, Russia
ORCID: https://orcid.org/0000-0002-8458-5266, e-mail: gavrilovamrg@gmail.com

Elena A. Chichinina
Lomonosov Moscow State University, Moscow, Russia
ORCID: https://orcid.org/0000-0002-7220-9781, e-mail: alchichini@gmail.com

Alla A. Tvardovskaya
Kazan (Volga Region) Federal University, Kazan, Russia
ORCID: https://orcid.org/0000-0002-2402-0669, e-mail: taa.80@ya.ru

Yury I. Semyonov
Scientific and Educational Center of the State institution “Academy of Sciences
of the Republic of Sakha (Yakutia)”, Yakutsk, Russia
ORCID: https://orcid.org/0000-0002-8766-3936, e-mail: yra_semen1109@mail.ru

Olga V. Almazova
Lomonosov Moscow State University, Moscow, Russia
ORCID: https://orcid.org/0000-0001-8852-4076, e-mail: almaz.arg@gmail.com

The aim of this work was to investigate the relationship between the development rate of executive functions and the screen time in 5—6 year old children within a year. The study involved 495 children from Kazan, Moscow and the Republic of Sakha (Yakutia), who were 5—6 years old at the beginning of the study. The sample population was divided into three equal percentage groups based on the total screen time per week. This approach made it possible to analyze contrasting cases, that is, children with minimum (from 1 to 11 hours per week) and maximum (from 19.5 to 70 hours per week) screen time. It has been shown that the level of cognitive flexibility improved throughout the year in children with minimum screen time, and dropped in children with maximum screen time. In children with minimum screen time, the level of cognitive inhibitory control increased statistically more significantly over the year than in children with maximum screen time. For the development rate of working memory and behavioral inhibitory control, there were no statistically significant differences between the groups.

Keywords: executive functions, cognitive flexibility, working memory, inhibitory control, digital devices, screen time, preschool age.

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Связь темпа развития регуляторных функций за год с экранным временем детей 5—6 лет из трех регионов России

А.Н. Веракса
Московский государственный университет имени М.В. Ломоносова (ФГБОУ ВО «МГУ имени М.В. Ломоносова»), г. Москва, Российская Федерация,
Психологический институт Российской академии образования (ФГБНУ «ПИ РАО»), г. Москва, Российская Федерация
ORCID: https://orcid.org/0000-0002-7187-6080, e-mail: veraksa@yandex.ru

М.Н. Гаврилова
Московский государственный университет имени М.В. Ломоносова (ФГБОУ ВО «МГУ имени М.В. Ломоносова»), г. Москва, Российская Федерация,
Психологический институт Российской академии образования (ФГБНУ «ПИ РАО»), г. Москва, Российская Федерация
ORCID: https://orcid.org/0000-0002-8458-5266, e-mail: gavrilovamrg@gmail.com

Е.А. Чичинина
Московский государственный университет имени М.В. Ломоносова (ФГБОУ ВО «МГУ имени М.В. Ломоносова»), г. Москва, Российская Федерация
ORCID: https://orcid.org/0000-0002-7220-9781, e-mail: alchichini@gmail.com

А.А. Твардовская
Казанский (Приволжский) федеральный университет (ФГАОУ ВО КФУ), г. Казань, Российская Федерация
ORCID: https://orcid.org/0000-0002-2402-0669, e-mail: taa.80@ya.ru

Ю.И. Семенов
Научно-образовательный центр Академии наук Республики Саха (Якутия)» (НОЦ ГБУ АН РС(Я)), г. Якутск, Российская Федерация
ORCID: https://orcid.org/0000-0002-8766-3936, e-mail: yra_semen1109@mail.ru

О.В. Алмазова
Московский государственный университет имени М.В. Ломоносова (ФГБОУ ВО «МГУ имени М.В. Ломоносова»), г. Москва, Российская Федерация
ORCID: https://orcid.org/0000-0001-8852-4076, e-mail: almaz.arg@gmail.com

Цель работы заключалась в изучении связи темпа развития регуляторных функций за год с экранным временем детей 5—6 лет. В исследовании приняли участие 495 детей из г. Казани, г. Москвы, Республики Саха (Якутия), которым на момент начала исследования было 5—6 лет. Выборочная совокупность была поделена на три равные в процентном соотношении группы на основе суммарного экранного времени за неделю. Такой подход обеспечил возможность анализа контрастных случаев, т. е. детей с минимальным (от 1 до 11 час. в неделю) и максимальным (от 19,5 до 70 час. в неделю) экранным временем. Показано, что у детей с минимальным экранным временем за год улучшился уровень когнитивной гибкости, а у детей с максимальным — ухудшился. У детей с минимальным экранным временем уровень когнитивного сдерживающего контроля за год увеличился статистически более значимо, чем у детей с максимальным экранным временем. В темпе развития рабочей памяти и поведенческого сдерживающего контроля статистически значимых различий между группами не обнаружено.

Ключевые слова: регуляторные функции, когнитивная гибкость, рабочая память, сдерживающий контроль, цифровые устройства, экранное время, дошкольный возраст.

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Introduction

At preschool age, the voluntariness, or, in other words, self-control is in process of active formation [4]. The development of self-control in childhood predicts life achievements, health and quality of life in adulthood [9], hence voluntariness can be considered a key formation at preschool age [1]. The formation of voluntariness in preschoolers is sensitive to systematic environmental influences [4]. One of such influences may be the access to digital devices [12], which preschool children now use for about 3 hours a day on average [7]. The term "digital devices" (hereinafter — DD) refers in this text to a TV, smartphone, computer or a tablet. The amount of time preschoolers spend in front of DD screens worries researchers and parents in view of the potential negative impact of DD on the development of voluntariness [13].

A number of studies have shown that the time spent in front of DD screens ("screen time") is inversely associated with the development of voluntariness in preschool children [16; 18; 21]. There are also connections between excessive screen time in early childhood and a low level of self-control development at the age of 5—7 years [8]. At the same time, many studies only consider the time spent watching TV, not taking into account various gadgets (the term "gadget" conventionally refers to a smartphone, tablet and computer as opposed to a TV) [16; 21]. Meanwhile, gadgets provide more diverse opportunities than a TV, which only allows watching video content [17]. With gadgets, a child can engage in various interactive activities (educational applications, multiplayer games, etc.), which, unlike passive TV viewing, can contribute to the development of self-control [2]. Thus, the time spent at gadgets may differ qualitatively from the time spent watching TV, so it is worth considering screen time for different types of DD separately — as passive and active screen time [17].

Some authors come to the conclusion that it is not screen time as such that negatively affects the development of voluntariness, but the fact that it takes time that a child could spend on other activities more beneficial to the development of self-control: live communication, games, physical and developmental activities [7]. Content is also important: often, children who get a lot of screen time consume a large share of poor-quality content unsuitable for their age, which negatively affects the development of self-control [2], while high-quality and age-appropriate developmental content can contribute to the development of voluntariness, if the screen time norms are not exceeded [15; 16].

In this work, the concept of executive functions by A. Miyake's was applied to study the voluntariness in preschoolers. The advantage of his approach lies in the detailed characteristics of self-regulation [1]. Originally developed for adults, but it has been shown to be applicable for children [3]. Executive functions (hereinafter referred to as EF) are a cluster of cognitive skills that enable purposeful problem solving and adaptation to new situations [19]. The components of the EF are: 1) working memory (auditory and visual) — the ability to retain information and use it to solve problems; 2) cognitive flexibility — the ability to switch between tasks, rules and stimuli; 3) inhibitory control — the ability to inhibit impulsive reactions and the dominant response in favor of a response required in the current context [9].

The purpose of this study was to clarify the relationship between the development rate of the EF over a year and the screen time in children aged 5—6 years. In order to obtain a more reliable representation for the children's use of DD, the study involved children from three regions of Russia with different populations and varying cultural, economic, infrastructural and climatic characteristics: from Kazan, Moscow, Yakutsk and other settlements in the Republic of Sakha (hereinafter — Yakutia). The main hypothesis of the study was that an increase in screen time happens at the expense of some opportunities for EF development, and, consequently, children with more screen time will have a lower rate of EF development than children with lesser screen time. This hypothesis is based on the cultural-historical approach and its ideas on the mechanisms of the development of voluntariness in preschoolers [4]. According to the cultural-historical approach, the main regularity of a child's cognitive development is the transformation of "natural" cognitive functions into culturally conditioned ("higher") ones [4]. This is achieved by mastering cultural means through communication with adults or peers. Spending a lot of time in front of the screen not only leads to a more limited experience mainly reduced to the visual component, but the child also misses opportunities to be included in activities crucial for this age: live play, communication, experimentation [15].

Sampling and research procedure

The study participants (495 children, 52% boys) live in three regions of Russia: 35.6% from Kazan, 32.5% from Moscow, 31.9% from Yakutia. At the start of the study, the average age of the children was 65 months (SD=5.04). The overwhelming majority of mothers (78%) rated the level of family financial security as average, 74% of mothers have higher education. All children attended municipal kindergartens.

In the course of the study, two stages of the EF evaluation were carried out. The first involved 1100 children aged 5—6 years from the senior groups of kindergartens. The first stage of the evaluation took place between October 2019 and May 2020. A year later, 891 of these 1100 children took part in the second stage of the EF evaluation. At the first stage, the mothers of 1029 preschoolers filled out an online questionnaire on how their children use DD. The results of both longitudinal diagnostics and mothers' questionnaires have been obtained for 495 children, who then made up the sample of this study.

At the first stage, mothers received a link to the questionnaire in an email from a municipal educational institution or in a parent chat in a messenger. All mothers who filled out the questionnaires gave informed consent to participate and to the participation of their children. The approximate time required to fill out the questionnaire is 20 minutes. It can be assumed that the mothers who took part in the survey are more interested in the issues related to the children's use of DD than those who did not.

At both stages of the study, the EF evaluation was carried out individually, in a quiet room familiar to children. The evaluation was conducted in two sittings, each about 15 minutes. The diagnostic techniques were split into two meetings to avoid children getting tired during the tests.

Methods

A set of EF diagnostic techniques previously tested on preschoolers was used [3]. This set includes subtests of the NEPSY-II complex [14]: ***"Sentences Repetition"*** to assess auditory verbal working memory, ***"Memory for Designs"*** — for visual working memory, ***"Inhibition"*** — for cognitive inhibitory control, ***"Statue"*** — for behavioral inhibitory control. To assess cognitive flexibility, the ***"The Dimensional Change Card Sort"*** technique was used [23].

An online questionnaire for mothers was launched to explore the use of DD by children. It includes questions about socio-demographic factors, additional developmental activities, and screen time (how many minutes a day the child spends in front of the TV screen and on gadgets; TV and gadgets assessed separately).

Statistical data analysis was performed using the SPSS 23.0 program. Methods of descriptive statistics, two-factor analysis of variance (ANOVA), t-test for dependent samples, one-sample Kolmogorov-Smirnov test, Mann-Whitney U-test, and Pearson's chi-squared test were used.

Results

Screen time statistics and socio-demographic factors

Based on the survey of 1029 mothers (52% — mothers of boys; 45% live in Kazan, 24% — in Moscow, 31% — in the settlements of Yakutia), the relationship between socio-demographic factors and screen time in 5—6 year old children was described.

Two-factor analysis of variance (ANOVA) revealed a significant effect of the region of residence factor on the total screen time (F (2958)=82.436; p<0.001), as well as a significant interaction between the factors of the region of residence and gender (F (2958)=9.516; p<0.001); no significant differences in gender were found. It has been shown that children living in Yakutia had the highest indicators of screen time compared to children from Moscow (t=-12.780; p<0.001) and Kazan (t=-7.281; p<0.001); children living in Kazan differ significantly from those from Moscow (t=6.691; p<0.001) (fig. 1). The separate analysis of gender differences in screen time by region showed the significant difference between boys and girls only for Yakutia (t=3.889; p<0.001) (Fig. 1).

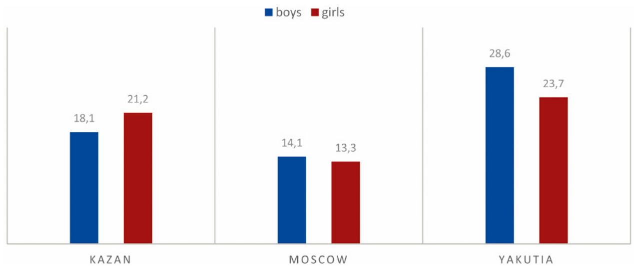

Fig. 1. Screen time of children from different regions (hour per week)

Using the t-test for dependent samples, differences were found in the average time spent on gadgets and watching TV per week (t=24.680; p<0.001; d=0.77). Children spend more time watching TV (13 hours per week) than at gadgets (7 hours per week).

The relationship between the development rate of the EF over the year and the screen time in 5—6 year old children

When assessing the differences in changes in the EF over the year between the groups, the differences between the groups shown in the first assessment were also taken into account. The purpose was to make sure that the differences in dynamics over the year are not due to the initial developmental level of the EF components.

To select contrasting samples by total screen time (active and passive screen time combined), the sample was divided into three equal percentage groups (each representing 33.3% of the total set of observations): (1) from 1 to 11 hours per week, (2) from 11.3 to 19 hours per week, (3) from 19.5 to 70 hours per week. In the further analysis, two extreme groups were considered — the group with the minimum (130 children) and the maximum (142 children) screen time. The differences in the group size are due to the fact that not all children were able to carry out all the EF diagnostic tests, for example, they said they were tired and did not want to continue.

The Kolmogorov-Smirnov test indicated that the data on all the EF indicators did not correspond to the normal distribution. In this connection, the comparison of two independent samples was carried out using the Mann-Whitney U-test. It has been shown that in children with minimum screen time, the level of cognitive inhibitory control increased statistically more significantly over the year than in children with maximum screen time (Table 1). In children with minimum screen time, the level of cognitive flexibility improved over the year,while in children with maximum screen time, it decreased (Table 1). There were no differences between the groups in the development rate of working memory and behavioral inhibitory control over the year.

Socio-demographic characteristics of children's groups with various screen time

Children from three regions were included unevenly in the group with minimum screen time: the majority of children being from Moscow and only 11% from Yakutia (Table 2). Meanwhile, in the group with the maximum screen time, almost 48% of children were from Kazan and almost 30% from Yakutia (Table 2). The mothers' education level was also unevenly represented throughout the groups: in the group with the lowest screen time, there were more mothers with higher education (Table 2).

Discussion

The study aimed to explore the relationship between the EF development rate over the year and the screen time of 5—6 year olds from Kazan, Moscow and Yakutia. The hypothesis that children with increased screen time would show a lower rate of EF development compared to children with lesser screen time has been confirmed, but only partially. The results of the study showed that children from the group with screen time from 1 to 11 hours per week (no more than 1.5 h per day) improved their cognitive flexibility during the year, while in children with screen time of 19.5—70 hours per week (more than 2 h 45 m per day) the indicators of cognitive flexibility have decreased over the year. In the group with screen time of no more than 1.5 h per day, the level of cognitive inhibitory control increased statistically more significantly than in the group with screen time of more than 2 h 45 m per day. Contrary to the expectations, there were no statistically significant differences between the groups in the development rate of behavioral inhibitory control and working memory over the year.

The differences between the groups in the development rate of cognitive flexibility over the year can be explained by the fact that children with maximum screen time spend little time on activities beneficial to the development of cognitive flexibility [7]. Specifically, to improve cognitive flexibility, it is necessary to switch between different rules, conditions and contexts. This happens in communication and live play, during organized classes (physical education, music, etc.), in the course of exploring something new. While interacting

Table 1

Comparison of groups of 5—6-year-old children with different screen time by the rate of EF development over the year

Technique parameter	1—11 hours per week		19.5—70 hours per week		Mann-Whitney U-test	p-level
	M	SD	M	SD		
"Inhibition". Inhibition, combined score	1.63	3.25	0.95	3.37	4722.000	0.045
"The Dimensional Change Card Sort», task with frames score	0.15	3.31	-0.85	2.93	5410.000	0.007
"The Dimensional Change Card Sort», total score	0.16	3.41	-0.81	3.25	5462.000	0.013

Table 2

Distribution of children in groups with various screen time by socio-demographic parameters

		1—11 hours per week, %	19,5—70 hours per week, %	Pearson's Chi-square	p-level
Child's gender	Girls	48.5	47.9	0.072	0.965
	Boys	51.5	52.1		
Mothers' education	Secondary general education	1.6	7.5	23.112	0.003
	Secondary vocational education	4.0	14.3		
	Incomplete higher education	4.0	6.0		
	Higher education	88.0	69.9		
	Academic degree	2.4	2.3		
Family income	Low	6.4	14.9	7.279	0.122
	Average	79.2	76.1		
	Above average	14.4	9.0		
Region	Kazan	26.2	47.9	46.308	0.000
	Moscow	62.3	23.2		
	Yakutia	11.5	28.9		

with DD, the child stays within only one context and type of conditions and rules determined by the kind of digital activity. Furthermore, a long, uniform pastime in front of the screen makes it impossible to alternate between diverse activities during the day, and hence between various tasks and rules.

Another possible explanation for the difference in the development rate of cognitive flexibility over the year between the groups could be that when children spend more than 2 h 45 m on DD, it is mostly video content, which, unlike some video games, does not require cognitive flexibility [2]. There are types of digital activity that demand cognitive flexibility, for example, multiplayer games, where children need to simultaneously respond to several other players and quickly change their course of action depending on them, as well as adapt to the changing context of the game. But when watching video content, cognitive flexibility is not involved — on the contrary, the child merely passively follows the plot. Thus, it can be concluded that children who spent less than 1.5 h a day in front of the screens were more likely to engage in activities that contributed to the development of their cognitive flexibility, while children with more than 2 h 45 m of screen time a day spent not enough time in changing conditions and rules, so their cognitive flexibility has deteriorated over the year.

Differences in the development rate of cognitive inhibitory control between groups can be explained by different degrees of parental control. Probably, children with 2 h 45 m and more screen time are not sufficiently supervised in their use of DD, while children with screen time less than 1.5 h have more parental control. The fact that parents monitor the child's screen time suggests that they establish appropriate rules and restrictions, which contributes to the development of inhibitory control. It can also be assumed that in these families, parents generally monitor the daily regimen and routine for the child, which creates favorable conditions for the development of inhibitory control.

There are a number of factors that can be valid explanations for the differences between the groups, in terms of the development rate of both cognitive flexibility and cognitive inhibitory control over the year. Thus, based on the survey completed by 1029 mothers at the first stage of this study, 40% of children have a total screen time of more than 3 hours a day, and for 10% of children it is more than 5 hours a day. From this, it can be assumed that in families where mothers reported extended screen time, the TV is on for the best part of the day. Therefore, it is not only about purposeful viewing of video content by a child, but also about spending time with a TV constantly turned on in the background, which can also affect the development of both cognitive flexibility and cognitive inhibitory control [16; 21]. There is another factor connected to the time spent consuming video content: it has been shown that the study participants spent significantly more time watching TV than on gadgets: on average 13 and 7 hours per week respectively. That means, the screen time for children from the maximum screen time group is mostly passive, which, unlike active screen time, cannot, by definition, involve cognitive flexibility and cognitive inhibitory control [2]. Moreover, studies have shown that the amount of time watching video content is inversely related to the development of the EF [16; 20]. In addition, the longer the child's screen time, the more likely it is that the child will watch age-inappropriate content associated with deterioration of the EF, in particular inhibitory control [2].

Another factor explaining the differences between the groups in terms of the development rate of both cognitive flexibility and cognitive inhibitory control over the year is the different amount of physical activity in the groups. Studies have shown that for preschoolers, excessive screen time is inversely correlated with the amount of physical activity [11], while a sufficient level of physical activity is important for the EF development [10]. At preschool age, lack of physical activity negatively impacts the maturation processes of the structures of the third block of the brain [5], which are responsible for programming, regulation and control in the course of cognitive activity. It can also be assumed that children from the maximum screen time group have worse sleep quality than their peers with the minimum screen time, which could be one of the reasons for the lower rate of EF development in children from the first group. A number of studies have shown that the use of DD before bedtime and long screen time negatively affect the quality of sleep in preschoolers [6], and that full sleep is necessary for the development of the EF in preschool age [13].

According to the cultural-historical approach, adults play a key role in the development of voluntariness in preschoolers [4]. It can be suggested that in the maximum screen time group, children communicated with their parents less than children from the minimum screen time group, since it is known that long screen time and even a TV in a background tend to impoverish child-parent communication [15]. Thus, in families where children spend a lot of time in front of a screen, there are fewer child-parent interactions, during which inhibitory control and cognitive flexibility could develop. Another explanation for the differences between the groups may be the different level of mothers' education. In families with lower income and mother's education, screen time is higher [22]. In such families, parents more often perceive DD as useful for development and education, but at the same time they do not monitor the content and screen time for children [22]. Low socio-economic status is not an unambiguously negative factor, as it rather increases sensitivity to both negative and positive effects of the DD [22].

The absence of differences between the groups over the year in the development rate of working memory can be explained by the fact that this EF component is as involved during the use of DD as in non-digital activities.

Thus, working memory is trained both when watching video content and when playing a video game, because one needs to keep visual and auditory stimuli in working memory in order to follow the plot of a video or deal with the tasks of a video game. Whereas for the development of cognitive flexibility and inhibitory control, one's own actions are required [2].

The absence of differences between the groups over the year in the development rate of behavioral inhibitory control may be due to the fact that most children received high scores for respective tasks at the first stage of evaluation, thus, it can be assumed that the technique was not sensitive enough for this age. At the same time, it was initially expected that, compared with children with minimum screen time, children with maximum screen time would have a lower development rate of behavioral inhibitory control, since they do less physical activity and, hence, fewer opportunities for training behavioral inhibitory control.

There are a number of limitations of this work that should be taken into account when planning further studies. Firstly, other aspects of the use of the DD, besides screen time, have not been considered. In particular, no information has been collected about what kind of video content children watch and what video games they prefer. At the same time, content characteristics are an important factor in the influence of DD on the EF development in preschoolers [2]. Also, it has not been analyzed what is the parents' role in the use of DD by children. Meanwhile, many studies have shown that, in terms of the EF development, the parental control of children's use of DD is of utmost importance [2]. Secondly, the collection of data on children's screen time by means of parents' questionnaires does not exclude the possibility of participants giving socially desirable responses. The third limitation of the study was the small sample size and unequal distribution of children from different regions within the compared groups. In addition, an analysis of regional differences is required, which would take into account the specifics of each region. Another limitation of the study was the lack of data on the home educational environment and the nature of child-parent relationships, which can play a key role in the EF development [16].

Conclusion

The main purpose of this work was to explore the relationship between the development rate of the EF over a year and the screen time in 5—6 year old children from Kazan, Moscow, Yakutsk and other settlements of Yakutia. The regional specificity in the screen time has been registered and requires further analysis. An inverse relationship between screen time and the development rate of cognitive inhibitory control and cognitive flexibility in preschoolers over the year was revealed. There were no statistically significant differences between the groups in the development rate of behavioral inhibitory control and working memory within the year. The relationship between EF development and TV time and the relationship between EF development and gadgets time require separate investigations. The data obtained in the study are relevant for parents, psychologists, teachers and are valuable for determining optimal ways for preschoolers to use DD.

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Information about the authors

Aleksander N. Veraksa, Corresponding Member, Russian Academy of Education, Doctor in Psychology, Professor, Head, Psychology of Education and Pedagogy Department, Psychology Faculty, Lomonosov Moscow State University, Moscow, Russia; Vice-Director, Psychological Institute, Russian Academy of Education, Moscow, Russia, ORCID: 0000-0002-7187-6080, e-mail: veraksa@yandex.ru

Margarita N. Gavrilova, PhD in Psychology, Junior Researcher, Department of Educational Psychology and Pedagogy, Faculty of Psychology, Lomonosov Moscow State University, Moscow, Russia; Junior Researcher, Laboratory of Childhood Psychology and Digital Socialization, Psychological Institute, Russian Academy of Education, Moscow, Russia, ORCID: 0000-0002-8458-5266, e-mail: gavrilovamrg@gmail.com

Elena A. Chichinina, Junior Researcher, Department of Educational Psychology and Pedagogy, Faculty of Psychology, Lomonosov Moscow State University, Moscow, Russia, ORCID: 0000-0002-7220-9781, e-mail: alchichini@gmail.com

Alla A. Tvardovskaya, PhD in Psychology, Associate professor, Institute of Psychology and Education, Kazan Federal University, Kazan, Russia, ORCID: 0000-0002-2402-0669, e-mail: taa.80@ya.ru

Yury I. Semyonov, Doctor in Philosophy, Doctor in History, Professor, Scientific and Educational Center of the State institution "Academy of Sciences of the Republic of Sakha (Yakutia)", Yakutsk, Russia, ORCID: 0000-0002-8766-3936, e-mail: yra_semen1109@mail.ru

Olga V. Almazova, PhD in Psychology, Associate professor, Department of Developmental Psychology, Faculty of Psychology, Lomonosov Moscow State University, Moscow, Russia, ORCID: 0000-0001-8852-4076, e-mail: almaz.arg@gmail.com

Информация об авторах

Веракса Александр Николаевич, член-корреспондент Российской академии образования, доктор психологических наук, профессор, заведующий кафедрой психологии образования и педагогики факультета психологии, Московский государственный университет имени М.В. Ломоносова (ФГБОУ ВО «МГУ имени М.В. Ломоносова»), г. Москва, Российская Федерация; заместитель директора, Психологический институт Российской академии образования (ФГБНУ «ПИ РАО»), г. Москва, Российская Федерация, ORCID: https://orcid.org/0000-0002-7187-6080, e-mail: veraksa@yandex.ru

Гаврилова Маргарита Николаевна, кандидат психологических наук, младший научный сотрудник, Московский государственный университет имени М.В. Ломоносова (ФГБОУ ВО «МГУ имени М.В. Ломоносова»), г. Москва, Российская Федерация; научный сотрудник, Психологический институт Российской академии образования (ФГБНУ «ПИ РАО»), г. Москва, Российская Федерация, ORCID: 0000-0002-8458-5266, e-mail: gavrilovamrg@gmail.com

Чичинина Елена Алексеевна, младший научный сотрудник кафедры психологии образования и педагогики факультета психологии, Московский государственный университет имени М.В. Ломоносова (ФГБОУ ВО «МГУ имени М.В. Ломоносова»), г. Москва, Российская Федерация, ORCID: 0000-0002-7220-9781, e-mail: alchichini@gmail.com

Твардовская Алла Александровна, кандидат психологических наук, доцент, Институт психологии и образования, Казанский (Приволжский) федеральный университет (ФГАОУ ВО КФУ), г. Казань, Российская Федерация, ORCID: 0000-0002-2402-0669, e-mail: taa.80@ya.ru

Семенов Юрий Иванович, доктор философских наук, доктор исторических наук, профессор, Научно-образовательный центр, Академия наук Республики Саха (Якутия) (ГБУ АН РС(Я)), г. Якутск, Российская Федерация, ORCID: 0000-0002-8766-3936, e-mail: yra_semen1109@mail.ru

Алмазова Ольга Викторовна, кандидат психологических наук, доцент кафедры возрастной психологии факультета психологии, Московский государственный университет имени М.В. Ломоносова (ФГБОУ ВО «МГУ имени М.В. Ломоносова»), г. Москва, Российская Федерация, ORCID: 0000-0001-8852-4076, e-mail: almaz.arg@gmail.com

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