Анализ профилей рабочей памяти и тормозного контроля и их влияние на выполнение учебной задачи с использованием цифровых технологий

Н. В. СУТОРМИНА

АННОТАЦИЯ

Введение. Эффективность выполнения учебных задач в цифровой среде требует понимания роли исполнительных функций, таких как рабочая память и тормозный контроль. Эти функции оказывают значительное влияние на способность подростков искать, обрабатывать и использовать информацию в сети Интернет для образовательных целей.

Цель. Настоящее исследование направлено на анализ профилей рабочей памяти и тормозного контроля у подростков, а также оценку их влияния на выполнение учебных задач с использованием цифровых технологий.

Материалы и методы. В исследовании приняли участие 62 подростка из разных школ Санкт-Петербурга. В работе использовались методики исследования рабочей памяти «Интерференция» О.М. Разумниковой и тормозного контроля «Рефлексометрия» Е.Г. Вергунова. Также подростки выполняли учебное поисковое задание на компьютере с использованием сети Интернет. После этого была оценена успешность выполнения задания. Для выявления профилей томрозного контроля и рабочей памяти использовался иерархический кластерный анализ, для проверки значимых различий между кластерами использовались критерии Краскела-Уоллиса и Манна-Уитни.

Результаты. Были выделены три кластера, различающихся по профилям исполнительного функционирования. Хотя значимых различий в выполнении учебного поискового задания с использованием цифровых технологий между кластерами не обнаружено, можно предположить, что уровень исполнительных функций оказывает влияние на успешность выполнения учебного задания. Участники первого кластера, демонстрирующие высокий уровень тормозного контроля и стабильные показатели рабочей памяти, показали наибольшую долю выполнения задания (50%). Участники третьего кластера выполнили задание несколько хуже (44%), что может быть связано с выраженной интерференцией во второй серии. Третий кластер демонстрировал высокий объём рабочей памяти в первой серии, но сильную интерференцию во второй серии. Однако в третьей серии они показали самые высокие результаты по сравнению с другими кластерами в рабочей памяти, что может быть связано с восстановлением когнитивных ресурсов и ослаблением эффекта интерференции. Участники второго кластера, характеризующиеся низким уровнем тормозного контроля и высокой проактивной интерференцией, показали самую низкую долю выполнения задания (33%).

Заключение. Результаты исследования, хотя и ограничены, подтверждают значимость исполнительных функций, таких как рабочая память и тормозной контроль, в контексте выполнения учебных задач с использованием цифровых технологий. Получившиеся результаты могут быть использованы для создания образовательных стратегий, ориентированных на улучшение тормозного контроля и развитие ресурсов рабочей памяти.

КЛЮЧЕВЫЕ СЛОВА

рабочая память, тормозный контроль, проактивная интерференция, последовательная зависимость, цифровые технологии, кластерный анализ

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Profiles of working memory and inhibitory control: implications for educational task performance using digital technology

N. V. SUTORMINA

ABSTRACT

Introduction. The effectiveness of educational tasks in digital environments depends on understanding the role of executive functions, such as working memory and inhibitory control. These functions significantly influence adolescents' ability to search, process, and apply information online for educational purposes.

Objective. This study aims to analyze working memory and inhibitory control profiles in adolescents and assess their impact on educational task performance in the context of digital technologies.

Materials and Methods. The study involved 62 adolescents from various schools in St. Petersburg (Russia). Working memory was assessed using the "Interference" method developed by O. Razumnikova, and inhibitory control was evaluated using the "Reflexometry" method by E. Vergunov. Participants also performed an Internet-based search task on a computer, and task performance was subsequently evaluated. Hierarchical cluster analysis was conducted to identify profiles of working memory and inhibitory control. The Kruskal-Wallis and Mann-Whitney tests were employed to assess significant differences between clusters.

Results. Three clusters with distinct executive functioning profiles were identified. Although no statistically significant differences were observed in digital search task performance between clusters, the findings suggest that executive functioning levels influence task success. Participants in the first cluster, characterized by high inhibitory control and stable working memory, achieved the highest task completion rate (50%). The third cluster performed slightly worse (44%), likely due to pronounced interference in the second series. However, they exhibited the highest working memory performance in the third series, possibly reflecting cognitive resource recovery and reduced interference. Participants in the second cluster, defined by low inhibitory control and high proactive interference, achieved the lowest task completion rate (33%).

Conclusion. Despite certain limitations, this study underscores the importance of executive functions, such as working memory and inhibitory control, in the context of educational tasks involving digital technologies. These findings provide a foundation for developing targeted educational strategies to enhance inhibitory control and optimize working memory resources.

KEYWORDS

working memory, inhibitory control, proactive interference, serial dependence, digital technology, cluster analysis

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INTRODUCTION

The Global Education Innovation Initiative at the Harvard Graduate School of Education, through its 21st Century Education initiative, emphasizes the importance of developing competencies in the cognitive domain, including critical thinking, problem-solving, and executive functions, which are key to controlling goal-focused efforts and achieving academic success [1]. Executive functions comprise a set of cognitive and neural mechanisms essential for controlling and regulating goal-directed cognitive and behavioral activities under dynamic conditions [2; 3]. Their development during adolescence is critical for academic performance [4], particularly in mathematics [5; 6] and science [7], as well as for effective emotion regulation [8] and resilience to stress [9].

There is ongoing debate regarding the identification of individual executive functions and their neural substrates [10; 11]. However, certain executive functions have been widely recognized by the scientific community. One such function is inhibitory control (IC) [12], which refers to the capacity to suppress automatic responses, resist irrelevant stimuli, and adjust behavior to meet situational demands and personal goals. This ability is essential for self-regulation, as it enables individuals to manage their emotions and actions in alignment with their aspirations [13].

Another well-established executive function is working memory (WM) [12]. WM is a cognitive system responsible for the temporary storage and manipulation of information required for complex cognitive tasks [11]. It plays a crucial role in guiding goal-directed behavior and addressing everyday challenges. Given its limited capacity, the ability to update and remove information from WM is a fundamental aspect of executive functioning and self-regulation. Moreover, WM has been shown to be a stronger predictor of academic success than IQ, particularly in children with learning difficulties [14].

The development of executive functioning, including WM, is closely tied to improvements in working memory capacity [15]. Both WM and inhibitory control continue to mature throughout adolescence and into young adulthood [16]. Furthermore, moderate transfer effects and enhancements in cognitive task performance have been observed following targeted training of either working memory or inhibitory control [11].

Due to its limited capacity, working memory depends on interference control processes to maintain focus and avoid distractions from irrelevant information [17]. Proactive interference occurs when previously relevant information competes with current information in working memory, leading to errors and slower response times. Interference is a primary factor limiting the efficiency of working memory [18; 19].

Working memory simultaneously protects current content from interference while also requiring rapid updating when new relevant information becomes available [20]. The ability to efficiently update working memory continues to develop throughout childhood and adolescence [21]. Effective updating is essential in real-world situations involving learning and information processing [22]. For optimal functioning, working memory must balance retaining information with updating it. Updating too quickly can cause the loss of relevant data, while slow updating can result in proactive interference. For instance, in short-term memory tasks, objects from a previous set may interfere with memory updating and be mistakenly included in the current set, a typical effect of proactive interference [23]. In delayed-response tasks, proactive interference increases as the delay lengthens and the amount of material held in working memory grows [24]. Furthermore, children are more vulnerable to proactive interference than young adults [25].

Proactive interference is a component of serial dependence, a systematic bias toward stimuli perceived earlier or from a previous series [23]. Serial dependence is a mnemonic phenomenon rather than a perceptual one, as it only arises when working memory is engaged. This phenomenon involves integrating recent information stored in working memory to form a coherent perception [26]. In serial dependence, current stimuli may appear more similar to recently perceived ones. For instance, in an orientation task, the angle of the current stimulus may be perceived as closer to the angle of the previous stimulus. Serial dependence helps maintain perceptual stability by using past stimuli to 'smooth out' changes. The visual system relies on recently perceived information to predict changes and stabilize the visual world. This process can be advantageous when successive stimuli are related, as their integration improves information processing efficiency. However, proactive interference, as part of serial dependence, can occasionally hinder performance by leaving irrelevant information in working memory [23]. Serial dependence is particularly evident in delayed-response tasks, where its effects peak after a six-second delay but diminishes after ten seconds, indicating its roots in working memory rather than perception [26]. Additionally, serial dependence is observed not only in the perception of objects, such as numbers, but also in more complex stimuli, like faces [23].

Sequential dependence can be interpreted as a manifestation of working memory impairment, where proactive interference arises due to irrelevant information disrupting further working memory processes. For instance, its negative effects become evident when repetitive objects are presented [27] or as the number of memorized items increases [28]. However, serial dependence can also be viewed as a stabilizing mechanism that, while generally adaptive, may occasionally result in maladaptive outcomes such as proactive interference. A remarkable feature of visual perception is its ability to maintain stability in the environment despite constant changes in retinal images caused by eye movements, blinks, or overlapping objects. Visual working memory plays a critical role in preserving continuous representations, enabling the perception of stability even in the face of these disruptions. Nevertheless, the limited capacity of working memory can sometimes result in the retention of irrelevant information. For example, proactive interference increases when memorizing word lists that include items from previous trials [23].

The unity and diversity model is frequently used to explain the interrelationships among executive functions [29]. Executive unity emerges from the interaction of various executive functions, such as inhibitory control and the retention and updating of information in working memory. This collaboration facilitates integrative processes, including problem solving, goal-directed behavior, and effective learning [30]. For instance, successful performance on working memory tasks requires selecting relevant stimuli and suppressing irrelevant ones, a process that relies on inhibitory control [31]. The unity and diversity model of executive functions has been validated in studies involving young participants [32]. It is hypothesized that during childhood, working memory, inhibitory control, and other executive functions rely on shared cognitive mechanisms. As development progresses, the structure of executive functioning shifts from unity toward greater diversity, particularly during middle childhood and adolescence [33; 34]. Enhanced inhibitory processes within working memory as maturation occurs have been shown to improve children's performance on complex cognitive tasks [35]. Furthermore, high levels of both inhibitory control and working memory have been linked to success in second language acquisition among school-aged children [36].

As noted earlier, executive functions are essential for learning and self-regulation during adolescence, particularly as students are frequently required, both at home and in the classroom, to search for relevant educational information using digital technologies, evaluate its credibility, synthesize it, and draw meaningful conclusions [37]. Research indicates that students with lower levels of executive functioning face greater challenges in suppressing irrelevant interference when using online resources for learning [38]. Furthermore, reduced inhibitory control has been linked to a higher likelihood of addictive Internet use [39].

Thus, executive functions – particularly working memory and inhibitory control – interact dynamically during adolescence, as highlighted by the concept of unity and diversity. These functions are essential for both academic achievement and maintaining cognitive-emotional stability. In this context, the present article investigates the profiles of working memory and inhibitory control, exploring their connection to performance on an educational task involving digital technologies.

MATERIALS AND METHODS

Sixty-two adolescents participated in the study, including 28 girls and 34 boys, with a mean age of 13.35 ± 2.07 years. No significant differences in gender or age were observed between the clusters. Working memory was assessed using the "Interference" technique developed by O. Razumnikova [40]. This method consists of three series. Each series begins with three objects (e.g., flowers, mushrooms, insects) displayed on the screen, and participants are instructed to select one object by clicking on it with the left mouse button. The number of objects then increases geometrically (d = 1), and participants must select a new object that has not been previously clicked. This process continues until the screen is filled with objects or a mistake is made. The technique evaluates working memory capacity and proactive interference based on the number of objects memorized in each series.

Inhibitory control was assessed using the "Reflexometry" technique developed by E. Vergunov, which is based on the go/no-go paradigm [41]. The 'no-go' series is divided into two sequential parts that follow and repeat each other. In this series, participants must press a key for all stimuli except the red one, which represents a 'no-go' response. Errors were evaluated based on the number of times a forbidden signal (red stimulus) was pressed during the two parts of the series.

The adolescents also completed a search-based educational task using a computer and the Internet, after which they were required to write down their answer. The correctness of the answer and the time taken to find it were evaluated. Following the search task, participants completed a questionnaire that assessed their subjective interest in the task and perceived task difficulty. Additionally, the adolescents reported the duration of their Internet use for educational purposes (in years), while their computer and information search skills were self-rated on a scale from 0 to 10 points.

For statistical analysis, hierarchical cluster analysis was performed using the Ward method and Euclidean distance as the metric for measuring distances between objects [42]. The analysis included variables related to inhibitory control and working memory. Data processing was conducted using the Scikit-learn library in the Python programming language [43]. All variables were standardized (converted to z-scores) to harmonize values across different scales [44]. To determine the optimal number of clusters, the elbow method and visual inspection of dendrograms were employed [42]. Given the non-normal distribution of the data, the Kruskal-Wallis H-test was applied to identify statistically significant differences between clusters. For variables with significant differences, pairwise post hoc analyses were conducted using the Mann-Whitney test with Bonferroni correction [44]. The level of statistical significance was set at 5%. Subsequently, variables not included in the clusters were analyzed using the Kruskal-Wallis H-test.

RESULTS

Hierarchical cluster analysis identified three distinct clusters. As shown in Table 1, the clusters differ significantly across all parameters at the $p < 0.01$ level, based on the results of the Kruskal-Wallis H-test.

Table 1

Mean Values of Z-Standardized Variables by Cluster Membership

Variable	Cluster 1, M (SD)	Cluster 2, M (SD)	Cluster 3, M (SD)	Kruskal-Wallis-H, p-value
IC: errors 1	6.96 ± 2.75	14.67 ± 3.40	9.61 ± 3.18	33.00, p<0.01
IC: errors 2	5.15 ± 2.84	13.72 ± 3.83	9.89 ± 3.41	35.61, p<0.01
WM 1	13.81 ± 5.42	16.72 ± 8.13	20.83 ± 6.04	10.76, p<0.01
WM 2	12.38 ± 6.41	11.50 ± 5.09	4.89 ± 1.57	22.80, p<0.01
WM 3	11.54 ± 5.59	7.22 ± 5.09	12.00 ± 5.68	10.18, p<0.01

The first cluster (n = 26; 42% of the sample) is the largest. It is characterized by a high level of inhibitory control, evidenced by the fewest errors compared to other groups, and a minimal level of proactive interference, as the results across all three WM series show little variation.

The second cluster (n = 18; 29%) is characterized by a low level of inhibitory control, as indicated by the highest number of errors in the no-go series compared to other clusters, along with a high level of proactive interference.

The third cluster (n = 18; 29%) is characterized by moderate inhibitory control, the highest performance in the first WM series among all clusters, significant interference in the second WM series, and a recovery in working memory updating after a decline, as reflected in the results of the third WM series.

Table 2 presents the results of the pairwise comparison of cluster variables conducted using the Mann-Whitney test with Bonferroni correction.

Table 2

Pairwise comparisons of variables between clusters

Variable	Cluster 1 - 2	Cluster 1 - 3	Cluster 2 - 3	Post hoc (Mann–Whitney U test, p<0.05)
IC: errors 1	**U = 11.50, p<0.001, r = 0.025**	U = 134.50, p>0.05, r = 0.287	**U = 285.00, p<0.001, r = 0.880**	2>3,1
IC: errors 2	**U = 16.50, p<0.001, r = 0.035**	**U = 59.50, p<0.001, r = 0.127**	**U = 250.50, p<0.05, r = 0.773**	2>3>1
WM 1	U = 179.50, p>0.05, r = 0.384	**U = 91.50, p<0.01, r = 0.196**	U = 115.00, p>0.05, r = 0.355	3>1
WM 2	U = 245.00, p>0.05, r = 0.524	**U = 417.50, p<0.001, r = 0.892**	**U = 285.00, p<0.001, r = 0.880**	1,2>3
WM 3	**U = 356.00, p<0.05, r = 0.761**	U = 216.50, p>0.05, r = 0.463	**U = 79.50, p<0.05, r = 0.245**	3,1>2

Cluster 2 is shown to have a significantly higher number of errors in the first part of the executive control series compared to Cluster 1 (1-2, U = 11.50, $p < 0.001$) and Cluster 3 (2-3, U = 285.00, $p < 0.001$). The same trend is observed in the second part of the executive control series. Participants in the second cluster made more errors in the second part of the no-go series compared to those in the third cluster (2-3, U = 250.50, $p < 0.05$) and the first cluster (1-2, U = 16.50, $p < 0.001$). Furthermore, the third cluster exhibited a significantly higher number of errors compared to the first cluster (1-3, U = 59.50, $p < 0.001$). The results of the first series of the working memory study differ significantly only between the first and third clusters (1-3, U = 91.50, $p < 0.01$). Specifically, the third cluster demonstrates significantly higher results compared to the first cluster. Conversely, in the second WM series, the third cluster shows significantly lower results compared to both the first cluster (1-3, U = 417.50, $p < 0.001$) and the second cluster (2-3, U = 285.00, $p < 0.001$). Finally, in the third WM series, the second cluster demonstrates a significantly lower score compared to the third cluster (2-3, U = 79.50, $p < 0.05$) and the first cluster (1-3, U = 356.00, $p < 0.05$).

As shown in Table 3, no significant differences were observed in the variables that were not included in the hierarchical clustering. The clusters did not differ in terms of age (KW = 3.38, p = 0.184), gender (Chi2 = 1.16, p = 0.561), or the number of correct/incorrect answers in the digital learning task (KW = 1.21, p = 0.546).

Table 3

Group comparisons of non-clustering variables related to the educational search task

Variable	All (N = 62)	Cluster 1 (N = 26)	Cluster 2 (N = 18)	Cluster 3 (N = 18)	Test	Statistics
Age, mean ± SD	13.35 (2.07)	13.73 (1.85)	12.61 (2.15)	13.56 (2.23)	*KW	3.38, p = 0.184
Sex, N (%) Males Females	 34 (55) 28 (45)	 15 (58) 11 (42)	 11 (61) 7 (39)	 8 (44) 10 (56)	**Chi2	1.16, p = 0.561

Answer to the task, N (%) Correct Incorrect	27 (44) 35 (56)	13(50) 13(50)	6(33) 12(67)	8(44) 10(56)	Chi2	1.21, p = 0.546
Task response time, mean ± SD	191.58 (160.19)	184.88 (152.73)	252.06 (194.16)	140.78 (115.77)	KW	3.15, p = 0.207
Subjective difficulty of the task, mean ± SD	2.74 (2.11)	2.73 (1.95)	3.22 (2.53)	2.28 (1.87)	KW	1.75, p = 0.416
Satisfaction with the result, mean ± SD	7.82 (2.24)	7.96 (1.97)	6.83 (2.57)	8.61 (2.00)	KW	5.89, p = 0.053
Interest in the task, mean ± SD	6.45 (2.14)	6.27 (2.20)	6.72 (2.05)	6.44 (2.23)	KW	0.44, p = 0.802
Duration of Internet use (years), mean ± SD	3.73 (1.86)	4.19 (2.06)	2.83 (1.34)	3.94 (1.76)	KW	5.71, p = 0.058
Computer skills, mean ± SD	6.39 (1.84)	6.54 (1.82)	6.39 (1.72)	6.17 (2.07)	KW	0.32, p = 0.852
Information search skills, mean ± SD	7.71 (1.82)	7.62 (1.63)	7.83 (1.62)	7.72 (2.32)	KW	0.59, p = 0.745

Note. *KW: Kruskal-Wallis test. **Chi2: Chi-square test.

Some moderate but statistically insignificant differences were observed in such variables as satisfaction with the results of the completed task (KW = 5.89, p = 0.053) and the duration of Internet use for educational purposes (KW = 5.71, p = 0.058).

DISCUSSION

This study investigates executive functions, namely working memory and inhibitory control, in adolescents. Hierarchical cluster analysis was employed to identify distinct profiles of these functions. Participants in the third cluster exhibit high working memory performance, as they memorized more objects in the first WM series compared to other clusters. However, they also demonstrated the highest level of interference in the second series, memorizing significantly fewer objects than the other clusters. In the third series, their performance improved, with the third cluster memorizing the largest number of objects. It has been shown that repetitive objects from previous trials [27] and a high working memory load, in the form of increased memorized material, enhance proactive interference [24]. It can be assumed that participants in the third cluster retained a large number of objects in working memory, and this load contributed to proactive interference. Alternatively, the WM results of the third cluster can be analyzed through the lens of serial dependence. Serial dependence may support greater working memory capacity by linking previously relevant information with new information; however, proactive interference emerges as a side effect of serial dependence when previous information becomes irrelevant. In this context, the same mechanism can either enhance working memory or, conversely, deplete resources needed for relevant information [23]. Thus, the high working memory capacity observed in the first WM series in the third cluster may be attributed to serial dependence, which facilitates the linking of previously memorized objects with newly presented ones in the field of view, thereby enhancing the retention of object sequences in working memory. However, the same mechanism has a disruptive effect in the second series, as objects from the first series reappear, leading to proactive interference. By the third series, the influence of serial dependence may diminish over time [26]. Consequently, working memory is updated, and adolescents in the third cluster memorize more objects in the third series compared to other clusters.

The first cluster exhibits the highest inhibitory control scores. Moreover, the results across the three WM series show minimal variation, which may suggest the absence of pronounced proactive interference in working memory. In contrast, the second cluster is characterized by lower levels of inhibitory control and marked proactive interference, resulting in the retention of fewer objects in the third WM series compared to other clusters. Previous studies have demonstrated a positive correlation between inhibitory processes in working memory and inhibitory control [15; 31], a finding confirmed by the present study. Accordingly, participants in the first cluster, characterized by high inhibitory control scores, exhibit no evidence of proactive interference across the three WM series. In contrast, participants in the second cluster display a pronounced proactive interference effect throughout all series. Furthermore, this study highlights substantial individual variability in the magnitude of serial dependence effects, ranging from unexpressed to pronounced serial dependence, as evidenced by differences in the number of memorized objects between clusters [26].

No significant differences were observed between clusters on variables related to searching for educational information on the Internet. Notably, 33% of participants in the second cluster successfully completed the study-related search task, with an average answer retrieval time of 252.06 ± 194.16 seconds. In comparison, 44% of participants in the third cluster and 50% in the first cluster completed the task, with average retrieval times of 140.78 ± 115.77 and 184.88 ± 152.73 seconds, respectively. Working memory performance has been shown to correlate with learning task performance during adolescence, even after controlling for socioeconomic factors [4]. The elevated level of proactive interference in working memory observed in participants from the second cluster may explain their lower rates of correct task answers and extended completion times, as proactive interference likely contributed to the displacement of relevant information from working memory [19].

An analysis using the Kruskal-Wallis test revealed near-significant differences between clusters for the variables Satisfaction with the outcome of the task (KW = 5.89, $p = 0.053$) and Duration of Internet use for educational purposes (KW = 5.71, $p = 0.058$). Participants in the third cluster reported the highest satisfaction scores for the completed assignment (8.61 ± 2.00), followed by those in the first cluster (7.96 ± 1.97), while participants in the second cluster reported the lowest satisfaction scores (6.83 ± 2.57). The duration of Internet use for educational purposes was also lower in the second cluster (2.83 ± 1.34 years) compared to the third cluster (3.94 ± 1.76 years) and the first cluster (4.19 ± 2.06 years), which may have limited the performance of participants in the second cluster. Adolescents who began using the Internet for educational purposes later may have less experience and fewer skills in evaluating and retrieving information online. For instance, they may struggle to assess the credibility of online sources and are more likely to rely on the first available source that appears to match their query [45].

CONCLUSION

According to a literature review, working memory and inhibitory control are critical for the successful execution of learning tasks, including those involving digital technologies, during adolescence. These cognitive functions significantly influence information processing, decision-making, and action regulation under conditions of increased cognitive load.

The following conclusions can be drawn from this study:

1. Profiles of working memory and inhibitory control vary significantly among adolescents, potentially impacting their success in learning tasks. Adolescents with high levels of inhibitory control exhibit less proactive interference in working memory.

2. No statistically significant differences were observed between clusters in the success rate of completing learning tasks using digital technologies. However, the analysis suggests that proactive interference is a critical factor that can diminish task performance efficiency. This effect is particularly pronounced in participants from the second cluster, who exhibit low inhibitory control, marked interference in working memory, and the lowest proportion of task completion.

3. Limited experience in using the Internet for educational purposes may negatively affect success in digital technology tasks, underscoring the importance of digital literacy.

The main practical outcome of this study is the identification of cognitive factors that influence the success of learning tasks. These findings can inform the development of tailored educational strategies designed to enhance inhibitory control and optimize working memory.

To implement these recommendations, it is essential to:

1. Develop training programs that focus on strengthening executive functions, including inhibitory and interference control.

2. Integrate digital literacy education into the curriculum, emphasizing effective Internet usage for instructional purposes, such as evaluating the credibility of information sources.

3. Adopt individualized approaches to support students with varying levels of working memory and inhibitory control, particularly in highly digitalized educational environments.

Thus, fostering the development of executive functions and digital literacy among adolescents represents a key objective for modern education systems.

LIMITATIONS

Serial dependence is a subtle effect, and its accurate measurement may require a larger number of trials than those included in this study. Furthermore, no statistically significant differences were observed in the success rates of the digital learning task, which could be attributed to the limited sample size. To more precisely identify potential differences or confirm their absence, future research could include a larger sample to enhance the statistical power of the analysis. Additionally, a larger sample size would allow for a more thorough examination of individual variations that may have gone undetected in the current study.

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Автор

Сутормина Надежда Владимировна
(Россия, Санкт-Петербург)
Младший научный сотрудник
Научно-исследовательская лаборатория "Когнитивные исследования в образовании"
Российский государственный педагогический университет им. А.И. Герцена
E-mail: nadya.sutormina.92@mail.ru
ORCID ID: 0000-0002-5073-8922

Author

Nadezhda V. Sutormina
(Russia, Saint Petersburg)
Junior Researcher
Research Laboratory "Cognitive Research in Education"
Herzen State Pedagogical University of Russia
E-mail: nadya.sutormina.92@mail.ru
ORCID ID: 0000-0002-5073-8922

Вклад автора

Сутормина Н. В.: концептуализация, методология, формальный анализ, проведение исследования, создание рукописи и ее редактирование

Author contribution

Nadezhda V. Sutormina: Conceptualization, Methodology, Formal Analysis, Investigation, Writing – Original Draft, Writing – Review & Editing

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