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Psychological features of interaction of students in grades 7–8 with hypertext: a theoretical and experimental study using an eye tracker

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Abstract

Context and relevance. Currently, hypertext systems are beginning to play an increasingly important role both in the media and in the educational process. Despite a significant array of hypertext studies, most of them are theoretical, and there is a shortage of works on educational hypertext. **Objective.** To present a pilot experimental study aimed at identifying, using an eye tracker, the features of the primary perception of an educational hypertext by 7–8 grade students, their orientation in the text and the distribution of attention in the process of working with the main text and hyperlinks. **Hypotheses:** 1) the first reading of the educational hypertext will be sequential, accompanied by students' familiarization with the content of hyperlinks as they appear in the main text; 2) due to the additional cognitive load that occurs when working with hypertext structures, adolescents will have a relatively low level of hypertext comprehension. **Methods and materials.** Oculographic method, statistical analysis of the oculographic recordings, questionnaire for data collection, authors' diagnostic tool "Hypertext comprehension". The sample included 33 students in grades 7–8 (12 boys and 21 girls, aged 12–15 years (M = 13,8, SD = 0,8)). **Results.** As for attention, the area of greatest intensity included text passages containing specific factual information. Although, due to the immanent properties of the hypertext, adolescents read it non-linearly, the first reading of the text was relatively consistent, without significant text gaps. High and relatively high levels of comprehension were shown by 12,1% of students, average — 48,5%, low and very low — 39,4%. **Conclusions.** In the process of reading, teenagers used not the F-pattern, but the commitment pattern. This result is largely explained by the specifics of working with educational hypertext, when students are given the instruction to read analytically. The prevalence of a low level of understanding indicates that schoolchildren have serious problems in semantic reading in general and reading electronic educational hypertexts in particular.

Keywords: reading and understanding of text, educational hypertext, eye tracker, adolescents, psychological specificity

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Психологические особенности взаимодействия учащихся 7–8-х классов с гипертекстом: теоретико-экспериментальное исследование с использованием айтрекера

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Резюме

Контекст и актуальность. В настоящее время гипертекстовые системы начинают играть все более важную роль и в средствах информации, и в образовательном процессе. Несмотря на значительный массив исследований гипертекста, большинство из них носит теоретический характер, также в дефиците оказываются работы, касающиеся учебного гипертекста. **Цель.** Выявление с помощью айтрекера психологической специфики взаимодействия учащихся 7–8 классов с учебным гипертекстом, а именно следующих особенностей: 1) первичного восприятия текста и следования установке на последовательное аналитическое чтение, 2) распределения внимания учащихся в процессе работы с основным текстом и содержанием гиперссылок, 3) ориентировки в тексте и его понимания. **Гипотезы:** 1) первичное чтение учебного гипертекста будет последовательным, сопровождаться ознакомлением учащихся с содержанием гиперссылок по мере их появления в основном тексте; 2) в силу дополнительной когнитивной нагрузки, возникающей при работе с гипертекстовыми структурами, у подростков будет доминировать недостаточно высокий уровень понимания учебного гипертекста. **Методы и материалы.** Окулографический метод, статистический анализ результатов регистрации окуломоторной активности, анкета с данными испытуемых, авторский диагностический инструментарий «Понимание гипертекста». В выборку вошли 33 учащихся 7–8 классов (12 мальчиков и 21 девочка, возраст — 12–15 лет (M = 13,8, SD = 0,8)). **Результаты.** С точки зрения

внимания в область наибольшей интенсивности попали текстовые отрывки, содержащие конкретную фактуальную информацию. Хотя в силу имманентных свойств, присущих гипертексту, подростки читали текст нелинейно, первичное чтение было относительно последовательным, без существенных текстовых пропусков. Высокий и относительно высокий уровни понимания показали 12,1% испытуемых, средний — 48,5%, низкий и очень низкий — 39,4%. **Выводы.** В процессе чтения подростки применяли не F-паттерн, а паттерн приверженности, что во многом объясняется спецификой работы с учебным гипертекстом, когда учащимся дается установка на аналитическое чтение. Преобладание низкого уровня понимания свидетельствует о наличии у школьников серьезных проблем в области смыслового чтения в целом и чтения электронного учебного гипертекста в частности.

Ключевые слова: чтение и понимание текста, учебный гипертекст, айтрекер, подростки, психологическая специфика

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Introduction

Since electronic hypertext emerged in the mid-1960s and especially in the last two decades, psychologists have been studying electronic hypertext quite actively about its specificity and influence on the mental development of students (N. Belyaeva, A. Voyskunsky, O. Arestova, M. Solodov, M. Lebedeva et al., K. Ganel et al., D. Destefano, J. Lefevre, I. Tsumbakh, I. Piksnar, K. Rayner, L. Salmeron). Interest in this issue is determined by the role that hypertext systems play in modern media, representing a real alternative to printed texts and taking an increasingly important place in the educational process.

Among the most important problems of the study of hypertext, psychologists highlight the following: increasing cognitive load on students including interacting with non-linear text (Voiskounskiy, 2017; DeStefano, LeFevre, 2007; Skulmowski, Xu, 2022; Taky-eddine, Madaoui, 2024); the specifics of navigation activities; the influence of the hyperlinks systems on users' attention and text comprehension (DeStefano, LeFevre, 2007; Schurer, Opitz, Schubert, 2023); the use of cognitive and metacognitive strategies for reading hypertext (Berlin Henis et al., 2023; Lebedeva, 2022; Mironova, Borisenko, Shishkova, 2024).

Analysis of relevant publications allowed us to identify a number of provisions that should be relied upon in hypertext research.

1. Hypertext, as one of the digital technologies, differs from classical printed text as hypertextuality is fully realized only in electronic hypertext, which has such characteristics as virtuality, dispersed structure, interactivity, compositional instability, nonlinearity, openness, multimedia etc. (Stroikov, 2024, pp. 16–17).

2. The specifics of hypertext structure determine the peculiarities of its perception and the reader's interaction with it. A virtual structure of an electronic text includes the main text and embedded hyperlinks leading to hypotexts. (The term "hypotext" is used in the most commonly accepted sense: as the minimal text unit of hypertext available after opening a hyperlink (Ryazantseva, 2010, p. 54)). This virtual structure allows for nonlinear reading, fragmentation, and the development of a reader's individual route. A number of scientists note that the reader, especially a novice with insufficient skills in navigating hypertext structures, may "get lost" in cyberspace, following links leading away from the main text and failing to cope with the initial task (Salmerón et al., 2015; Schurer, Opitz, Schubert, 2023).

3. Interaction with hypertext increases cognitive load due to the necessity to integrate and retain information from different information units in working memory. An increased cognitive load can affect the success of task completion negatively (DeStefano, LeFevre, 2007). On the other hand, as the recent studies show, proper organization of the educational process can minimize the negative aspects of interaction with hypertext (such as loss of orientation, wandering from the topic being studied, etc.) and develop a strategy for balancing cognitive load in digital learning (Skulmowski, Xu, 2022; Sweller, van Merri nboer, Paas, 2019).

In general, despite the significant number of studies dedicated to hypertext research, they are mostly theoretical in nature and often duplicate information obtained at the early stages of its study. There is a shortage of research related to educational hypertext, which differs from non-educational (authentic) hypertext primarily by the specifically organized educational and scientific information it contains. Educational hypertext is marked by such features as strict compliance with the educational task set, completeness and integrity, defined structure, and a limited number of hyperlinks that contain reliable information. Due to these properties, educational hypertext allows the schoolchildren, to a certain extent, to manage their cognitive activity.

Another shortcoming of modern hypertext research is the rare use of precise methods. There is a shortage of studies conducted using oculography (eye tracking) method, a technique for recording eye movements. There is a number of such studies that have been performed by foreign scientists (Rayner et al., 2006; Salmerón et al., 2015; Strukelj, Niehorster, 2018), but this method is rarely used with Russian-language samples (see, for example: (Beloedova, 2023; Berlin Henis et al., 2023; Oganov, Kornev, 2018)).

Studying hypertext using the oculographic method is a very promising direction. It allows for the objectification of both the process of text perception and the ways of interacting with the text. The analysis of eye-movement activity makes it possible to study models of reading behavior and its types, as well as reading strategies. However, we should take into account that the practical use of an eye tracker has a number of limitations and difficulties (see Pokhoday et al., 2022 for details), which will be discussed below.

The aim of the research is to identify, using an eye tracker, the psychological specifics of 7th — 8th grade students' interaction with educational hypertext, namely, the following characteristics: 1) the initial perception of the text and the approach to consistent analytical reading; 2) the distribution of students' attention in the process of working with the main text and the content of hyperlinks; 3) navigation in the text and its understanding.

On the basis of the stated goal, the researchers formulated the following hypotheses:

1. Since educational hypertext is distinguished by its special modeling of the infor-

mation presented for organizing and managing students' activities, we assumed that the initial reading of educational hypertext will be consistent and the students will simultaneously read the content of hyperlinks as they appear in the main text.

2. Due to the additional cognitive load that arises when working with hypertext structures, adolescents are likely to demonstrate an insufficient level of understanding of educational hypertext.

Research Materials and Methods

During the study, the researchers conducted an exploratory pilot experiment using the following methods and techniques:

1. Oculographic method. To record eye movements, we used a Gazepoint GP3 eye tracker with a recording frequency of 60 Hz and 9-point calibration before the experiment. Depending on the computers available in schools, the researcher demonstrated the stimulus data on either 14-inch monitors with a resolution of 1920 × 1080 pixels (n = 9) or 17-inch monitors with a resolution of 1280 × 1024 pixels (n = 24). The study participants sat at a distance of 700–800 mm from the screen. The participants' head position was not fixed during the recording. The eye tracker only tracked the recording of the primary reading, work with the diagnostic test was not subject to video recording.

Statistical analysis of the results of oculomotor activity registration was developed using the Python programming language and jamovi software (V. 1.6.23.0).

2. A questionnaire with the subjects' personal data. In the questionnaire, the students indicated their age, gender, and grade.

3. The author's diagnostic toolkit "Understanding Hypertext", based on I.R. Galperin's theory of the types of information in the text (Galperin, 2007). It implements a gradual-level approach which views understanding not as a binary opposition (understood / did not understand), but as a phenomenon that unfolds stage-by-stage (understood more / less) (Shcherbakova, Obolskaya, 2023). Previously, using this approach, we developed a diagnostic technique to define the level of text understanding by adolescents in the process of comprehended reading from paper and from screen (Mironova, Borisenko, Shishkova, 2024).

As the stimulus material, we chose a fragment from the textbook "Pushkin, his Friends and Contemporaries", dedicated to the ancestors of A.S. Pushkin (Granik, Kontsevaya, Mironova, 2023), since the research was carried out in line with the development of the scientific school of the Russian Academy of Education academician G.G. Granik, in particular, with her research on reading and understanding the text (Borisenko, Mironova, Shishkova, 2022). The book is part of the series "School literary studies on a psychological basis". Based on this text, we developed an experimental educational humanitarian-oriented hypertext, which includes nine hyperlinks of varying size and complexity and an illustrative series of five drawings: a self-portrait of Pushkin in 1829, the Pushkin family coat of arms (in the main text), a portrait of Peter I, and the images of Ethiopia and Cameroon on the map of Africa (in hyperlinks). The hypertext is 4.5 pages long in A4 format (1,058 words). Such a long text was chosen, first of all, due to the need for scrolling and hyperlink navigation. The Flash readability index (FRE) for this text is 44 points[1] — it corresponds to the category of rather complex yet accessible to students of this age group texts.

A specially developed diagnostic toolkit includes tasks for reading two types of text

[1] See: Readability and naturalness of large texts. URL: https://progaonline.com/textquality/result/c719bc1e-4ca53ed6aff686106308e035 (date of request:15.09.2024).

information: factual (describing events, place and time of action) and conceptual ("the system of views, thoughts and feelings the author reflected in the text" (Galperin, 2007, p. 27)). It includes 12 tasks, 5 of which are closed-type and 7 are open-type, requiring a short or detailed answer. These tasks were designed so that the subjects could successfully complete them only by reading both the main text and the content of hyperlinks. The criteria for evaluating detailed answers were the completeness of the statement and its adequacy to the original text. Qualitative analysis was based on the method of expert assessments using a three-point scale. The expert group included five specialists (three philologists, two psychologists) with experience of working with adolescent schoolchildren. The consistency of the experts' opinions was assessed with Cronbach's alpha coefficient; the rate was 0,87. As a result, five levels of text comprehension were identified based on the total scores (very low: almost complete distortion of meaning — 0–24% of the maximum possible score; low: superficial comprehension — 25–49%; average: partial comprehension — 50–69%; relatively high: good but not complete and fully accurate comprehension — 70–84%; high: sufficiently complete and accurate comprehension — 85–100%).

Sample. The pilot study conducted in April–May 2024, involved 33 subjects: 7th–8th grade students from two secondary schools in Moscow and the Moscow Region (12 boys and 21 girls, aged 12–15 years (M = 13,8, SD = 0,8); 7th grade, n = 11; 8th grade, n = 22). All participants had normal or corrected to normal visual acuity, and good or excellent academic performance in relevant subjects (Russian language, literature, history).

The empirical study procedure. First, the subjects filled out a questionnaire, and the eye tracker was calibrated. Then, the students were given instructions. They were told to carefully read the text presented on the computer screen. As they read, they should sequentially open the hyperlinks in the text. After that, they needed to complete reading comprehension tasks. The instructions required analytical reading, focused on revealing the text's content and structure, which, in terms of foreign psychologists (Salmerón et al., 2015), corresponds to deep processing of the text. The reading time, during which eye movements were recorded, was not limited. After reading the text, the subjects answered diagnostic questions in writing with the permission to refer to the text while answering.

The total duration of the experiment for each subject was 35 to 40 minutes.

Results and Discussion

To analyze the data obtained using oculography (for experimental data sets, see (Borisenko, Ganicheva, Mironova, Shishkova, 2025)), we selected the following parameters: the number of fixations and their average duration, the total time of reading the text, the number of clicks on hyperlinks, the duration of viewing relevant hypertext positions, and the distribution of average fixation durations within paragraphs. The selected parameters are generally accepted for analysis in modern eye-tracking studies (Pokhoday et al., 2022; Salmerón et al., 2015; Strukelj, Niehorster, 2018).

During the research, we made an important observation regarding the distribution of attention among the subjects: contrary to widespread assertions that the main strategy of reading from screen is scanning reading, employed mostly according to the principle of the well-known "F-pattern", when the number of visual fixations is concentrated in the upper and left parts of the page (Nielsen, 2006), the F-pattern was not used by the subjects while reading the experimental educational hyper-

text. This is probably due to the fact that the F-pattern describes the behavior of users in the process of viewing web content, but our subjects had a different purpose of reading — not skimming, but analytical educational reading of the hypertext.

Fig. 1 shows an example of a typical heat map of gaze fixations during initial acquaintance with the first page of the stimulus text.

Data visualization shows that the text is being read quite consistently, without significant gaps. In terms of attention, the area of greatest intensity included the second and the third paragraphs containing specific factual information about Pushkin's ancestry. Researchers note that the average duration of fixations increases when low-frequency and less predictable words are fixed and when a section of text contains a greater number of important thoughts (Nazarov, Meshcheryakov, 2009). We can also include in this list hyperlinks (there are four of them in this fragment, all of them have an important meaning-making function) and keywords (great interest in his lineage, the Pushkin family, Boris Godunov, mother's family tree, was a black man).

As a result, the adolescents applied in the process of reading not the F-pattern, but the so-called "commitment pattern", or "compliance with obligations" pattern discovered by researchers from the Nielsen Norman Group in addition to the main F-pattern and along with others (Z-pattern, "layer cake", "spotted pattern" etc.). The essence of the commitment pattern is fixing the gaze on almost every element of the page and reading according to the principle "line by line, paragraph by paragraph". It is noted that this pattern is rarely used, mainly by motivated readers really interested in the content (Pernice, 2017).

So the research revealed that although, in general, due to the inherent properties of hypertext, most schoolchildren read the text non-linearly, following hyperlinks, the initial reading of both the main text and hypotexts was relatively consistent. This sequence of reading is largely explained by the characteristics of this study where the educational hypertext is the object.

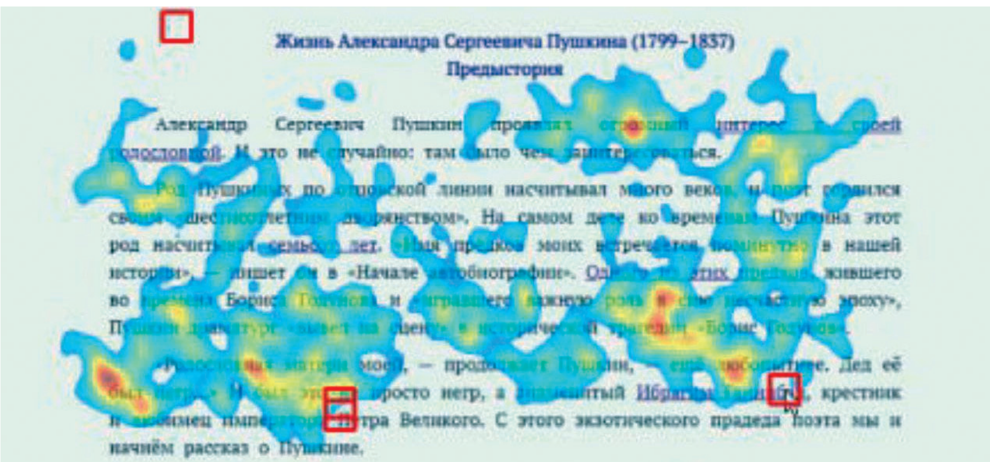

Fig. 1. Individual heat map of the initial hypertext page (first three paragraphs): the red squares indicate the locations of mouse clicks

Now let us consider the procedural aspect of reading some of the most important structural components of hypertext such as the wording of the task and the so-called strong positions of the text, including the heading complex.

The participants kept their eyes on the task formulation for quite a long time (on average 3.8 seconds, the standard error of median (SEM) = 0,75), demonstrating the correct response to the instructions (setting to analytical reading), on the title and subtitle — 2,3 seconds (SEM = 0,40), on the illustrations before the text — 1.4 seconds (SEM = 0,40). At the same time, the participants who used a 14–inch screen read the task significantly slower than the participants who worked with a 17-inch screen (Mann — Whitney criterion, p = 0,002). Students who worked with a 14-inch screen also read the main text more slowly (p = 0,003). The results are quite natural: the smaller the screen size, the more difficult the reading process is, and this fact is confirmed by the data available in the literature dedicated to the relation between screen size and reading speed (Lebedeva, 2022; Rayner et al., 2006).

Fig. 2 shows another example of a heat map showing the average duration of fixations on different parts of the top of the home page, the center and the peripheral areas of the screen.

The longer average fixation on text fragments than on illustrations can be explained by the fact that the visual component does not play a significant role for this specific hypertext: all the drawings, except one, have

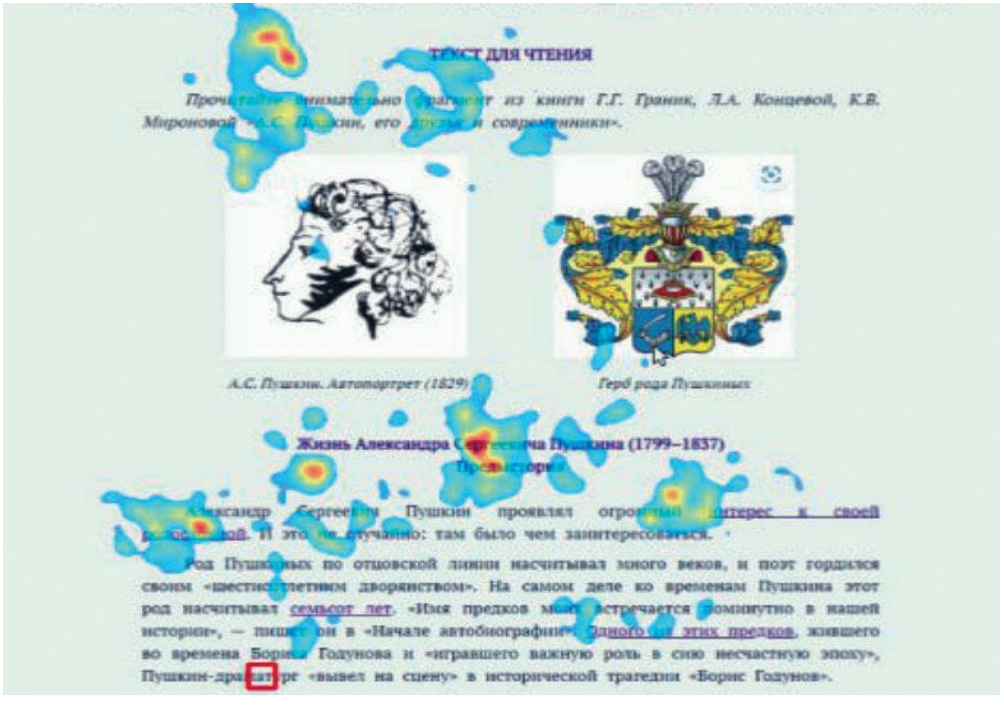

Fig. 2. Individual heat map of the top of the home page of an educational hypertext, constructed for one student

decorative or illustrative functions and have no significant semantic content.

The average hypertext reading speed is an important indicator. It was calculated with the traditional method (the number of words in the entire hypertext divided by the reading time). For the text presented, the average reading speed was 115 words per minute. So we can see that the speed of reading hypertext is quite slow on average, which is probably due to the additional cognitive load related to clicking on hyperlinks. Foreign scientists in their studies (Rayner et al., 2006; Strukelj, Niehorster, 2018) recorded similar results showing an increase in text processing time (and especially the number of fixations) in the case of analytical reading of a complex text. At the same time, we regard the obtained result as preliminary; analysis of the hypertext reading speed requires additional oculographic research.

Next, let us consider data related to navigational activity and the effectiveness of text comprehension.

The characteristics and effectiveness of hypertext reading are determined by the number of hyperlinks clicked by the user. The more hyperlinks are clicked, the more information becomes available and can be perceived by the reader. The ability to compose an individual reading route is one of the advantages of hypertext structures compared to traditional linear text. This indicator is important for eye-tracking studies of hypertext: it reveals the individuality and effectiveness of interaction with the text. However, in our case, we are talking about interaction with an educational text; accordingly, we tried to minimize the variability of the educational task performance by setting the goal of attentive, analytical reading and the requirement to click all hyperlinks and then return to reading the main page using the “Back” button.

The table shows the number of students who opened different numbers of hyperlinks.

Table

Number of opened hyperlinks

Number of hyperlinks	Number of students who opened hyperlinks (n = 33)
8–9	19 (57,5%)
5–7	6 (18,2%)
2–4	3 (9,1%)
0–1	5 (15,2%)

As we can see, the majority of subjects (75,7%) followed the instructions and clicked the most part of the hyperlinks while reading the text. However, the number of students who followed less than half of the links was also quite large — about a quarter (24,3%). In addition, a small part of adolescents (five people, 15,2%) ignored the instructions and read the material as a regular text, not clicking hyperlinks at all (or clicking only one of them) and, therefore, missing out on more than half of the available information. This indicates either a conscious refusal by the students to follow the instructions or that this group of students did not understand the specifics of hypertext and had no experience working with it.

At the next stage, we analyzed the level of understanding of the hypertext using the developed diagnostic tools. The results were as follows: 13 subjects (39,4%) demonstrated a low or very low level of understanding, 16 people (48,5%) demonstrated an average level, and only 4 (12,1%) demonstrated a high or relatively high level. That is, the hypothesis regarding the predominance of an insufficient level of understanding was confirmed.

It should be noted that we also conducted a parallel comparative study of the comprehension level when reading two versions of educational hypertext, identical in content — electronic and printed. It was found that stu-

dents who worked with the electronic version coped with the diagnostic test significantly better ($p < 0,05$) — both in general and with finding factual information in particular. At the same time, no significant differences were found in understanding conceptual information ($p > 0,05$) (Mironova, Borisenko, Shishkova, 2024). However, just as in the study we present now, the level of comprehension turned out to be quite low: only 9,7% of students were able to understand and formulate the main idea of the text absolutely correctly, and about half (50,5%) failed to complete the task.

In general, we can state stated that 7th–8th grade students have an insufficient level of practical skills necessary for effective interaction with educational hypertext. This is probably due to the fact that the process of mastering the skills for working with electronic text develops spontaneously, and the school currently is not responsible for teaching students digital reading.

Conclusion

In our study, we identified the characteristics of the primary perception of educational hypertext by 7th–8th grade students, their abilities to navigate such a text, and the distribution of attention during the process of working with both the main text and hyperlinks. We revealed the specifics of adolescents' interaction with hypertext in terms of the specifics of reading, navigation activity, and text comprehension, and collected preliminary data on reading speed. New data have been obtained on the procedural and productive aspects of how 7th–8th grade students understand complex educational hypertext.

1. The study revealed that, in general, due to the inherent properties of hypertext, the subjects read the text non-linearly. However, the primary reading recorded by the eye tracker was relatively consistent, without significant text gaps. The well-known F-pattern was not confirmed in our experiment. The subjects used the opposite pattern — the "commitment pattern", which is characterized by reading the entire text while the gaze is fixed on almost every element of the page.

2. We defined the features of navigational activity of 7th–8th grade students in interacting with hypertext. Contrary to widespread fears that hyperlinks can take the reader away from the main route and lead to loss of orientation, the majority of subjects (75,7%) navigated the links from beginning to end in the given order. However, the number of students who opened less than half of the links or did not open them at all was also significant (24,3%).

3. Generally, in the sample ($n = 33$), only 12,1% of students demonstrated a high or relatively high level of understanding of the text. In both groups, very low and low levels of understanding predominated (39,4%). The data obtained support our hypothesis that adolescents have certain cognitive difficulties when working with hypertext, which may negatively affect understanding.

The prospects for further study of hypertext are open in several directions, including expanding the sample size, correcting the course of the experiment (performing diagnostics without the access to the previously read text, which will increase the representativeness of the data recorded using an eye tracker), and conducting comparative studies — with electronic and printed hypertext, electronic educational and authentic hypertext, etc.

The limitations of the study are related to the use of two monitors of different sizes, the type of eye tracker, and the small sample size, though sufficient for initial validation.

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Ksenia V. Mironova — planning and conducting the experiment; data analysis and interpretation; annotation, writing and design of the manuscript.

Svetlana V. Shishkova — planning and conducting the experiment; writing and design of the manuscript.

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