https://doi.org/10.24833/2687-0126-2025-7-4-83-99

HOW PRE-READING TASKS SHAPE L2 READING STRATEGIES IN DIGITAL ENVIRONMENTS: EVIDENCE FROM EYE-TRACKING, EEG, AND GSR WITH ADVANCED L2 LEARNERS

Olga Nagel
National Research Tomsk State University (Tomsk, Russia)
olga.nagel2012@yandex.ru

Irina Temnikova
National Research Tomsk State University (Tomsk, Russia)
temnikova196@mail.ru

Valeria Nesterenko
National Research Tomsk State University (Tomsk, Russia)
valerie2602000@gmail.com

Abstract: As digital text becomes the dominant medium for education, understanding the neurophysiological mechanisms underlying second language (L2) reading is crucial for minimizing cognitive overload. This research comprises three exploratory studies employing complementary methodology to investigate the complex nature of reading strategies in the digital sphere of education. The paper aims to reveal how instructional design (specifically platform usability, task typology, and metacognitive scaffolding) influences cognitive load, emotional engagement, and strategy selection. The studies used a multimodal approach combining electroencephalography (EEG), galvanic skin response (GSR), eye-tracking, and self-report measures. Study 1 assessed platform usability. Although EEG spectral analysis indicated optimal baseline cognitive load ($p > 0.05$), eye-tracking and GSR revealed that navigational and visual design flaws were significant sources of extraneous load and user frustration. Study 2 investigated the impact of pre-reading tasks (structural vs. communicative) on Chinese learners of Russian. Eye-tracking metrics showed that communicative tasks promoted active, monitoring-heavy strategies effective for selective processors, whereas structural tasks facilitated thorough, detail-oriented processing that maximized accuracy for non-selective readers. Study 3 compared metacognitive scaffolding against traditional instructions. Results demonstrated that even though scaffolding successfully altered the learning process by inducing a more strategic, planned approach (verified by oculomotor behavior), it came at the cost of significantly increased cognitive load and reduced emotional engagement. These findings provide compelling evidence for a transactional model of digital language learning relevant to professional communication pedagogy. The research concludes that effective outcomes emerge from a dynamic, three-way interaction between the learner's cognitive profile, pedagogical task design, and the usability of the digital environment. Digital

L2 instruction must be cognitively informed, balancing strategic benefits against the mental effort required to deploy them.

Keywords: academic bilingualism, L2 reading strategies, instructional design, cognitive load, metacognition, eye-tracking, digital learning

How to cite this article: Nagel, O., Temnikova, I., Nesterenko, V. (2025). How Pre-Reading Tasks Shape L2 Reading Strategies in Digital Environments: Evidence From Eye-Tracking, EEG, and GSR With Advanced L2 Learners. *Professional Discourse & Communication, 7*(4), 83–99. https://doi.org/10.24833/2687-0126-2025-7-4-83-99

1. INTRODUCTION

The investigation of neurophysiological mechanisms underlying second language (L2) reading comprehension is a cutting-edge research area, especially with the development of online learning practices demanding effective L2 instruction to ease cognitive overload that many learners experience when processing foreign-language materials. The importance of L2 reading in digital environments is not merely a function of technological trends, but a fundamental shift in the nature of literacy itself. It is particularly important now because of a confluence of two powerful forces: the absolute dominance of digital text as the primary medium of information, and the unique, often hidden, cognitive challenges this medium imposes on the language learner. It is believed that integrating neurophysiological methods into L2 instruction research offers a data-driven pathway to enhance digital learning efficacy. Neurophysiological insights (e.g., EEG, eye-tracking) can optimize digital course design by identifying: cognitive bottlenecks in L2 text processing, emotional stress triggers (via GSR) during comprehension, as well as effective and dominant reading strategies that, in their respect, might guide developers of didactic materials to target specific needs of diverse learners. Reading is the cornerstone of knowledge acquisition and cognitive development, serving as the primary medium for instruction in both traditional and digital learning environments.

This paper aims to contribute to empirical evidence on specificities of cognitive processing during reading tasks by non-native speakers in digital environments and to reveal how instructional design might influence the processing patterns and strategy selection process. The first study looks at the digital learning environment itself as a primary factor with its design (navigation, clarity, visual layout) capable of triggering cognitive load and emotional responses (frustration, engagement) that can facilitate or hinder learning, regardless of pedagogical intent. The second study focuses on the effect of pedagogical task design (structural vs. communicative pre-tasks) to reveal learners' innate cognitive strategy (selective vs. non-selective reading). The third study explicates learners' metacognitive profiles through scaffolding, which can successfully shape cognitive strategies and processes, but this intervention directly trades off with cognitive load and emotional state.

2. LITERATURE REVIEW

The EEG research into changes in bioelectrical activity of the brain in students while reading word combinations in English (L2) employing the analysis of the functional interactions of the cerebral cortex regions showed that reading in English for Russian students is a fundamentally complex process (Sokolova & Cherkasova, 2014). A foundational body of eye-tracking research has established that L2 reading is a cognitively distinct process from L1 reading, characterized by different neural pathways (Abutalebi & Green, 2016) and observable oculomotor patterns. It is well-documented that L2 readers exhibit longer fixation durations and more frequent regressions, particularly on unfamiliar syntax and vocabulary (Rayner et al., 2016). Furthermore, research indicates that learners at the same proficiency level employ vastly different reading strategies (Cohen, 1998; Aarnoutse & Schellings, 2003), which are theorized to correlate with varying depths of comprehension (Block, 2005; El-Koumy, 2004). However, a critical gap remains in objectively linking these macro-level strategies to specific, quantifiable eye-movement indices. Though we know strategies differ, we lack a clear, empirical model defining the oculomotor footprint of, for instance, a "selective" versus "non-selective" reading strategy, as well as differences primarily reflected in total fixation count, regression frequency, or scanpath complexity. The present study addresses this gap by using eye-tracking not merely to confirm differences but to operationalize and classify reading strategies based on a composite of fixation duration, regression count, and scanpath analysis during a diagnostic task, thereby creating a behavioral baseline against which instructional interventions can be measured.

The design of instructional materials, particularly in text-dominant digital environments, is a known determinant of learning success. Well-designed instructions enhance motivation and guide performance, while unclear instructions lead to disengagement and errors (Eiriksdottir & Catrambone, 2011; Maddison & Kumaran, 2016). A key instructional element is the pre-task, with typologies ranging from procedural to principle-based. It is postulated that such tasks can support metacognitive development by guiding learners' approach to the text (Mandl & Friedrich, 1992), yet many students struggle to apply these strategies spontaneously (Baker, 1994; Lin, 2001). What remains intensely contested is whether and how different pre-task types directly shape online reading behavior and comprehension outcomes. The fundamental question is whether a task designed to activate schemata (e.g., communicative tasks) elicits a different oculomotor and cognitive pattern than one designed to scaffold vocabulary and structure (e.g., structural tasks) and whether one might promote a more efficient or effective reading strategy than the other. This study directly investigates this by manipulating pre-task typology (structural vs. communicative) to determine its causal effect on both the reading process (via eye-tracking) and the comprehension product (via accuracy scores), thereby moving beyond post-hoc self-reports to a mechanistic understanding of how instruction influences L2 reading behavior.

The push to embed metacognitive training in instruction is well-supported, with the goal of helping learners plan, monitor, and evaluate their comprehension. However, this support is not cognitively neutral; it demands additional mental effort, and some learners may initially find it restrictive (Calvi & De Bra, 1997). This points to a potential trade-off: while metacognitive prompts may improve strategic processing, they may also increase cognitive load. Poorly structured tasks are already known to heighten cognitive load (observed via EEG) and reduce comprehension (Kliesch et al., 2022), and L2 reading anxiety can further jeopardize performance by altering strategy selection (Song, 2010). The critical, and largely unmeasured, unknown is the precise psychophysiological cost of metacognitive scaffolding. While its benefits are often advocated, the concomitant effects on cognitive load (EEG) and emotional arousal (GSR) are rarely quantified in tandem with performance, failing to define whether explicit metacognitive instruction creates a high-cost, high-reward scenario, or the induced load potentially overwhelms its benefits. This study fills this gap by integrating multimodal psychophysiological measures (EEG, GSR) with performance data to triangulate the cognitive, affective, and behavioral outcomes of metacognitive prompts, providing a holistic picture of their true impact on the L2 digital reading activity.

3. METHODOLOGY

The reviewed literature collectively reveals a disconnect between instructional intentions, learner strategies, and their underlying cognitive and affective correlates. The present study integrates these threads to investigate how intentional instructional designs (pre-tasks, metacognitive prompts) directly influence the L2 reading process as measured through its behavioral, cognitive, and affective signatures. Based on this synthesis, we test the following hypotheses:

H1: Communicative pre-tasks will increase regression frequency and reading comprehension accuracy relative to structural tasks, as they promote more active, monitoring-heavy text engagement.

H2: The effect of pre-task typology will be moderated by the reader's baseline strategy; selective readers will show the greatest comprehension benefit from communicative tasks, while non-selective readers will benefit most from structural tasks.

H3: Metacognitive prompts will raise subjective and physiological cognitive load (EEG) but improve performance consistency and strategic alignment between self-reported and observed (eye-tracking) behaviors, despite potentially reducing emotional valence (GSR).

Employing neurophysiological methodologies (electroencephalography and eye-tracking) and integrating them with questionnaires and surveys, the study aims to establish an empirical foundation for optimizing L2 reading pedagogy in digital learning environments. Through systematic identification of cognitive-affective processing barriers, these studies generate a foundation for evidence-based recommendations to enhance instructional design and learning outcomes. There are three main focuses of the research questions stated in the paper.

Firstly, it is claimed (Research question 1) that technical aspects of teaching and learning materials in a digital environment are of great importance, and properly structured and organized materials enhance students' academic progress.

Secondly, the paper states that pre-reading task typology influences reading strategy deployment among advanced Chinese learners of Russian as a foreign language (RFL) when processing instructional texts (Research question 2).

Thirdly, advanced instructional design — integrating metacognitive scaffolding and anxiety-reducing protocols — proves vital for enhancing comprehension and engagement in increasingly text-based virtual education environments (Research question 3).

Data collection was conducted at The Centre of Cognitive Research and Neuroscience at Tomsk State University using the NTrend-ET500 eye-tracking system. The device recorded binocular gaze data at a sampling rate of 500 Hz. Stimuli were presented on a 1920×1080 AOC monitor, with the eye-tracker mounted below the display. Participants were seated at a viewing distance of 60–68 cm.

To ensure data quality, a 9-point calibration and validation procedure was implemented for all participants. The protocol included dynamic adjustments for lighting and positioning. Calibration was validated against a strict accuracy threshold. If the average spatial deviation exceeded 0.5°, the procedure was repeated. Concurrent psychophysiological measures included Galvanic Skin Response (GSR) to assess emotional arousal and Photoplethysmography (PPG) to monitor vascular tone.

Three independent but correlated studies employing the equipment mentioned above are presented to reveal neurophysiological mechanisms involved in reading second-language instructions in educational settings. Each study, though involving a unified experimental tool base, focused on a particular research question in the domain of the perception of second language instruction.

4. STUDY DESIGNS AND RESULTS

4.1. Research question 1

The first exploratory study was aimed at identifying the core research question: Which platform design factors (navigation, media quality, instruction clarity) most strongly predict cognitive load and frustration during L2 reading?

4.1.1. Participants and design

Researchers at Tomsk State University (TSU) conducted scientifically grounded marketing research employing a variety of methods based on the above-mentioned equipment of The Centre of Cognitive Research and Neuroscience combined with direct surveys and interviews to test perception of didactic online materials designed by a team of developers from TSU Research and Education Center "Online Platforms in Language Education" (Multimedia Complex for Studying English (B2 Level, State Registration Certificate for Database No. 2024623976)). 20 students of the Faculty of Foreign Languages took part in the research; they were to do language training tasks on the platform in the laboratory settings.

4.1.2. Results

Taking into consideration the exploratory nature of the research and its broad perspective, we present a generalized interpretation of the data obtained from the survey and psycholinguistic experiment (EEG (electroencephalography) data to reveal cognitive load during task performance; vascular tone monitoring via galvanic skin response (GSR) to assess emotional engagement and reactions; eye-tracking data to assess attention distribution). Survey results revealed that the platform demonstrated a favorable reception among participants (20 students), with task sequencing and structural organization being consistently rated as logically coherent and pedagogically sound in post-intervention evaluations. Neurophysiological measurements, particularly electroencephalographic (EEG) spectral analysis, revealed no statistically significant deviations from baseline cognitive load thresholds ($p > .05$), suggesting optimal information processing demands were maintained throughout the experimental protocol. The results revealed navigation issues, as, for example, scrolling back to the top of the page caused frustration (evidenced by autonomic reactions) and eye-tracking revealed that this navigation step was unclear and time-consuming. Besides, eye-tracking patterns showed users searching for audio speed controls. Criticisms included poor audio/video quality. Some sections were hard for the participants to locate, complicating navigation. Some tasks caused frustration due to unclear instructions, though overall emotions were neutral to positive. Participants also reported visual discomfort, claiming that the orange-and-white color scheme and font influenced their performance, which was proved by increased blinking in the area of the reported colors.

The data revealing difficulties the learners encountered while dealing with online instructions triggered interest in further research into the task instruction perception. For example, the marketing research stated that when completing the task, the participants had difficulties navigating the site, and at the same time, they also posed a question whether it was necessary to write the entire sentence or only the missing word. Hectic eye movements also signal participants' frustration in this part (Fig. 1)

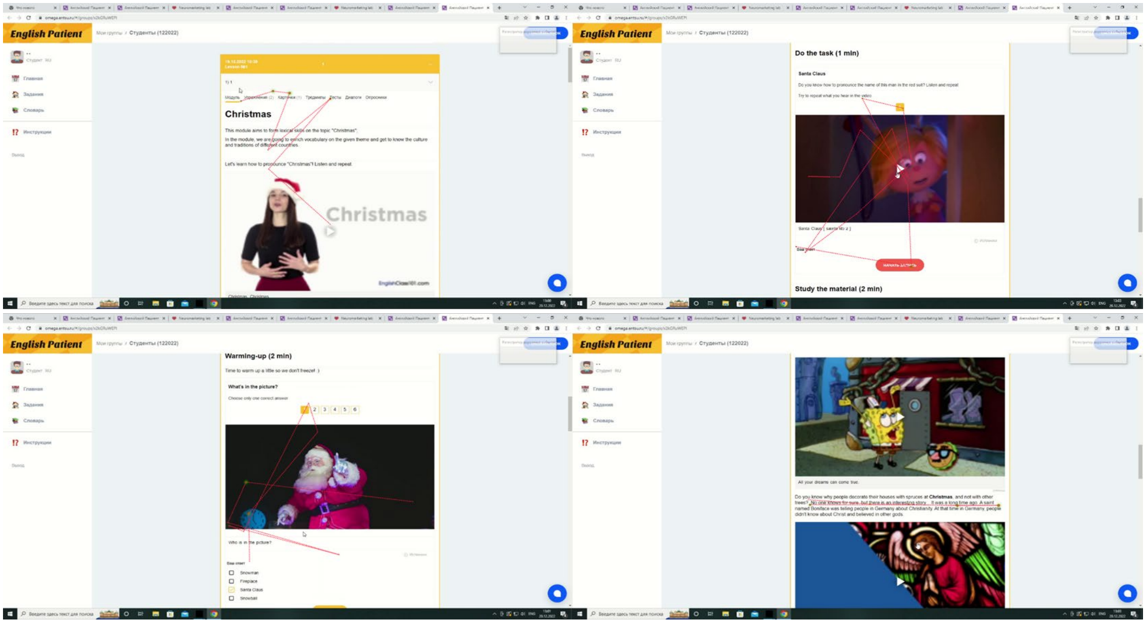

Figure 1. *Demonstration of eye-movement patterns of students completing the platform tasks online*

According to SCR data, the animated content evoked positive emotions when it first appeared. However, when completing the "Warming-up" task, some students experienced negative emotions, as they did not immediately understand how to move on to the next picture after completing the task; not all respondents noticed the small check mark with the result. The "Reading and listening" section aroused interest mainly, but not all respondents launched all the videos, as they could not understand whether they needed to watch them or not. After completing all the tasks, respondents did not immediately understand that they needed to scroll up to move to the next section, which caused negative emotions. When scrolling to the top of the page, respondents experienced mainly irritation.

Therefore, the abovementioned exploratory research initiated further questions to study online task comprehension and perception of users' interactive patterns employed while reading and completing the tasks in L2.

4.2. Research question 2

The present research question aims to investigate the impact of pre-reading task typology on reading strategies employed by Chinese students when engaging with academic texts in Russian as a Foreign Language (RFL). We hypothesized that pre-text tasks can affect reading strategies and their transformation. In this case, there is a need to create a two-stage experiment in which two control groups will perform different pre-text tasks to find out which type of these exercises really contributes to the formation of successful strategies and affects the subjective complexity of the text.

4.2.1. Participants

The participants in the experiment were 28 students of Tomsk State University, studying mainly at the Faculty of Philology. The age of the respondents ranged from 20 to 29 years. All respondents were native Chinese speakers who had been studying Russian for more than four years and assessed their level of language proficiency as B1+/B2. As in the previous experiment, this sample included students whose academic level corresponded to advanced or who had the corresponding certificates.

Each respondent successfully passed the calibration of the oculograph (0,03 – 0,6), which indicated high-quality data recording. The participants in the experiment had normal or corrected (lenses/glasses) vision.

4.2.2. Stimulus material

The material for the experiment was 2 educational texts in Russian, corresponding in complexity to the beginning of the second certification level.

Text 1 was presented to the subjects as diagnostic to determine the reading strategies *(selective vs non-selective reading strategy)* they use when solving the behavioral task. Text 1 consists of 22 sentences, 320 words. There are 197 unique words. The keywords in text 1 are: *child, large family, family, parent, minus, plus, older, younger, sister, brother.* The text covers 89% of the words of the lexical minimum of level B2.

Text 2 was the target stimulus and was presented to respondents sometime after the diagnostic text. Respondents began reading Text 2 after completing the pre-text tasks. The first experimental group completed structural pre-text exercises (e.g., *Match the synonyms, antonyms, etc.*), the second experimental group – communicative ones (e.g., *Read the words. Determine the main idea of the text (the theme of the text) using the following words*). Text 2 consists of 30 sentences, 384 words. It contains 230 unique words. The keywords are: *metropolis, city, to be located, residence, minus, life, entertainment, leisure, choice, option, education, development.* The text covers 86% of the words of the lexical minimum of level B2.

Both texts were taken from the textbook by E.V. Kosareva and A.V. Khrunenkova, "Time to Discuss" (2020), which is designed for students of the second certification level. The original texts from the manual were shortened and also underwent lexical and grammatical transformation. These changes were caused by the need to record the stimulus on the screen.

4.2.3. Experimental procedure

Experiment 2 consisted of 3 stages: (1) instructions on the equipment used and signing of the informed consent; (2) an input questionnaire on an electronic medium; (3) the main stages of the experiment: diagnostic and target text reading.

The input questionnaire consisted of 8 questions revealing respondents' last name, first name, and patronymic; respondents' age; respondents' department of study; year of study; duration of Russian language study; duration of residence in Russia; preferred channels for learning Russian; and respondents' level of language proficiency. Since this study does not make intergroup differences by gender, the corresponding question was excluded from the questionnaire.

The diagnostic text reading was aimed at identifying the reading strategies of each subject *(selective vs non-selective reading strategy)* when performing a behavioral task. The target stage was aimed at working with paper forms with pre-text tasks. Half of the subjects received forms with structural tasks, the other half with communicative tasks. Respondents were not limited in time, but it is worth noting that communicative tasks, on average, took longer to complete. In both cases, respondents were allowed to use a dictionary. The procedure of the target stage was the following: before reading the text, the subject was in a state of rest for 54 seconds (part of the time with their eyes closed, part with their eyes open, looking at a static picture) to collect the GSR data and then normalize them; the text stimulus was fixed on the screen; the respondents finished reading the text; they raised their right hands; psychophysiological indicator data recording was completed, the researcher removed the equipment from the participant and asked the subject to undergo testing based on the results of reading the second text. The respondents took the test on an electronic medium (tablet/mobile phone/computer). The data uploaded to the server were available in the Neurobarometer software. Both texts (diagnostic and target) were marked into AOI for automated statistical calculation. The GSR data were cleared of artifacts and normalized to the resting state of each subject.

4.2.4. Results

By maintaining consistent text stimulus presentation on-screen, we were able to calculate the total number of fixations for each participant during reading. Table 1 presents the averaged reading metrics of Chinese students processing the target text, categorized by pre-reading task type.

Table 1. *Reading performance metrics by pre-reading task type*

Pre-Reading Task Type	Total Fixations (count)	Mean Fixation Duration (ms)	Regressive Fixations (count)	Regression Frequency (%)	Mean Reading Time (min)	Accuracy Rate (%)
Structural	517	370	145	29	5.7	80
Communicative	636	320	200	31	5.4	85

As it can be seen in Table 1 the structural task group exhibited fewer total fixations (517 vs. 636) but longer average fixation durations (370 ms vs. 320 ms), suggesting deeper lexical processing, while the communicative task group showed higher regressive fixation counts (200 vs. 145) and slightly increased regression frequency (31% vs. 29%), indicating more frequent review and monitoring behavior. Despite longer mean reading time in the structural group (5.7 min vs. 5.4 min), the communicative task group showed higher accuracy (85% vs. 80%). This suggests that communicative pre-tasks may enhance comprehension by promoting active engagement, even at the cost of additional regressions. Structural tasks appear to encourage localized, detail-oriented reading (fewer but longer fixations), whereas communicative tasks trigger more dynamic, recursive reading strategies (higher regressions but better comprehension).

For the diagnostic text, the mean fixation duration was 340 ms, with a total of 480 fixations recorded. These values align with expectations given the text's reduced length compared to experimental stimuli. As the diagnostic text served to establish baseline reading strategies during behavioral tasks, the data were further analyzed by strategy type (Table 2).

Table 2. *Reading metrics stratified by reading strategy and pre-task type for diagnostic text*

Pre-Task Type	Strategy	Total Fixations	Mean Fixation Duration (ms)	Regressive Fixations	Regression Frequency (%)	Mean Reading Time (min)	Accuracy (%)
Structural	Selective	573	290	165	28.8	5.5	75
	Non-selective	424	360	135	31.8	6.1	85
Communicative	Selective	522	310	220	42.1	5.3	85
	Non-selective	740	330	240	32.4	5.6	80

Strategy-dependent processing patterns were revealed. Selective strategies (focused attention on key elements) are characterized by shorter fixations (290-310 ms vs. 330-360 ms for non-selective) and higher regression frequency in communicative tasks (42.1% vs. 28.8% in structural), suggesting active cross-checking of information. Non-selective strategies (holistic text processing) are associated with longer fixations (360 ms in structural tasks), which indicates deeper semantic analysis, paradoxically linked to higher accuracy (85%) in structural tasks despite slower reading (6.1 min).

Pre-task moderation effects are supported by the fact that communicative pre-tasks amplified selective strategy use (42.1% regression rate vs. 28.8% in structural), implying enhanced metacognitive monitoring and optimal accuracy (85%) with efficient reading time (5.3 min). Structural pre-tasks benefited non-selective processors, which can be seen in the highest accuracy (85%) despite a slower pace, likely due to systematic comprehension. In general, selective strategies were marked by faster reading and moderate accuracy, non-selective strategies – by slower, but more precise reading in structural contexts.

Thus, it can be claimed that communicative pre-tasks promote adaptive strategy use, particularly for selective processors who optimize both speed and comprehension. Structural pre-tasks favor non-selective, thorough processing, yielding high accuracy at the cost of time. Regression patterns reveal task-strategy interactions: high regression frequency ≠ poor performance (e.g., 42.1% in communicative/selective correlates with 85% accuracy).

The average duration of fixations does not differ a lot between the selective/non-selective reader groups, with values deviating by 10-30 ms. Non-selective readers who performed pre-text communicative tasks have the highest total number of fixations, with this indicator for communicative tasks exceeding the same indicator by 42%. These same readers demonstrate the highest number of regressive fixations, almost twice as many as the non-selective readers who performed structural tasks before reading the text. Although the results presented in Table 2 seem somewhat surprising and even unpredictable, they allow us to draw an important conclusion that structural tasks make reading the text easier for a particular type of reader. The results of the selective reader group are also interesting, with their regressive fixation frequency being 42.1%, indicating multiple re-readings of the text. Despite the fact that the frequency of regressive fixations reflects the complexity of the text, this type of reader showed the best test results.

4.3. Research question 3

This study experimentally analyzes the effects of metacognitive scaffolding versus traditional task formats, hypothesizing that explicit metacognitive prompts will enhance knowledge activation and learning outcomes. The experiment on completing a reading MCQ (multiple-choice question) task with metacognitive instruction was aimed at testing the hypothesis that if a person processes (plans, controls) their actions while studying, the educational results are more pronounced.

4.3.1. Participants and design

The experiment was designed and conducted as a part of the project intended to investigate the metacognitive experience of the students studying a foreign language and its impact on the educational results they achieve. The study examines the characteristics of cognitive load, attention, emotional involvement, and interest, and identifies psychophysiological correlates of metacognitive activity. Students' metacognitive awareness, planning, regulation, and control, when activated, are hypothesized to enhance the process of learning and help students to achieve more proficient educational results.

The speech activity to be examined is reading. The study focuses on whether the instruction to the reading MCQ task, formulated to trigger students' thinking about their experience and effective strategies of doing the tasks of this kind, can result in more effective learning outcomes, though with the increase in their cognitive load.

20 students of the Faculty of Foreign Languages, studying in the field of Translation and Translation Studies, took part in the experiment. They were randomly divided into 2 groups (experimental and control) of 10 people each. The participants have at least a B2 level of English, have uncorrected vision and hearing, do not have psychiatric and psychoneurological diseases, head injuries, epilepsy; the participants do not take psychotropic drugs and do not have implanted stimulants. 17 participants were women (85%) and 3 were men (15%), all of them having been studying English for more than 5 years.

An important task was to identify the psychophysiological correlates of metacognitive activity in the process of completing the task and to verify the survey and psychophysiological data. The substantive emphasis is placed on the differences in the instructions for the reading task: 1) the classic version of the instruction *(read the text and choose an answer to the question about the text)* and 2) a version of the instruction with specification of the metacognitive experience, knowledge, and strategies for completing a task of this type. The text of a metacognitive instruction for the MCQ reading task was as follows: *"Before reading the text, think about your background knowledge about the topic of the text, study the task (read the questions and answer options, elicit the difference in the answer options, and try to predict the correct one). Read the text to understand the main idea of the text as a whole, basic points of each paragraph of the text and the way they are related to each other; identify the key words, figure out the meanings of words you haven't encountered before with the help of the context; choose the correct answer to each question after the text to check your understanding, reread the text for detail to make your final decision."*

The study utilizes a mixed-method design:

1) questionnaires of metacognitive awareness of reading, self-efficacy in completing multiple-choice questions on a text, metacognitive experience of completing the task (difficulty, confidence in the correctness of the answer, adherence to task completion strategies), emotional background of completing the task, etc. (Soto et al., 2018);

2) recording psychophysiological indicators during the completion of questionnaires and multiple-choice reading tasks on a text (EEG, eye tracker, photoplethysmograph, biobracelet);

3) semi-structured interviews with study participants dedicated to reflection on the experience of completing the task.

The objective of the study using neurophysiological equipment and stimulus material is to detect the presence or absence of influence of metacognitive instruction on the behavior of the subject during the performance of tasks in English. To achieve this goal, two groups of subjects were formed: group 1 (metacog (1) – hereinafter), participants doing the reading MCQ task with a classical instruction; group 2 (metacog (2) – hereinafter), participants doing the reading MCQ task with a metacognitive instruction. The method of presenting stimulus material is a free (non-fixed) stimulus. The stimulus material was presented to the respondent linearly (without the possibility of returning to the previous page). The study procedure was the following: (1) informing participants and obtaining their consent – (2) preparing the participant for the study (setting up and fixing the equipment) – (3) recording EEG to monitor the cognitive load during the task (comparison and description of two presented pictures in English) – (4) filling out questionnaires (part 1) – (5) filling out questionnaires (part 2) – (6) completing the reading task – (7) filling out questionnaires (part 3) – (8) interview.

The study design for both groups included questions for self-assessment of various aspects of metacognitive activity during the task, including the use of strategies during the task, awareness of strategy use, changing the strategy during the task, assessing the effectiveness of the strategy used, and changing one's own way of performing tasks of this type in the future. Students were asked to say whether they either strongly disagree, disagree, or did not decide, or agree, or strongly agree with the statements related to each aspect of students' learning activity: metacognitive awareness, planning, regulation, and control.

Example of a statement on metacognitive awareness: *I know the strong and weak points of my reading skills* (Strongly disagree/ Disagree/ Not decided/ Agree/ Strongly Agree);

Example of a statement on planning: *I define specific objectives for myself before I start doing a reading task* (Never/ Rarely / Sometimes/ Often/ Always);

Example of a statement on assessment: *When I finish reading, I can evaluate whether I understood the text well or not* (Strongly disagree/ Disagree/ Not decided/ Agree/ Strongly agree);

Example of a statement on control: *While I'm reading, I can determine how much I understand* (Never/ Rarely/ Sometimes/ Often/ Always).

The analysis of the individual profiles of the participants according to the metacognition questionnaire as a whole allows us to conclude that the participants' metacognitive skills are mostly above average.

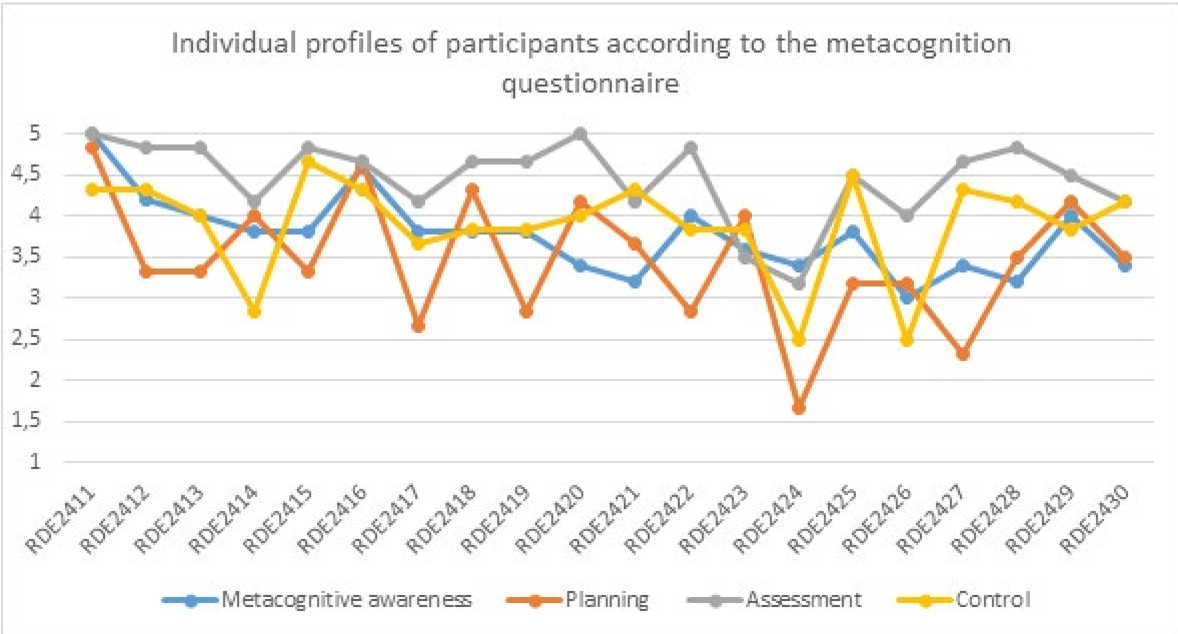

Figure 3. Individual profiles of participants according to the metacognition questionnaire (vertically: degree of participant agreement; horizontally: participants' codes (20 participants))

It should be noted that three participants demonstrated below-average scores on the reading comprehension regulation control scale (regulation) and five participants demonstrated below-average scores on the pre-task planning scale (planning). One of the participants (RDE2424) demonstrated a tendency toward lower scores on all scales. It should also be noted that, in general, participants demonstrated the highest scores in comparison with other scales on the reading comprehension assessment control scale, with the exception of two participants. In addition, it should be noted that profiles were identified in which various aspects of metacognitive activity can be characterized as "balanced" (e.g., profiles RDE2411, RDE2416, RDE2423, RDE2429) and as "unbalanced", that is, having gaps in the level of self-assessment of certain metacognitive skills (e.g., RDE2415, RDE2419, RDE2422, RDE2427). The presented profiles allow us to obtain a clear idea of individual differences in self-assessment of the level of development of metacognitive skills, which are important for successful acquisition and completion of tasks in reading, as one of the types of speech activity.

The analysis of individual profiles of participants by groups, taking into account the number of correct answers allows us to say that within one group there are differences in individual profiles, which indicates the need to solve the problem of personalization in the implementation of the metacognitive approach to learning and to study various factors that determine the success of completing tasks in different types of speech activity.

The analysis of the objective data obtained using the oculography method allows us to identify the main models of oculomotor behavior when performing the task. Objective data were collected from 17 participants in the experiment, of which 8 people were participants in the experimental group, and 9 people were in the control group. The scanpaths of 3 participants (2 from the experimental group and 1 from the control group) were excluded from the analysis because of poor recording quality. The collected data contain the information about the patterns of oculomotor behavior of the experiment participants when answering each of the 4 questions of the reading task and choosing the correct answer; in total, the number of reactions is 68.

The following models of oculomotor behavior of participants and their characteristics were distinguished (Table 3).

Table 3. *Models of oculomotor behavior of participants in experimental and control groups*

Reaction specifications Models	Total reactions	Experimental group reactions	Control group reactions	Task completion condition
Model 1: text – question – answer options	6	3	3	completion of task 1
Model 2: text – question – answer options – text	6	2	4	completion of tasks 1, 2 and 3
Model 3: question – answer options – text	20	18	2	completion of tasks 1 - 4
Model 4: question – text – answer options – text	8	2	6	completion of tasks 1 - 4
Model 5: question – text – answer options	18	6	12	completion of tasks 1 - 4
Model 6: question – text title – text – question – answer options	1	1	0	completion of task 1
Model 7: question – text – question – answer options	1	0	1	completion of task 3
Model 8: text – question – text – answer options	3	0	3	completion of tasks 1, 2 and 4
Model 9: question – answer options – text – answer options – text – answer options – text – answer options – text	1	0	1	completion of task 3
Model 10: question – answer options – text – answer options – text	1	0	1	completion of task 4
Model 11: question – text – question – text – answer options	2	0	2	completion of task 4
Model 12: text – answer options – question – text	1	0	1	completion of task 3

In general, two basic strategies for completing the task described by the study participants can be distinguished. The first strategy is that the first stage of completing the task includes a general familiarization with the text, the second stage involves familiarization with the questions and answer options to them, and choosing the correct answer with its verification in the text (if necessary). The second strategy involves preliminary familiarization with the questions and answer options so that when subsequently reading the text, one can focus on those fragments of the text that contain the information necessary to choose the correct answer. A comparative analysis of the subjectively described strategy and models of oculomotor behavior of the participants when performing the task shows that the description of the strategy for completing the task in the experimental group corresponds to the models of oculomotor behavior, while such a correlation is not observed in the participants of the control group.

5. DISCUSSION

This study was designed to investigate the complex interplay between instructional design, cognitive processes, and strategic behavior in L2 digital reading. Moving beyond a descriptive account, this discussion interprets our key findings through the lens of established theoretical frameworks. To articulate what the obtained empirical results reveal about the underlying mechanisms of digital language learning, we offer our key findings through the lens of established theoretical frameworks.

Our first research question examined how the design of a digital learning platform influences L2 readers' cognitive and emotional states. The results confirmed that even pedagogically sound content is mediated by the ergonomics of its interface. While EEG indicated stable overall cognitive load, moments of frustration were pinpointed via GSR and eye-tracking during navigation (e.g., scrolling to proceed) and in response to specific visual design elements (e.g., the color scheme).

This pattern offers a nuanced confirmation of Cognitive Load Theory (CLT). The stable EEG suggests the intrinsic load of the language tasks was well-calibrated. However, the spikes in frustration and visual discomfort are clear indicators of extraneous cognitive load imposed by the interface itself (Sweller, 2011). This finding challenges the view of platform design as a neutral container, demonstrating instead that it is an active variable in the learning equation. Poor navigational cues and suboptimal visual ergonomics do not merely cause annoyance; they consume finite cognitive resources that would otherwise be allocated to language comprehension. Our data thereby bridge CLT with principles of human-computer interaction, asserting that in digital learning environments, usability is a precondition for cognitive efficiency.

The second research question focused on how pre-task typology shapes reading strategies and comprehension. The central finding was that communicative pre-tasks, while eliciting more regressions and fixations, led to higher comprehension accuracy than structural tasks. A superficial interpretation might view these increased regressions as a sign of difficulty. However, when contextualized with the higher accuracy scores, a more theoretically meaningful explanation emerges.

This pattern directly refines models of eye-movement control in reading (Rayner, 2009; Just & Carpenter, 1980). Rather than being mere indicators of processing failure, the regressions observed in the communicative group appear to reflect strategic, metacognitive monitoring. The readers under study were actively cross-checking information between the text and the questions, engaging in a recursive process of hypothesis-testing and meaning-construction. This aligns with the view of regressions as a component of comprehension-monitoring rather than just decoding difficulty (Hyönä et al., 2003). Consequently, our findings argue for a more nuanced interpretation of eye-tracking metrics in strategic L2 reading, where regression frequency can be a marker of engaged, higher-order processing rather than deficiency.

Furthermore, the interaction between the pre-task type and the reader's baseline strategy (selective vs. non-selective) provides an important contribution. It demonstrates that the efficacy of an instructional intervention is not absolute but is transactional, dependent on the learner's pre-existing cognitive profile. This finding challenges one-size-fits-all pedagogical models and underscores the need for a more personalized approach to instructional design in L2 reading.

The third research question probed the effects of explicit metacognitive prompts. The results revealed a clear trade-off: the group receiving metacognitive instructions demonstrated a stronger alignment between their self-reported strategies and their actual oculomotor behavior, indicating a more conscious and regulated approach. However, this strategic clarity came at the cost of higher cognitive load, as measured by EEG. This outcome is powerfully interpreted through the framework of Self-Regulated Learning (SRL), particularly Winne's (2005) model. Metacognitive prompts effectively externalize the internal standards and processes that define skilled self-regulation, guiding learners through phases of planning and monitoring. The observed increase in cognitive load is consistent with the notion that deploying metacognitive strategies is effortful; it constitutes a germane cognitive load—a productive investment of resources in building schemas for how to learn (Sweller, 2011). The fact that this group's eye movements were more coherent and strategy-consistent suggests the prompts were successful in fostering what Winne terms "cognitive engagement." This implies that the initial cost in mental effort may be a necessary step toward the automation of more effective reading strategies over time.

While this study offers robust insights, its limitations must be acknowledged. The sample, though sufficient for a controlled experimental design, was small and culturally homogeneous, comprising advanced L2 learners from a single linguistic background. This necessarily constrains the generalizability of the findings. Future research should seek to validate these effects with larger, more diverse populations across different proficiency levels. Furthermore, the cross-sectional nature of this study captures only a snapshot of strategic behavior. Longitudinal designs might be needed to investigate whether the strategic shifts induced by pre-tasks and metacognitive scaffolding are sustained and how the associated cognitive load evolves with practice.

6. CONCLUSION

This study set out to illuminate the neurocognitive underpinnings of L2 reading in digital environments by investigating three core questions. The integrated findings, drawn from multi-method physiological and behavioral data, provide conclusive answers with substantial theoretical and practical implications. First, regarding how digital platform design influences the learning process, we conclude that instructional design features are not a neutral backdrop but are pedagogically decisive. Elements like navigational logic and color schemes directly shape extraneous cognitive load and emotional engagement, as evidenced by GSR peaks and oculomotor signs of frustration. This finding solidly aligns with Cognitive Load Theory, demonstrating that poor interface ergonomics actively consumes the finite cognitive resources necessary for language comprehension. Second, on the influence of pre-reading task typology, we conclude that communicative and structural tasks promote distinct, yet valuable, processing patterns. Communicative tasks, leading to higher accuracy and more regressions, foster active monitoring and recursive comprehension-checking – a process where regressions signal metacognitive engagement rather than failure. Structural tasks, associated with fewer but longer fixations, support a more thorough, detail-oriented semantic processing. This reveals that task choice effectively tilts the balance between strategic depth and processing efficiency. Third, concerning the impact of metacognitive scaffolding, we conclude that explicit metacognitive prompts successfully engender more self-regulated learning. This is demonstrated not only through self-reports but, crucially, through a measurable alignment between claimed and actual oculomotor behavior. The concomitant rise in EEG-measured cognitive load underscores the effortful nature of metacognitive regulation, supporting Winne's (2005) model of SRL by showing that such scaffolding externalizes the internal standards of skilled readers, even at an initial cost in mental effort.

A primary contribution of this work is its methodological integration, being among the first to triangulate eye-tracking, EEG, and GSR to dissect the L2 digital reading process. This multi-layered perspective provides a more holistic understanding of how instruction impacts the learner's mind and body. We must, however, acknowledge the constraints of our study, including its small sample size and culturally specific participant pool, which invite caution in generalizing the findings and highlight the need for future large-scale, longitudinal replication.

Looking forward, our results carry a clear message: the design of digital learning must be cognitively informed. This means engineering interfaces to minimize extraneous load, selecting pre-task typologies strategically to align with learning objectives and learner profiles, and embedding metacognitive prompts to foster the development of expert reading strategies. Ultimately, advancing L2 education in the digital age requires a conscious fusion of pedagogical principles with empirical insights from cognitive science, creating environments that are not only informative but also intrinsically supportive of the human brain that engages with them. In conclusion, this study moves the field forward by demonstrating that digital L2 reading is a tripartite transaction between the learner's cognitive profile, the pedagogical design of tasks, and the ergonomic design of the platform. Our findings compel a shift in perspective: digital instructional elements are not peripheral but are decisive factors that shape cognitive load, emotional engagement, and strategic processing.

The study proposes that effective e-learning design must be evidence-based and cognitively informed. It is insufficient to focus solely on linguistic content or pedagogical intent; the digital interface and instructional scaffolds must be engineered to minimize extraneous load while strategically promoting germane load through tasks that trigger adaptive metacognitive monitoring. As such, the future of L2 educational technology lies in its integration of principles from applied linguistics, instructional design, and cognitive neuroscience to create environments that are not only informative but also cognitively hospitable and strategically empowering.

Conflict of interest
The authors declare that there is no conflict of interest.

REFERENCES

1. Sokolova, L.V., & Cherkasova, A.S. (2014). Funktsional'noe vzaimodeistvie korkovykh zon v teta-diapazone u studentov v protsesse chteniya grammaticheskikh konstruktsii na russkom i angliiskom yazykakh [Functional Interaction of Cortical Areas in Theta-Band of Students during Reading Russian and English Grammatical Constructions]. E*kologiya Cheloveka [Human Ecology],* 5, 35-40 (in Russian).

2. Aarnoutse, C., & Schellings, G. (2003). Learning reading strategies by triggering reading motivation. *Educational Studies, 29*(4), 387–409. https://doi.org/10.1080/0305569032000159688

3. Abutalebi, J., & Green, D.W. (2016). Neuroimaging of language control in bilinguals: Neural adaptation and reserve. *Bilingualism: Language and Cognition, 19*(4), 689–698. https://doi.org/10.1017/S1366728916000225

4. Baker, M. (1994). A model for negotiation in teaching-learning dialogues. *Journal of Artificial Intelligence in Education, 5*(2), 199-254.

5. Block, E. (1986). The comprehension strategies of second language readers. *TESOL Quarterly, 20*(3), 463-494. https://doi.org/10.2307/3586295

6. Calvi, L., & De Bra, P. (1997). Improving the usability of hypertext courseware through adaptive linking. In M. Bernstein, K. ØSterbye, & L. Carr (Eds.), HYPERTEXT'97: *Proceedings of the Eighth ACM Conference on Hypertext* (pp. 224–225). https://doi.org/10.1145/267437.267470

7. Cohen, A. D. (1998). *Strategies in learning and using a second language*. Longman.

8. Eiriksdottir, E., & Catrambone, R. (2011). Procedural instructions, principles, and examples: How to structure instructions for procedural tasks to enhance performance, learning, and transfer. *Human Factors, 53*(6), 749–770. https://doi.org/10.1177/0018720811419154

9. El-Koumy, A. S. K. (2004). Metacognition and reading comprehension: Current trends in theory and research. Education Resources Information Center (ERIC), USA. http://dx.doi.org/10.2139/ssrn.2364871

10. Hyönä, J., Lorch, R.F., & Rinck, M. (2003). Eye Movement Measures to Study Global Text Processing. In R. Radach, J. Hyönä, & H. Deubel (Eds.), *The Mind's Eye: Cognitive and Applied Aspects of Eye Movement Research* (pp. 313-334). https://doi.org/10.1016/B978-044451020-4/50018-9

11. Just, M.A., & Carpenter, P.A. (1980). A theory of reading: From eye fixations to comprehension. *Psychological Review, 87*(4), 329-354. https://doi.org/10.1037/0033-295X.87.4.329

12. Kliesch, M., Pfenninger, S. E., Wieling, M., Stark, E., & Meyer, M. (2022). Cognitive benefits of learning additional languages in old adulthood? Insights from an intensive longitudinal intervention study. *Applied Linguistics, 43*(4), 653–676. https://doi.org/10.1093/applin/amab077

13. Kosareva, E.V., & Khrunenkova, A.V. (2020). *Vremya obsuzhdat': uchebnoe posobie po rechevoi praktike dlya inostrannykh uchashchikhsya. 3 izd. [Time to discuss: a textbook on speech practice for foreign students. Third edition].* Moscow: Russian language. Courses (in Russian).

14. Lin, X. (2001). Designing metacognitive activities. *Educational Technology Research and Development, 49*(2), 23–40. https://doi.org/10.1007/BF02504926

15. Maddison, T., & Kumaran, M. (2016). *Distributed learning: Pedagogy and technology in online information literacy instruction.* Chandos Publishing.

16. Mandl, H., & Friedrich, H. F. (Eds.). (1992). *Lern- und Denkstrategien. Analyse und Intervention [Learning and thinking strategies. Analysis and intervention].* Hogrefe Verlag für Psychologie.

17. Rayner, K. (2009). Eye movements in reading: Models and data. *Journal of Eye Movement Research, 2*(5), 1-10.

18. Rayner, K., Schotter, E.R., Masson, M.E., Potter, M.C., & Treiman, R. (2016). So much to read, so little time: How do we read, and can speed reading help? *Psychological Science in the Public Interest, 17*(1), 4-34.

19. Song, J. (2010). *The effects of anxiety on Korean ESL learners' reading strategy use and reading comprehension* [Master's dissertation, University of Texas at Austin]. https://repositories.lib.utexas.edu/bitstream/handle/2152/ETD-UT-2010-05-1477/SONG-THESIS.pdf

20. Soto, C., Gutierrez de Blume, A.P., Asun, R., Jacovina, M., & Vasquez, C. (2018). A deeper understanding of metacomprehension: Development of a new multidimensional tool. *Frontline Learning Research, 6*(1), 31–52. https://doi.org/10.14786/flr.v6i1.328

21. Sweller, J. (2011). Cognitive Load Theory. In J.P. Mestre, & B.H. Ross (Eds.), *Psychology of Learning and Motivation, 55,* 37-76. https://doi.org/10.1016/B978-0-12-387691-1.00002-8

22. Winne, P.H. (2005). A perspective on state-of-the-art research on self-regulated learning. *Instructional Science, 33*(5), 559–565. https://doi.org/10.1007/s11251-005-1280-9

About the author:

Olga Nagel, Dr. Sc. (Philology), is a Professor in the Department of English Philology and Dean of the Faculty of Foreign Languages at National Research Tomsk State University (Tomsk, Russia). ORCID: 0000-0001-6210-1526

Irina Temnikova, Cand. Sci., is an Associate Professor in the Department of English Philology at the Faculty of Foreign Languages at National Research Tomsk State University (Tomsk, Russia). ORCID: 0000-0002-0207-2978

Valeria Nesterenko is a Junior Researcher at the Center for Cognitive Research and Neuroscience at National Research Tomsk State University (Tomsk, Russia).

Received: July 21, 2025.
Accepted: November 24, 2025.