Journal of Experimental Psychology: Human Perception and Performance

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Online First Publication, June 26, 2025. https://dx.doi.org/10.1037/xhp0001354

AMERICAN PSYCHOLOGICAL ASSOCIATION

Journal of Experimental Psychology: Human Perception and Performance

ISSN: 0096-1523

https://doi.org/10.1037/xhp0001354

Morpho-Syntactico-Semantic Parafoveal Processing: Eye-Tracking Evidence From Word $n+1$ and Word n in Russian

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Two experiments compared morpho-syntactico-semantic parafoveal processing of five-letter words $n+1$ (Experiment 1) with five-letter regions at the end of longer words n (Experiment 2), understudied cross-linguistically. Earlier boundary-change studies showed that subject/object case assignment in Russian can be extracted from a parafoveally presented but never directly fixated letter when the related preview is the most expected continuation (Stoops & Christianson, 2017, 2019). This study reversed the syntactic expectations for the identical and related previews (Cloze ratings: 94% grammatical identical object vs. 0% ungrammatical related subject). The related preview was read more slowly than the no-change preview in the later measures: go-past for the words $n+1$ and n, according to both frequentist and Bayesian analyses. Additionally, the study clarifies the augmented allocation of attention hypothesis—skilled readers process parafoveally visible parts of a longer word faster than length-controlled upcoming word $n+1$, yet the message-level contextual linguistic information affected the target words n and $n+1$ similarly. The most intriguing finding is the delayed morpho-syntactico-semantic effect: even though the morphologically ungrammatical marking was parafoveally available, the syntactic fit only affected delayed processing, manifested as increased reading of previous text. More cross-linguistic work is needed to understand the role of higher level linguistic information beyond the predictability of individual lexical items on parafoveal processing during reading.

Public Significance Statement
The results indicate that, while low-level orthographic processing can be processed in parallel by skilled readers, it is the language-related, message-level interpretative processing that proceeds serially. Our study suggests that the morpho-syntactico-semantic characteristics of the target word are a significant informative layer used by skilled readers and that this has been overlooked by current models that rely largely on lexical predictability.

Keywords: eye tracking and reading, parafoveal processing, syntactic predictability, attentional allocation hypothesis in word n versus word $n+1$, morpho-syntactico-semantic processing

Syntactic prediction while reading scripts in languages with flexible word order and rich inflectional systems is difficult because key communicative relationships, like who did what to whom (i.e., thematic role assignments), are often signaled not by the position of the noun phrase in the sentence but by the inflectional markings on the words. That means that skilled readers should prioritize the processing of such orthographic units in these languages. Cross-linguistic studies that have examined the time course of morphosyntactic processing suggest that morphosyntactic/morphosemantic sampling might be accomplished parafoveally (i.e., before the eyes directly

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Anastasia Stoops is now also affiliated with the National Center for Supercomputing Applications (NCSA), Center for AI Innovation (CAII) at Urbana, IL, United States.
Parts of this study were presented at the 20th Annual Meeting of the Visual Sciences Society (VSS 2020). This research was supported by the National Science Foundation (Grant BCS-0847533 to Kiel Christianson). We thank members of EdPsych Psycholinguistics Lab at the University of Illinois at Urbana-Champaign for help with recruiting and conducting the study; Natalia Maltseva and Saratov University students for their help with the norming studies; Denis Drieghe and Tatiana Ionin for their informative discussions through the item construction, experimental implementation, and data analysis stages of the project; and Raymond Bertram and Athanassios Protopapas for helpful reviews of an earlier version of this article. The experiment was not preregistered. The data and analytical scripts used in the experiment are available as the additional online materials at https://doi.org/10.17605/OSF.IO/7A3Q4.
Anastasia Stoops served as lead for conceptualization, data curation, formal analysis, investigation, methodology, project administration, resources, visualization, and writing–original draft. Jack Dempsey served in a supporting role for formal analysis and writing–review and editing. Kiel Christianson served as lead for funding acquisition, contributed equally to conceptualization, data curation, methodology, and writing–review and editing, and served in a supporting role for formal analysis and writing–original draft.
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fixate the key regions) in certain languages due to either different linguistic typologies (Hebrew, Deutsch et al., 2003, 2005) or perceptual biases of the writing systems (Korean, Kim et al., 2012); however, this type of parafoveal processing might instead be a later, foveal process in languages with concatenative morphologies (e.g., English, Schotter et al., 2012). Yet, recent evidence for the parafoveal processing of case markers in languages with concatenative morphologies, shallow orthographies, and flexible word order, such as Russian (Stoops & Christianson, 2017, 2019), calls for a reevaluation of earlier assumptions.

The current study uses the gaze-contingent boundary-change paradigm (Rayner, 1975). Prior to the direct fixation of the target region, it appears in an altered form. As the eyes cross the invisible boundary, located before the target region, the preview is replaced with a target without readers' conscious awareness of the change due to saccadic suppression (Matin, 1974). Beneficial and/or costly preview effects, reflected by increased or reduced fixation durations on the target region compared to some baseline, represent the depth of parafoveal processing of the tested information type.

Research has shown that parafoveal preprocessing of upcoming words at the orthographic and phonological levels facilitates the lexical processing of those words after they are foveally fixated. Vasilev and Angele (2017) in a Bayesian meta-analysis of 93 cross-linguistic studies summarize that readers of alphabetic scripts on average fixate the target word 20–50 ms longer depending on the type of manipulated preview compared to the no-change preview. The less word-like previews, such as X-strings, random letters, and pseudowords, result in stronger disruption than unrelated real word previews, suggesting lexicality is an important influence in parafoveal processing.

The lexicality effect is supported further by evidence from studies that placed the boundary within words. Such studies report interference from manipulated characters in the range of 100–150 ms, which is several times higher than the traditionally reported manipulated preview-target difference from between-word experiments. For example, two letter manipulations at the end of a longer English monomorphemic word like *fountain* (preview: founta**om**) caused readers to look 151 ms longer on the second half of the word after the manipulated characters were replaced with the target characters (*-in*) compared with the no-change preview *fountain*. Larger within-word disruptions are attributed to the augmented attention tied to lexical access of the currently fixated word *n*, suggesting the capacity for flexible, contextually sensitive attentional allocation within the parafoveal portion of the visual field (Drieghe et al., 2010; Häikiö et al., 2010; Hyönä et al., 2004; Juhasz et al., 2009; White et al., 2008).

Additionally, the preceding context of sentences seems to modulate the processing of the parafoveally displayed words, in some cases before they are being fixated directly. For example, Slattery (2009) placed the one-character manipulated previews (*birch-birth*) into sentences that supported either an unbiased context (1a) or a biased context (1b).

1a. She knew that giving **birch** [preview: **birth**] trees to the park would help beautify it.
1b. He planted the **birch** [preview: **birth**] trees beside the house to clock the summer sun.

In the unbiased context condition (1a), participants read the target word *birch* 33 ms faster on the first pass (gaze duration [GD]) with *birth* as a preview (253 ms) than in the biased condition (1b; 286 ms). This suggested that the preceding context in (1a) facilitated recognition of the preview word *birth* at the lexical level. Logically, if the preview that was different from the target was processed deeply at the meaning level beyond orthographic familiarity and integrated into the message level, then at some point, there should be a cost associated with meaning adjustments since the sentence ultimately was about *birch trees* not about *birth trees*. Indeed, the total fixation duration measure revealed that readers reread the target word *birch* with the same preview *birth* 20 ms longer (1a: 356 ms) in the unbiased condition than in the biased condition (1b: 336 ms). Although the context facilitated preview integration into the overall message on the first pass, ultimately, when the previewed word did not fit into the sentence and was at odds with the meaning of the target word that readers saw, participants reread the target more overall.

Slattery's work demonstrated that both early (first-pass) measures associated with word identification stages and later (second-pass) measures associated with the integration of the target word into the message being communicated (Reichle et al., 2009; Staub, 2011) are sensitive to boundary-change manipulations. This study points to the need to understand the depth of semantic and syntactic word processing in the parafovea, beyond orthography and phonology, to consider the time course of such processing.

Stoops and Christianson's series of studies (2017, 2019, 2020, 2022) provide examples of eye-tracking work that systematically considers both early and late measures while investigating the depth of parafoveal processing of morpho-syntactico-semantic processing by skilled readers in a morphologically rich language. Their work manipulated parafoveal previews based on grammatical case expectations generated by Russian readers. In Russian, a flexible word order language, relations such as who did what to whom are marked by the inflectional case at the end of the word and not by the position of the word in a sentence. Thus, the English sentence "Yesterday a girl saw a woman outside of the store" can have a variant where the main verb (saw) precedes both nouns (a girl) and (a woman) as in Figure 1.

Russian readers know that the girl was the agent because the nouns are marked for case at the end of the word, and the verb in past simple tense marks the subject for number and gender such that readers are expecting a subject of the feminine gender even before they read the noun, as shown in Figure 1. Interestingly, Cloze's results revealed that, right after the verb, Russian readers had no expectation for exactly which noun would occur, but they did expect the noun to use the accusative case denoting the patient role for the noun. Russian is a pro-drop language and given a single out-of-context experimental sentence in a noncanonical verb phrase (VP)-noun phrase (NP)-NP word order the number and gender information provided by the main verb seem to be enough for the participants to omit the subject in most cases (93% of all responses: 79% NP_{object}-$NP_{subject}$; 12% adjunct adverbial clause with null subject; 2% adverbial modifier). When the noun in the expected case was displayed in the parafovea (related change: girly → girla) the processing cost over the no-change preview (girla → girla) was greater than the disruption caused by the nonword preview (girlд → girla; the consonant д cannot occur in that location). Thus, readers were most disrupted when they could parafoveally view the noun in the expected form, but upon fixation saw a less expected form. This result would only be observed if readers had begun to interpret the sentence consistent with the sematic information available in the

Figure 1
Preview Conditions in English Glosses With Russian Case Marker Endings

Note. Adapted from "Parafoveal Processing of Inflectional Morphology on Russian Nouns," by A. Stoops and K. Christianson, 2017, *Journal of Cognitive Psychology*, *29*(6), pp. 653–669 (https://doi.org/10.1080/20445911.2017.1310109). Copyright 2017 by Taylor & Francis. See the online article for the color version of this figure.

parafovea and communicated by the last letter of the word, which suggests a very deep level of parafoveal processing.[1]

Based on these results and prior cross-linguistic work that inserted a boundary change in the middle of a longer word, Stoops and Christianson proposed the augmented attention allocation hypothesis, which states that skilled readers process parafoveally visible parts of a longer word at a deeper level than length-controlled upcoming word $n+1$. They tested the hypothesis by inserting the boundary change in the middle of longer words (word n) in nouns (2019) and verbs (2022) and found that the related preview yielded different reading patterns for word $n+1$ versus word n. The related preview caused a processing cost over the no-change preview in GD, go-past, and total time (TT) for both word $n+1$ and word n. However, in word $n+1$, the related preview led to a higher processing cost than both the identical and nonword previews, whereas in word n it seemed to have its own trajectory: higher processing cost than the no-change condition but less cost than the nonword preview in all the eye tracking measures on the postboundary region after the change and on the later, whole-word cumulative measures. Such a scenario is only possible when the letter that was available only parafoveally was processed not only orthographically but also syntactically, thereby activating a structure that clashed with the syntactic structure of the target case marker for the related preview and blocked the integration of the target word in the case of the nonword preview. These results indicate that higher level linguistic information in the parafovea, in this context grammatical case markings, is indeed processed by skilled readers—which was not previously thought to be possible (Stoops & Christianson, 2017, 2019, 2020, 2022). Moreover, participants do seem to have a contextually sensitive attentional allocation ability in the parafovea of the visual field that is augmented for word n processing, since the manipulations within the word were not only more disruptive but seemed to have a completely different processing time course. Importantly, previous studies point to readers' ability to dissociate lexical processing attributed to early stages of word identification (does the word look like a real word in the language?) versus the integration of the words into the sentential context.

The present work addresses gaps in earlier research by examining both word-identification (early, first-pass) and message-level integration (late, second-pass) eye-tracking measures of the target word in grammatical (identical) versus ungrammatical (related and nonword) contexts not yet examined in Russian. Earlier work has examined the case where the preview was a highly expected object versus a grammatical but less preferred identical subject (78% vs. 22% according to Cloze test completions reported in Stoops & Christianson, 2019). This study reused sentences from Stoops and Christianson (2017, 2019) with the VP-NP_1-NP_2 structure, but instead of the first NP, the target word was the second NP: verb subject **object**. As a result, the new target word reversed the Cloze expectations such that the identical target (object) is highly expected (94%), but the related preview (second subject) is not grammatical (0%; see Figure 2).

In this study, and crucially differing from previous studies, the identical no-change preview is not only a better fit, but it also occurs in a syntactically unambiguous context. The target word occurs in a highly expected object position after the main ditransitive verb that requires two arguments, and the subject has been already processed. If the related preview is only processed at the lexico-orthographic level (i.e., "it looks like it is a word in my language"), then it will not differ from the no-change preview. If morphosyntactic information is activated when the letter is processed (even parafoveally) automatically and independently of contextually sensitive attentional control, then the related preview will be read more slowly than the identical preview when the readers fixate the target word, because the morphosyntactic information communicated by a different letter needs to be reconciled with the morphosyntactic information communicated by the letter from the predicted target word. However, if syntactic fit modulates parafoveal and foveal word identification and integration processes, then we could see no difference between related and no-change previews during early word

[1] Stoops and Christianson (2017, 2019) only used feminine nouns of the first declension type because this is the only type in Russian that marks nominative and accusative cases distinctly and unambiguously. Neuter nouns of the second Declension type and feminine nouns of the third Declension type have the same case ending "e" and "soft sign," respectively, in both nominative and accusative cases, and masculine nouns have a null ending in the nominative case and a case marker "a" in the accusative case, thus changing the word length of the preview and the target, which was crucial to control since participants report noticing a flicker when the preview and the target differ in word length even by one letter.

Figure 2

Preview Conditions for the Current Studies in English Glosses With Russian Case Marker Endings

Note. See the online article for the color version of this figure.

identification processes while observing a processing cost for the related preview during later, message-level integration of the target word. To test the augmented allocation of attention hypothesis, the boundary change was inserted before the target noun (Experiment 1) and within the target noun (Experiment 2).

Experiment 1: Word *n* + 1

To investigate the time course of morphosyntactic information activation while the target word is completely in the parafovea (word *n* + 1) we inserted the boundary change between the target word and the preceding noun.

Method

Participants

Forty-three Russian native speakers (22 female, $M_{age} = 28$, range = 22–54), who either visited or resided in the Champaign-Urbana, Illinois area, gave their consent to participate. To determine Russian language proficiency and reading practices, all participants completed the Russian Language Proficiency Assessment Test (Luchkina et al., 2021). All participants were classified as native speakers since they all completed their high school and undergraduate education in Russia. All participants were actively engaged in reading Russian script around the time when they participated in our study. According to the language background questionnaire portion of the assessment (adopted from Language Experience And Proficiency Questionnaire; Marian et al., 2007), all participants read in Russian between 60% and 100% (on average about 1.5 hr a day) of their leisure nonprofessional time. Three participants were excluded from the analyses: two participants reported during a posttest debriefing session (for the debriefing script, see Appendix A in the additional online materials on the Open Science Framework (OSF) page at https://doi.org/10.17605/OSF.IO/7A3Q4) seeing the change manipulation (screen flickering and/or word/letter change), and one participant's eye movements could not be consistently tracked. All participants had normal or corrected-to-normal vision. Participants received $15 compensation. The work was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) and approved by the University of Illinois Institutional Review Board.

Materials and Design

The stimuli were 60 sets of sentences averaging seven words in length (range = 7–12) presented all on one line (see Appendix B for a complete list in the additional online materials on the OSF page at https://doi.org/10.17605/OSF.IO/7A3Q4). The three preview manipulations on the target included an identical (no-change) preview, a morphologically related preview (ungrammatical subject inflectional ending), and a nonword preview (inflection replaced with an illegal consonant) as shown in (1a–c).[2] When the eyes saccaded across the boundary, the preview word was replaced with the target word. That means that participants never fixated the target word with the related and nonword endings in their foveal view. For the related and nonword conditions in (1b–c), while the eyes fixated the first NP (subject), the target word was displayed either with the related or nonword preview. When participant's eyes landed on the target word, the ending was always displayed in the correct object case, as shown in the identical no-change preview in (1a).

(1a) Identical preview – no-change

В кабинете	закрыла	рамка|	**папку**$_{ACC}$	на столе
In the study	blocked	frame$_{NOM}$	**folder**$_{ACC}$	on the table.

(1b) Related preview - ungrammatical inflectional ending

В кабинете	закрыла	рамка|	**папка**$_{NOM}$	на столе
In the study	blocked	frame$_{NOM}$	**folder**$_{NOM}$	on the table.

(1c) Nonword preview - illegal consonant ending

В кабинете	закрыла	рамка|	**папкд**$_{nonword}$	на столе
In the study	blocked	frame$_{NOM}$	**nonword**	on the table.

"In the study a picture frame blocked **a folder** on the table."

[2] Because we used the monospaced Courier New font, the two descending strokes in "д" had the same length in pixels as the one descending stroke in "у"; thus, "д" and "у" were visually more similar to each other than to the nondescender "a." The vertical line (|) indicates the position of the invisible boundary after the first NP.

Short Russian nouns (five characters), all with feminine gender and first declension, served as stimuli for this experiment. They were controlled for word frequency ($M = 123$ per million words, $SD = 78$) and lexeme frequency ($M = 103$, $SD = 83$), according to the online frequency dictionary for Russian (https://www.artint.ru/projects/frqlist/frqlist-en.php). The **VP-NP-NP** sentence frames were reused from Stoops and Christianson (2017), but the same target nouns were put in the second NP position (verb subject object [VS**O**]) in this study (cf., first NPs [V**S**O] in Stoops and Christianson (2017)).

Items were distributed across three lists in a Latin square design. Each participant saw all 60 experimental sentences but only 20 items for each of the three preview conditions. To avoid unintended cross-item syntactic priming (Tooley & Traxler, 2010; Traxler et al., 2014) by presenting only sentences in the one noncanonical word order (VSO), filler sentences with subject verb object (120 sentences) and object verb subject (additional 120 sentences) were also used as fillers in this experiment along with the 60 experimental sentences from Experiment 2. Participants read a total of 360 sentences. To avoid lexical priming effects, none of the participants who took part in this experiment participated in the experiment reported in Stoops and Christianson (2017) that used the same sentences.

Norming Studies

Semantic Plausibility. Plausibility of the sentential arguments as both subjects and objects for these sentences was assessed and reported in Stoops and Christianson (2017). Experimental items had both a plausibility rating higher than 3 and an equal plausibility rating for both nouns with a mean plausibility score of 4.6 ($SD = 0.6$) on the 7-point scale. Results confirmed that the semantic relationship between the arguments in the experimental items was not affected by the noncanonical word order in the sentence frame.

Semantic Predictability. To assess the semantic predictability of individual experimental lexical items, a modified version of a traditional Cloze test (Taylor, 1953) was used. Thirty additional participants finished 60 experimental sentence beginnings which retained the exact wording of the experimental sentences up to the second argument (В кабинете закрыла рамка …/ In the study a picture frame blocked$_{\text{Past3rdPersonSingularFeminine}}$ …). Participants were asked to complete the sentence using as many words as they deemed necessary to create a complete sentence that made sense to them.

No exact prediction for the lexical items used in the experimental sentences was made (0% completions).

Syntactic Predictability. That same Cloze test allowed us to compute the syntactic predictability of the experimental items by examining the grammatical properties of the words participants used to finish sentence beginnings. Analyses of the participants' responses ($N = 1{,}800$) confirmed that the accusative case was the most expected (94%) syntactic continuation. The rest of the answers used adjunct modifiers for the first NP (6%). The Cloze test also confirmed the illegality of the morphological preview as none of the answers used the feminine, masculine, or neutral nouns in their nominative case (0%).

Apparatus

Eye movements were recorded with an SR Research Eyelink 1000 eye tracker set to a 1,000 Hz sampling rate, with an average spatial resolution of <0.01°. The text was displayed in 14-point Courier New monospace font. Participants were seated 72.5 cm away from a 20-in. LCD monitor with a refresh rate of 150 Hz. At this distance, approximately 3.03 characters subtend 1° of visual angle. Given the sampling rate of the eye tracker and the refresh rate of the monitor, the display change occurred on average within 4 ms. Head movements were minimized with chin and headrests. A drift correction recalibration procedure would initiate automatically throughout the experiment to ensure that average spatial resolution would not go above 0.01°. Although viewing was binocular, eye movements were recorded only from the right eye.

Procedure

Participants' eye movements were calibrated using a 9-point calibration procedure (max variance = 0.25°). After a 12-item practice session, each trial began with a gaze trigger, which consisted of a black circle presented in the position of the first character of the text. Once a stable fixation was detected on the gaze trigger, the sentence was presented in full. Participants pressed a button on a standard game controller to indicate that they had finished reading the sentence. At this point, the sentence disappeared. In 25% of the trials, a question about the content of the sentence appeared, which participants answered with a mean accuracy of 98% by pressing the corresponding button on the controller. Sentences were presented in a random order for each participant. Participants had the option to take a break after every 100 sentences. The entire experiment lasted on average 90 min. The coded paradigm is available upon request, and the data and analytical scripts used in the experiment are available at https://doi.org/10.17605/OSF.IO/7A3Q4.

Results

Measures

Analyses included five major durational measures and three probability measures associated with early word identification stages (early measures) and integration of the target word into the syntactic structure of the sentence (late measures). Two additional measures were included to probe the oculomotor control, namely launch position and launch distance, which are modulated by low-level orthographic variables like, for example, word length.[3] Early measures included: first fixation (FF) launch distance—the length of the initial saccade into the word; FF landing position—the position of the eyes within the word during the FF; single fixation (SF) duration—the duration of the fixation on the target word when only one first-pass fixation on the target word was recorded; FF duration—the duration of the FF on the target word regardless of the number of first-pass fixations; and GD—the sum of all fist-pass fixations on the target word before leaving the word in either direction. Late measures included: go-past time (GPT)—time spent reading the target word and any words prior to that after initially entering the target region until the eyes leave the target region to the right; and TT—the sum of all fixations on the target word, including refixations after

[3] We thank Raymond Bertram for this recommendation to include these two measures as additional benchmarks for comparisons with other cross-linguistic studies.

the eyes have moved to other words in the sentence. Probability measures included the probability of skipping the target during first-pass reading (FP skipping); regressions out of the target word to the earlier parts of the sentence; and regressions in to the target word from words later in the sentence.

This design allows us to test lexical and syntactic processing as distinguished between early and late measures by examining two key comparisons: one being a technical control and one testing the processing stages. The technical control effect is obtained when the nonword preview elicits longer fixation durations than the no-change preview. The demonstration of this identity effect is a crucial control in this paradigm to show that the parafoveal manipulation is indeed working, and the readers are extracting parafoveal information. The second contrast, comparing no-change and related previews across early and late measures, allows us to clearly differentiate between lexical and syntactic processing. If skilled readers process linguistic information parafoveally and integrate it into the sentence in an automatic fashion, then the related preview will be read more slowly than no-change previews as soon as such information is integrated, possibly in both early and late measures as we have seen in Stoops and Christianson (2019). If syntactic fit modulates parafoveal processing, readers might only be processing the ungrammatical second subject in the preview at the level of lexical familiarity (i.e., "yes this word looks like a word in my language"). Given that the root of the preview is the same as the root of the target word, they will process the orthographic features of the wordform regardless of whether they process the role this word plays in the sentence parafoveally. Under such a scenario, related previews should not be different from no-change previews. However, if the morphosyntactic case communicated by the related preview is processed parafoveally, it should interfere with the integration of the target case marker. The eye-tracking measure that reveals this cost for the related over the identical preview will indicate the temporal nature of and processing stage at which such information is integrated. Specifically, by changing the related preview to be ungrammatical and therefore not expected, this study is the first to test whether the syntactic fit is a contextual characteristic accessible to readers when performing preprocessing in the parafovea.

Data Exclusion Criteria. Trials were removed if the target word was skipped and never fixated (15% of trials). Analyses of deleted trials revealed no differences in skipping rates between the experimental conditions.[4] Trials were eliminated if the participant blinked immediately before or after fixating the target word (4%) or if the display change completed more than 10 ms into a fixation (1%) or was triggered by a saccade that initially landed to the left of the boundary (3%). Fixations shorter than 80 ms and longer than 3 *SD*s from each participant's conditional mean were excluded from the analyses (3%). Based on the parameters of our experiment, the fovea consisted of three characters ahead of fixation and three characters behind. The case marking on the target word when viewed from the pretarget word thus fell within the parafovea. As a result, we conclude that the effects reported here can be attributed to parafoveal and not foveal processing. Additionally, to ensure that the target case marking was available in the parafovea prior to the eyes crossing the boundary change, we planned to exclude any trial that contained fixations originating from the main verb, word $n-2$ relative to the target word, but saccade launch site analyses revealed no such trials. All data exclusions left 1,252 trials available for analyses. See power considerations in Appendix A in the additional online materials on the OSF page at https://doi.org/10.17605/OSF.IO/7A3Q4.

Analyses

Fixations (FF, SF, GD, GPT, TT) and fixation probabilities (FP skipping, regressions in and out) for the target word $n+1$, the pretarget word n, and the posttarget word $n+2$ were analyzed. No significant differences were obtained for words n or $n+2$; therefore, the results reported below reflect eye-movement measures only for the target word $n+1$. Condition means and standard errors for the reading measures are provided in Table 1 and Figure 3 with underlying distributions for the two critical early (SF) and later (GPT) measures. Since none of the fixation probability and oculomotor models yield any significant differences between preview manipulations, these results are not discussed further. Plots in Figure 3 were created using ggplot2 and gghalves packages in R (Allen et al., 2019; van Langen, 2020).

We fit both frequentist and Bayesian models to the eye-movement data. For the Bayesian models, we used the data reported by Stoops and Christianson (2017) as priors to inform posterior distributions of effect sizes and intercepts in this study. Since these eye movement data do not follow a Gaussian distribution and instead follow a gamma distribution, we analyzed raw data and linked both generalized linear mixed-effect models and Bayesian models to gamma distributions for the reading measures, as recommended for skewed data (Lo & Andrews, 2015). Reading time measures were analyzed using both generalized linear mixed-effect models and Bayesian hierarchical models with identical fixed and random effects structures, using both the lme4 package (Version 1.1-21; Bates et al., 2020) and brms package (Bürkner, 2017) in R (Version 3.6.1; R Core Team, 2019).

We used treatment contrasts for our preview factor such that the intercept corresponds to the mean of the baseline condition and the contrast coefficients indicate how far or close the means of the experimental conditions are from that baseline. Two separate sets of models with different baseline levels for the preview factor were fit to the data to allow for maximal contrast comparisons. The first compared the nonword baseline to identical and related previews. The second compared the identical baseline to related and nonword previews through releveling following Pedhazur and Kerlinger (1982). A single model with the most complex random effects structure (random intercepts for participants and items) that converged for all measures was retained following Barr et al. (2013). To allow for a comparison with previous cross-linguistic findings (e.g., English: Dann et al., 2021; Finnish: Hyönä et al., 2018, 2021; Uighur: Yan et al., 2014), the two variables of oculomotor control were mean-centered in all the models. Models with interactions between initial landing position, saccade launch distance, and preview are not considered here since no significant

[4] While skipping rates observed in this experiment are within the ranges reported in the prior literature (e.g., Cutter et al., 2020; Rayner et al., 2011; Veldre et al., 2020), they are higher than the skipping rates reported in the previous work with these sentences (Stoops & Christianson, 2017). We attribute the observed pattern to low-level orthographic factors such as word length. The target word in the earlier work was preceded by a longer (7+ character) word, while the target word in this experiment occurs after short 5-character nouns.

Table 1

Mean (Standard Error) for Reading Measures on the Target Across Conditions With Related Condition Compared Against Identical and Nonword Baselines

Measure	Preview conditions: Identical	Related	Nonword
Word *n* initial fixation launch distance and landing position (in characters)			
FF launch distance	3.43 (0.07)	3.53 (0.07)	3.54 (0.07)
FF landing position	1.26 (0.06)	1.35 (0.07)	1.34 (0.07)
Fixation duration			
FF	263 (5.78)	266 (5.11)	268 (5.31)
SF	277 (7.24)	284 (7.15)	**297 (7.11)**
GD	310 (7.74)	314 (7.14)	**326 (7.14)**
GPT	442 (14.99)[a]	**478 (18.08)**	**482 (15.89)**
TT	548 (17.39)[a]	**577 (16.45)**	**584 (18.92)**
Fixation probability			
FP skipping	.02 (0.01)	.04 (0.01)	.04 (0.01)
Regressions out	.26 (0.01)	.27 (0.01)	.25 (0.01)
Regressions in	.28 (0.01)	.25 (0.01)	.24 (0.01)

Note. Bolded values indicate both significant ($p < .05$) effects in frequentist models and/or directional Bayes factors with at least 95% probability. Bolded values for the nonword condition indicate significant difference from the identical condition. FF = first fixation; SF = single fixation; GD = gaze duration; GPT = go-past time; TT = total time; FP = first pass.
[a] Difference between the baseline (identical or nonword) and the related conditions.

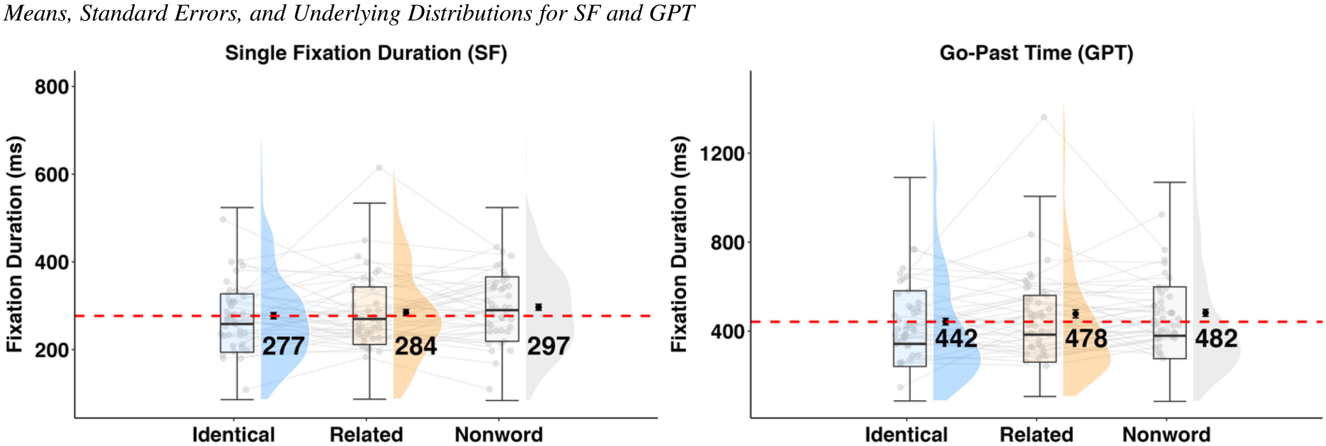
interaction effects were observed. Models revealed no main effect of initial landing position, so the final models all included two fixed effects of saccade launch distance and preview with random intercepts for participants and items. The same model with additional random slopes for participants and items did not converge for FF, SF, and GD. For this reason, only random intercepts were used when fitting the Bayesian models to the data. However, as a noise reduction technique, for the two theoretically interesting key late measures—go-past and TT of the target word, we report the frequentist and Bayesian models with random slopes of preview and random intercepts by participants and by items. While both simpler and more complex models yielded the same results, the model comparisons showed that this model with more complex random structure was a better fit (smaller Akaike information criterion for GPT: $14{,}530_{\text{simpler model}} > 14{,}502_{\text{more complex model}}$; TT: $14{,}970_{\text{simpler model}} > 14{,}958_{\text{more complex model}}$). See Table 2 for the summary of models for fixation durations and probability measures.

Priors were set to normal distributions for the intercept and each of the effect parameters. These models were fit using the same fixed effects structure and random effects structure with intercepts by item and participant and were run for 10,000 iterations (5,000 warmup/burn-in) with eight cores for computing efficiency. All models successfully converged. Posterior distributions illustrated the likelihood of effects based on 95% credible interval (CrI) zero-crossings (see Figure 4). To obtain the probability of the preview benefit versus cost, we ran directional hypothesis tests (directional Bayes factor [BF_{DIR}]) using the hypothesis function in brms. These BF_{DIR}s, along with the CrIs from model-generated posterior distributions are listed in Table 3. The corresponding BF_{DIR} value indicates how much more likely this effect is versus the effect in the opposite direction.

The significant main effect for the initial saccade launch distance was observed in the first-pass measures (FF, SF, and GD). The fixation durations were shorter following longer incoming saccades: all $|t|s > 2.70$. This pattern has been observed cross-linguistically (e.g., Finnish: Hyönä et al., 2018, 2021; Uighur: Yan et al., 2014). Recently, in line with the evidence that visual acuity modulates preview benefit effects (Kliegl et al., 2013 but cf. Miellet et al., 2009), Dann et al. (2021) found that, in English, the effect for morphologically related complex words was larger at closer saccade launch distance when compared with the baseline condition. Crucially, we controlled for such visual factors as word length for the preboundary and postboundary regions in this study. Additionally, unlike Finnish and Uighur studies that manipulated the morphological complexity of their items and compared morphologically complex and monomorphemic targets, we used only morphologically complex items. As a result, we do not find

Figure 3

Means, Standard Errors, and Underlying Distributions for SF and GPT



Note. Dashed line is set to the identical mean. Numbers under the dashed line and black dots correspond to the conditional means and point ranges to standard errors, respectively. Box plot error bars represent 1st and 4th quartiles for the distribution of individual means for each participant across each condition (gray dots connected with gray lines). SF = single fixation; GPT = go-past time. See the online article for the color version of this figure.

Table 2

Results of the (Generalized) LME Models for the Untransformed Fixation Duration, Fixation Probability Measures on Word n + 1 With 95% Effect Size CrI and BF_{DIR}

Measure	Contrast	*b*	*SE*	*t/z*	BF_{DIR}	Posterior probability
FF	Intercept	**295.51**	**11.52**	**25.65*****		
	Identical versus nonword	−10.96	6.20	−1.78	9.13	.90
	Related versus nonword	−3.69	6.60	−0.56	2.13	.68
	Related versus identical	7.27	6.62	1.10	3.69	.79
	FF launch site	**−6.15**	**2.08**	**−2.95****		
SF	Intercept	**337.99**	**15.25**	**22.17*****		
	Identical versus nonword	**−18.10**	**7.36**	**−2.46***	**124.79**	**.99**
	Related versus nonword	−11.48	7.58	−1.51	14.03	.93
	Related versus identical	6.63	7.35	0.90	3.82	.79
	FF launch site	**−8.65**	**2.59**	**−3.34*****		
GD	Intercept	**296.79**	**12.42**	**23.89*****		
	Identical versus nonword	**−16.64**	**7.59**	**−2.19***	**26.25**	**.96**
	Related versus nonword	−5.82	7.79	−0.75	4.45	.82
	Related versus identical	10.82	7.60	1.42	4.05	.81
	FF launch site	**8.44**	**3.57**	**2.37***		
	Second-pass reading measures modeled with random interaction structure for preview, subject, and item intercepts and slopes (measure ~ preview + launch + [preview|subject] + [preview|item])					
GPT	Intercept	**472.83**	**16.83**	**28.100*****		
	Identical versus nonword	**−46.07**	**16.34**	**−2.82****	**97.52**	**.99**
	Related versus nonword	−4.85	14.17	−0.34	1.66	.62
	Related versus identical	**49.50**	**13.84**	**3.58*****	**46.06**	**.98**
	FF launch site	6.64	5.58	1.19		
TT	Intercept	**580.78**	**15.85**	**36.64*****		
	Identical versus nonword	**−50.68**	**13.92**	**−3.64*****	**39**	**.98**
	Related versus nonword	6.16	13.60	−0.45	2.45	.71
	Related versus identical	**−44.11**	**13.00**	**−3.39*****	11.43	.92
	FF launch site	7.73	6.36	1..22		

Note. Bolded values indicate statistically significant contrast differences. LME = linear mixed effects; CrI = credible intervals; BF_{DIR} = directional Bayes factor; FF = first fixation; SF = single fixation; GD = gaze duration; GPT = go-past time; TT = total time.
* $p < .05$. ** $p < .01$. *** $p < .001$.

evidence for the modulation of preview effects by either initial saccade launch distance or initial landing position.

The identical preview was read faster than the nonword preview in early (SF, GD) and late (GPT, TT) measures (all *t*s > 2.19), and all directional Bayes factors indicate either strong (>10) or very strong (>30) directional likelihood for this nonword preview cost. Bayesian posterior probabilities quite consistently range between .99 and 1 for all measures except for GD (.96), revealing that the identical preview is more likely to be read faster when compared to the nonword previews.[5] Since this was our technical control condition, it reveals that the paradigm worked successfully as skilled readers were disrupted by the nonword preview in both early and later reading measures.

The ungrammatical morphologically related preview yielded longer GPT than the identical preview (identical = 442 ms, related = 478 ms). This was found in both frequentist and Bayesian models. Thus, we can safely conclude that the second nominative case marker that was only visible while the eyes fixated the preceding word induced more rereading for **earlier parts** within the sentences. This contrasts with earlier work on Russian parafoveal effects (Stoops & Christianson, 2017), suggesting the syntactic fit of the parafoveally fixated material, which this study is the first to investigate, influences integrative stages of processing.

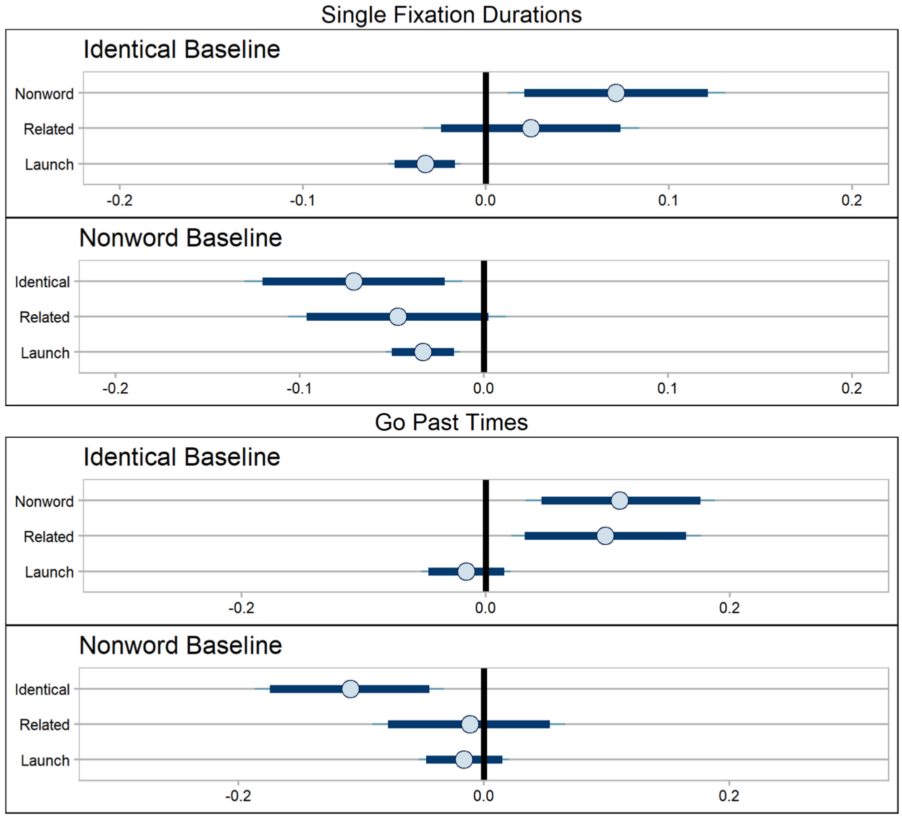
Experiment 1: Interim Conclusion

The pattern of results observed in this study contrasts with those observed in Stoops and Christianson (2017). In the earlier study, there were no differences observed between identical and nonword previews in any of the measures, while related previews elicited longer reading times in GD, GPT, and TT compared with the identical baseline. In the current study, we observed a nonword preview cost compared with the identical baseline in SF, GD, GPT, and TT, while related previews yielded a cost over identical previews in go-past and TT. We believe that this discrepancy comes from an increased focus on parafoveal lexical retrieval in the current study by virtue of not having to focus on morphosyntactic analysis, as the target word in this experiment was (largely) unambiguous. Recall that in this experiment, the **VP-NP-NP** sentence frames from Stoops and Christianson (2017) were reused, but the target nouns here were the second NPs (VSO), rather than the first NPs in Stoops and Christianson (2017)). While in the earlier studies the target word could be either subject or object, in this study the target word has to be an object, as evidenced by our Cloze norming. As such, the lack of morphosyntactic ambiguity (i.e., the near-ceiling predictability of the syntactic frame) may have magnified the importance of lexical access, rather than syntactic fit. Initial deeper lexical processing may have also generated a higher level of lexical uncertainty in the case of nonwords and, with that, an increased tendency to reinspect the target word. In sum, for the related preview, a real word with poor

[5] The posterior probability of .99 corresponds to constructing 99% CrI; moreover the directional 99% CrI corresponds to 99 + [(100 − 99)/2]% = 99.5% of posterior estimates show this effect.

Figure 4

Posterior Effect Estimates From the Bayesian Linear Mixed-Effect Model of Single Fixation and Go-Past Durations



Note. Black lines represent a posterior estimate of zero. In each posterior distribution, the light blue (light gray) circle represents the mean posterior estimate and the dark blue (dark gray) line represents the 95% CrI, in which 95% of posterior estimates occur. CrI = credible interval. See the online article for the color version of this figure.

syntactic fit, morpho-syntactico-semantic information triggered more rereading of earlier parts of the sentence.[6]

Experiment 2: Word *n*

To test the predictions of the augmented attention allocation hypothesis and to see how the time course of morphosyntactic information activation changes when participants have already fixated the target word (word *n*), we inserted the boundary change within a longer 10+ character noun keeping the syntactic structure the same as in the Experiment 1.

Method

Participants

The participants from Experiment 1 were the same as in Experiment 2 since data for both experiments were collected in the same session.

Materials and Design

The stimuli were 60 sets of sentences averaging seven words in length in which long Russian nouns (range = 10–19 characters, $M = 12.9$ characters) were embedded as targets. Targets were balanced for word ($M = 323$ per million, $SD = 85$) and lexeme ($M = 295$ per million, $SD = 76$) frequencies. The invisible boundary was always between the fifth and sixth character from the end of the target word. This resulted in a five-character postboundary region, compared to the six-character postboundary length used in Experiment 1 (one space + five letters). Some of the words had prefixes in addition to the word-final case-marking, but the boundary change was always located in the word stem preceding the case-marker in these multimorphemic items.

The case-marking suffix appeared in one of three preview conditions (identical, morphologically related, nonword), as in Experiment 1. An example of the preview manipulations for the target word in the two syntactic positions is in (2a–2b). The vertical lines indicate the location of the boundary. When the eyes crossed the boundary (| in 2 below), which was invisible to the participants, the preview character was replaced with the correct target character.

[6] We thank Raymond Bertram for helping us phrase this interpretation during earlier versions of this article.

Table 3
Word N Mean (Standard Error) for Reading Measures on the Target ROI With Related Condition Compared Against Identical and Nonword Baselines

Measure	Preview conditions		
	Identical	Related	Nonword
Preboundary region (visible preview)			
FF	248 (4.06)	240 (4.17)	240 (4.17)
SF	248 (4.76)	247 (5.16)	250 (4.86)
GD	299 (7.29)	303 (7.74)	300 (7.49)
GPT	393 (17.25)	425 (26.55)	413 (23.64)
Regressions out	.15 (.02)	.12 (.02)	.09 (.02)
Regressions in	.27 (.02)	.31 (.02)	.28 (.02)
Postboundary region (after the change)			
FF launch distance	3.38 (0.15)	3.34 (0.16)	3.20 (0.13)
FF landing position	2.31 (0.11)	2.23 (0.10)	2.32 (0.10)
FF	248 (4.72)	239 (4.94)	240 (4.76)
SF	224 (5.30)	**226 (5.56)**	**244 (5.60)**[a]
GD	252 (6.41)	258 (6.16)	**268 (5.80)**
GPT	325 (19.5)[a]	**383 (17.9)**	**370 (13.9)**
TT	348 (18.20)[a]	**415 (21.30)**	**403 (19.00)**
FP skips	.15 (.02)	.15 (.02)	.12 (.02)
Regressions out	.14 (.04)	.20 (.04)	.20 (.04)
Regressions in	.17 (.04)	.25 (.04)	.21 (.04)
Whole word			
GD	443 (10.60)	463 (10.60)	**475 (11.90)**
GPT	461 (10.59)[a]	**500 (11.11)**	**514 (11.82)**
TT	716 (20.9)[a]	**838 (22.70)**	**829 (24.60)**
Regressions out	.14 (.02)	.13 (.02)	.14 (.02)
Regressions in	.24 (.01)	.28 (.01)	.25 (.01)

Note. Bolded values indicate both significant ($p < .05$) effects in frequentist models and/or directional Bayes factors with at least 95% probability. Bolded values for the identical condition indicate significant difference from the nonword condition. ROI = region of interest; FF = first fixation; SF = single fixation; GD = gaze duration; GPT = go-past time; TT = total time.
[a] Difference between the baseline (identical or nonword) and the related conditions.

(2a) Identical preview - same case change

На вокзале спросила собеседница **путешестве|нницу** о расписании поездов.

At the railway station asked interlocutor$_{NOM}$ **traveler$_{ACC}$** about the train schedule.

(2b) Related preview - ungrammatical inflectional ending

На вокзале спросила собеседница **путешестве|нница** о расписании поездов.

At the railway station asked interlocutor$_{NOM}$ **traveler$_{NOM}$** about the train schedule.

(2c) Nonword preview - illegal consonant ending

На вокзале спросила собеседница **путешестве|нницд** о расписании поездов.

At the railway station asked interlocutor$_{NOM}$ **non-word** about the train schedule.

"At the railway station an interlocutor asked the traveler about the train schedule."

The **VP-NP-NP** sentence frames were reused from Stoops and Christianson (2019), but the target nouns were the second NPs (VSO) in this study (cf. first NPs (VSO) in Stoops and Christianson (2019)). Items were distributed across three lists in a Latin square design. Each participant saw all 60 experimental sentences but only 20 items for each of the three preview conditions. Participants read these sentences during the same reading session as the sentences for Experiment 1. None of the participants who took part in this experiment participated in the experiment reported in Stoops and Christianson (2019) that used the same sentences.

Norming Studies

Semantic Plausibility. We used the same procedure as in the Experiment 1. The plausibility of the sentential arguments as both subjects and objects for these sentences was assessed and reported in Stoops and Christianson (2019). The norming studies confirmed that both nouns were equally plausible (mean plausibility 4.9, $SD = 0.5$) as subjects and objects in the experimental sentence frames. Plausibility ratings obtained from the two norming studies did not differ significantly ($p > .1$). Results confirmed that the semantic relationship between the arguments in the experimental items was not affected by the noncanonical word order in the sentence frame.

Semantic Predictability. We used the same procedure as in the Experiment 1. No exact prediction for the lexical items used in the experimental sentences was made (0% completions).

Syntactic Predictability. We used the same procedure as in the Experiment 1. Analyses of the participants' responses ($N = 1,800$) confirmed that the accusative case was the most expected (94%) syntactic continuation. The rest of the answers used adjunct modifiers for the first NP (6%). The Cloze test also confirmed the illegality of the morphological preview as none of the answers used the feminine, masculine, or neuter nominative case (0%).

Apparatus

Same as in Experiment 1.

Procedure

Same as in Experiment 1.

Results

Measures

Same as in the Experiment 1. First-pass (early) measures were recorded for preboundary and postboundary regions of interest for the target word. Additionally, second-pass (later) measures for the postboundary region and the target word are reported for the between-experiment comparison of the later measures on the length-controlled regions. For the launch and landing site measures, we chose the postboundary region as a target.

Data Exclusion Criteria. Based on the parameters of our experiment, the fovea consisted of three characters ahead of fixation and three characters behind. The case marking on the postboundary region when viewed from the preboundary region thus fell within the parafovea. As a result, we conclude that the effects reported here can be attributed to parafoveal and not foveal processing. Additionally, to ensure that the target case-marking was available in the parafovea prior to the eyes crossing the boundary, we intended to exclude any trial where participants skipped the preboundary region but observed zero such instances. Additionally, same criteria as in Experiment 1 were used to deal with blinks, outliers, and boundary change-related modulations. These exclusions left 2,160 trials available for analyses. See power considerations in Appendix A in the additional online materials on the OSF page at https://doi.org/10.17605/OSF.IO/7A3Q4. The data and analytical scripts used in the experiment are available at https://doi.org/10.17605/OSF.IO/7A3Q4.

Condition means and standard errors for the reading measures are provided in Table 3 and, as illustration, Figure 5 with underlying distributions for the two critical measures (early postboundary SF and a later whole word TT measures).

Analyses

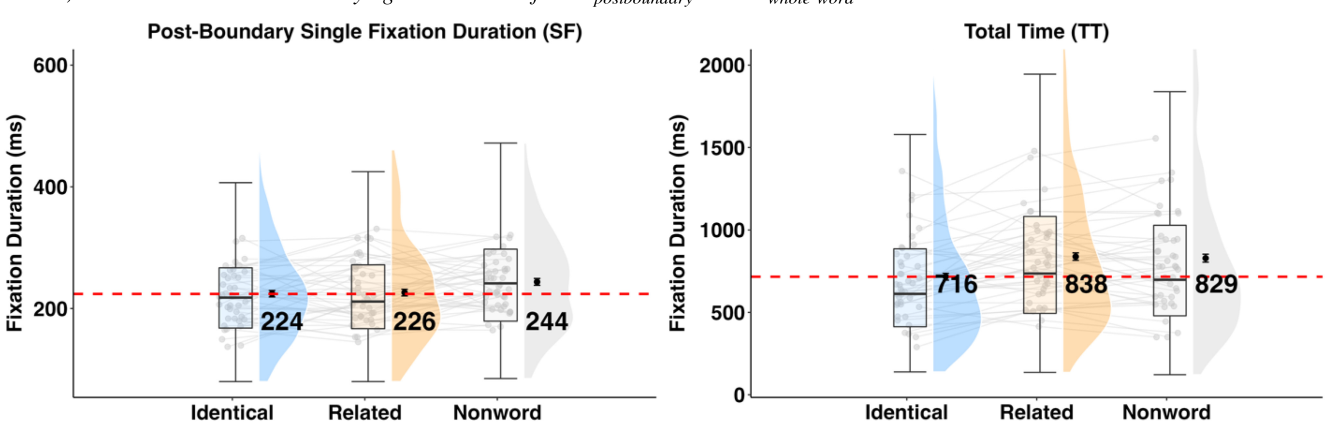
Data and model selection procedures were the same as in Experiment 1. We used the data reported by Stoops and Christianson (2019) as priors for Bayesian analyses to inform posterior distributions of effect sizes and intercepts in this study. See Table 4 for the summary of models for fixation durations and probability measures. Fixations (FF, SF, GD) and fixation probabilities (regressions in and out) for the preboundary region were analyzed but did not yield any sensitivity to the experimental manipulations and were not reported. Postboundary and whole-word regression in and out probability models were not reported, as they were insensitive to experimental manipulations. We discuss the means and the models for the postboundary GPT and TT measures in a later section but report them in Tables 3 and 4 to reduce the number of tables in the manuscript. For the three theoretically interesting key early and late measures—postboundary SF duration, whole word GPT, and TT we report the frequentist and Bayesian models with random slopes of preview and random intercepts by subject and item as they were a better fit according to the model comparison metrics (Akaike information criterion for $SF_{postboundary}$: $7{,}240_{simpler\ model} > 7{,}200_{more\ complex\ model}$; $GPT_{whole\ word}$: $16{,}567_{simpler\ model} > 16{,}561_{more\ complex\ model}$; $TT_{whole\ word}$: $18{,}010_{simpler\ model} > 17{,}984_{more\ complex\ model}$; Figure 6).

Two first-pass measures in the postboundary region (SF and GD) and one late measure (whole word TT) yielded significant main effects for the initial saccade launch distance. Models with Launch × Preview interaction showed null effects and were not reported. Preview manipulation did not modulate launch or landing sites in Experiment 2 analogous to what we observed in Experiment 1 for the same reason: all stimuli consisted of morphologically complex items ((prefix) + root + suffix). Longer saccades resulted in longer initial fixations on the postboundary region but less total viewing of the whole word. This last result is different from the pattern observed in Experiment 1 and is driven largely by the word length. The words in Experiment 2 are longer and the initial fixations into the target postboundary region were all launched from within the target word. When people landed on the preferred viewing position closer to the beginning of the longer word they were able to process the target word with less rereading. While visual acuity in reading Russian script between and within words behaved quite similarly to what has been reported cross-linguistically in English (Dann et al., 2021), Finnish (Hyönä et al., 2018, 2021), and Uighur (Yan et al., 2014), more studies are needed to better understand attentional processes within long words cross-linguistically.

The results for the identical versus nonword contrast indicated that the paradigm worked as expected as they mirror the results observed in

Figure 5

Means, Standard Errors and Underlying Distributions for $SF_{postboundary}$ and $TT_{whole\ word}$



Note. Dashed line is set to the identical mean. Numbers under the dashed line and black dots correspond to the conditional means and point ranges to standard errors, respectively. SF = single fixation; TT = total time. See the online article for the color version of this figure.

Table 4

Results of the (Generalized) LME Models for the Untransformed Fixation Duration, Fixation Probability Measures With 95% Effect Size CrI, and BF_{DIR}

Measure	Contrast	*b*	*SE*	*t/z*	BF_{DIR}	Posterior probability
	Postboundary region (after the change)					
FF	Intercept	**189.81**	**33.52**	**5.66*****		
	Identical versus nonword	−10.21	18.08	−0.57	8.38	.33
	Related versus nonword	−1.33	17.66	−0.08	1.07	.11
	Related versus identical	11.54	18.02	0.64	8.78	.42
	FF launch site	12.90	9.20	1.40		
GD	Intercept	**249.45**	**11.89**	**20.99*****		
	Identical versus nonword	**−21.81**	**7.26**	**−3.01****	**223.72**	**1**
	Related versus nonword	**−13.62**	**6.74**	**−2.02***	4.05	.80
	Related versus identical	8.19	7.12	1.15	9.41	.90
	FF launch site	**5.04**	**2.08**	**2.42***		
	Key reading measures modeled with random interaction structure for preview, subject, and item intercepts and slopes (measure ~ preview + launch + [preview|subject] + [preview|item])					
	Postboundary region (after the change)					
SF	Intercept	**222.02**	**11.92**	**18.62*****		
	Identical versus nonword	*−21.30*	*11.65*	*−1.83^*	**453.55**	**1**
	Related versus nonword	−11.09	12.24	−0.91	**97.52**	**.99**
	Related versus identical	8.04	10.06	0.80	2.1	.68
	FF launch site	**6.43**	**2.23**	**2.81****		
	Whole word					
GPT	Intercept	**539.00**	**20.89**	**25.80*****		
	Identical versus nonword	**−57.02**	**14.40**	**−3.96*****	**823**	**1**
	Related versus nonword	−20.32	14.62	−1.39	3.81	.79
	Related versus identical	**36.77**	**11.83**	**3.11****	**74**	**.99**
	FF launch site	−2.09	3.64	−0.58		
TT	Intercept	**906.29**	**14.70**	**61.67*****		
	Identical versus nonword	**−106.90**	**17.57**	**−6.08*****	**9,999**	**1**
	Related versus nonword	8.17	17.03	0.48	4.49	.82
	Related versus identical	**114.94**	**13.01**	**8.83*****	**Infinity**	**1**
	FF launch site	**−17.67**	**5.63**	**−3.14****		

Note. Bolded values indicate statistically significant contrast differences. Values in italic denote marginally significant effects. LME = linear mixed effects; CrI = credible intervals; BF_{DIR} = directional Bayes factor; FF = first fixation; GD = gaze duration; SF = single fixation; GPT = go-past time; TT = total time.
^ $p < .1$. * $p < .05$. ** $p < .01$. *** $p < .001$.

Experiment 1 and are quite consistent with what was observed previously for identical versus nonword comparison for Russian word *n* (Stoops & Christianson, 2019). Just as in Experiment 1, the ungrammatical morphologically related preview was read slower than the identical preview in all later measures for both postboundary and whole word regions, and these results are identical in the models with more complex random structure. Additionally, we see two new effects not observed on the word $n+1$ manipulation in Experiment 1: a lexicality effect in the relatively early measures and a morpho-syntactico-semantic effect in the late measure of TT. First, participants initially read the postboundary region after the change with the related preview faster than for the nonword preview ($SF_{postboundary}$), same as no-change preview in this measure as seen in the Bayesian model with the most complex random effects structure. Second, participants not only spent more time rereading earlier parts of the sentence following a related preview in Experiment 2 as they did in Experiment 1; they also fixated the target word longer overall.

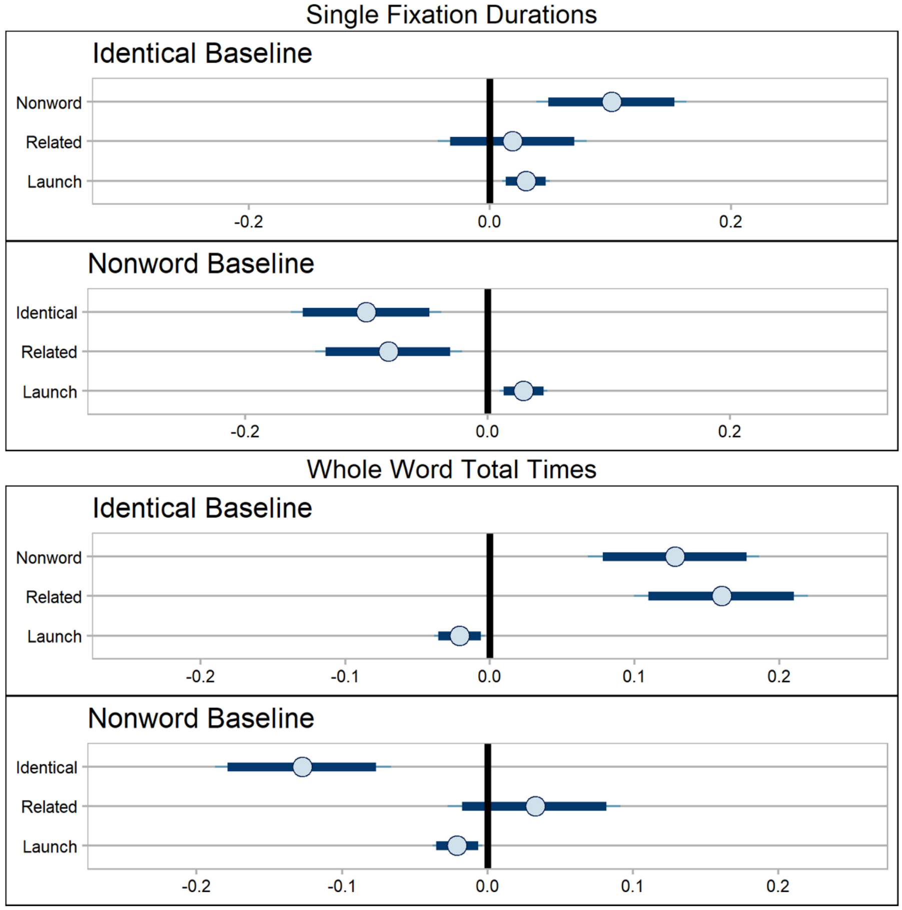
Augmented Allocation of Attention: Comparison of the Preview Effects Between Experiment 1 and Experiment 2

The augmented allocation of attention hypothesis states that once skilled readers fixate the longer word, they recognize it more efficiently compared to two smaller words due to there being fewer lexical competitors. To directly test this hypothesis, we ran another series of generalized linear mixed effects models with the Preview × Experiment interaction term with random slopes by preview, experiment, and their interaction and random intercepts by participant and by item. Two comparisons have been made: word $n+1$ versus character length controlled postboundary region of word *n* (Table 5) and to compare word level processing for later measures word $n+1$ versus word *n* (Table 6). Based on previous work in Russian, skilled readers do seem to have deeper processing of the parafoveal portions of the longer words once they fixate the beginning of the words (Stoops & Christianson, 2019). Given that this is the first study using ungrammatical related previews, we might see distinct word integration stages compared to what we might expect with highly predictable related previews. On the other hand, in the case of unambiguous context here, the ungrammatical related previews might elicit a similar preview cost compared with the identical preview in the later measures for both word *n* and word $n+1$.

Launch distance for the data combined from both experiments affected early and late measures differently. Longer saccades into the target region yielded shorter FF but longer GD for word

Figure 6

Posterior Effect Estimates From the Bayesian Linear Mixed-Effect Model of Fixation Durations



Note. Black line represents an effect of zero. In each posterior distribution, the light blue (light gray) circle represents the mean effect estimate and the dark blue (dark gray) line represents the 95% CrI. CrI = credible interval. See the online article for the color version of this figure.

$n+1$ and word n postboundary region. In the FF duration, the effect is negative; in other words, the farther the launch site, the shorter the FF duration. On the other hand, in GD the effect is positive: the farther the launch site, the longer the GD. The latter effect is more readily interpretable: relatively little parafoveal processing can be done from a far distance, resulting in longer GDs. The former effect may be interpreted by assuming that in response to a far launch site, readers are likely to program a refixation in the word, which would then result in a short initial fixation. It is known that fixations followed by a refixation on a word tend to be short (e.g., Vitu et al., 2001).[7]

All three previews reveal significant differences across the two experiments. Participants read the five-letter words (Experiment 1) slower than the five-character region that is part of a longer word (Experiment 2): in FF, the nonword preview was read about 28 ms slower as part of word $n+1$ than within the word n, while 8 ms and 12 ms differences in the same direction for identical and related were not significant; SF and GD indicate an average of 60 ms advantage for the word n; for the GPT measure the advantage doubles only for the manipulated conditions (related = 100 ms and nonword = 130 ms), and this advantage almost quadruples for TT ($TT_{postboundary}$: identical = 215 ms, related = 185 ms, nonword = 206 ms).

However, when we compare whole words from the two experiments (Table 6), the pattern reverses: word n yields longer reading times for all three previews in GD (around 150 ms on average) and almost double that in TT (identical = 170 ms, related = 237 ms, nonword = 207 ms). The advantage for the five-character region at the end of the word n over the five-letter word observed in this study on the early and late measures for the five-letter postboundary region is in line with earlier cross-linguistic findings (e.g., 225 ms advantage for monomorphemic vs. compound longer words in English demonstrated by Drieghe et al. (2010)). Yet this advantage not only disappears but is reversed in the cumulative measures that compared whole words. This latter result is largely driven by word length, as all the target words in the second experiment were 10+ characters long.

[7] We thank the anonymous reviewer for offering this interpretation.

Table 5

Word n + 1 and Postboundary Region Word n Results of the (Generalized) LME Models for the Untransformed Fixation Duration With the Interaction Between Preview and Experiment (Preview × Experiment)

Measure	Contrast	*b*	*SE*	*t/z*
	Word $n+1$ (five characters) versus word n postboundary region (five characters)			
FF	Intercept	**274.26**	**9.14**	**30.32*******
	Identical versus nonword	−10.68	5.97	1.79
	Related versus nonword	−3.95	5.98	−0.66
	Related versus identical	6.73	6.12	1.09
	FF launch site	**−5.18**	**1.93**	**−2.68****
	Identical: $N+1$ versus N	−8.62	11.30	−0.76
	Related: $N+1$ versus N	−12.52	14.11	−0.89
	Nonword: $N+1$ versus N	**−28.40**	**9.74**	**−2.92****
	$N+1$ versus N: identical versus nonword	**−37.02**	**11.46**	**−3.23****
	$N+1$ versus N: related versus nonword	15.87	11.82	1.34
	$N+1$ versus N: related versus identical	−21.15	13.68	−1.55
SF	Intercept	**315.39**	**10.91**	**28.91*******
	Identical versus nonword	**21.11**	**10.43**	**2.02***
	Related versus nonword	−14.79	10.03	−1.48
	Related versus identical	6.29	40.15	0.16
	FF launch site	0.62	2.10	0.30
	Identical: $N+1$ versus N	**−66.36**	**20.09**	**−3.30*******
	Related: $N+1$ versus N	**−61.93**	**11.01**	**−5.63*******
	Nonword: $N+1$ versus N	**−69.06**	**12.49**	**−5.53*******
	$N+1$ versus N: identical versus nonword	2.40	35.84	0.07
	$N+1$ versus N: related versus nonword	5.67	13.79	0.41
	$N+1$ versus N: related versus identical	3.13	57.89	0.05
$GD_{postboundary}$	Intercept	**294.23**	**12.47**	**23.59*******
	Identical versus nonword	16.16	10.88	1.49
	Related versus nonword	−8.65	7.06	−1.23
	Related versus identical	4.79	14.05	0.34
	FF launch site	**6.55**	**1.82**	**3.61*******
	Identical: $N+1$ versus N	**−69.24**	**11.48**	**−6.93*******
	Related: $N+1$ versus N	**−56.15**	**13.31**	**−4.22*******
	Nonword: $N+1$ versus N	**−63.35**	**13.05**	**−4.86*******
	$N+1$ versus N: identical versus nonword	5.97	15.07	0.40
	$N+1$ versus N: related versus nonword	4.67	9.05	0.52
	$N+1$ versus N: related versus identical	12.39	17.18	0.72
$GPT_{postboundary}$	Intercept	**429.17**	**31.04**	**13.83*******
	Identical versus nonword	**49.23**	**8.88**	**5.54*******
	Related versus nonword	−7.79	7.82	−1.00
	Related versus identical	**51.35**	**23.41**	**2.20***
	FF launch site	6.13	6.24	0.98
	Identical: $N+1$ versus N	10.72	23.32	0.46
	Related: $N+1$ versus N	**−100.36**	**10.54**	**−9.52*******
	Nonword: $N+1$ versus N	**−130.34**	**23.52**	**−5.54*******
	$N+1$ versus N: identical versus nonword	5.33	8.38	0.64
	$N+1$ versus N: related versus nonword	6.53	9.29	0.70
	$N+1$ versus N: related versus identical	1.20	11.92	0.10
$TT_{postboundary}$	Intercept	**534.01**	**32.73**	**16.31*******
	Identical versus nonword	**49.51**	**23.53**	**2.10***
	Related versus nonword	−3.31	26.47	−0.13
	Related versus identical	35.63	27.10	1.32
	FF launch site	7.72	6.51	1.19
	Identical: $N+1$ versus N	**−215.95**	**25.87**	**−8.35*******
	Related: $N+1$ versus N	**−185.72**	**21.67**	**−8.57*******
	Nonword: $N+1$ versus N	**−206.79**	**26.61**	**−7.77*******
	$N+1$ versus N: identical versus nonword	6.56	31.62	0.21
	$N+1$ versus N: related versus nonword	5.44	41.53	0.13
	$N+1$ versus N: related versus identical	31.82	34.34	0.93

Note. Bolded values indicate statistically significant contrast differences. LME = linear mixed effects; FF = first fixation; SF = single fixation; GD = gaze duration; GPT = go-past time; TT = total time.
* $p < .05$. ** $p < .01$. *** $p < .001$.

The nonword preview was read significantly slower as part of word $n+1$ than as part of word n, and while there was no main effect of the control comparison (identical-nonword) in the pooled data, this comparison was 37 ms larger on word $n+1$ than word n. A main effect of nonword interference with the identical was observed in the three theoretically important measures: SF, $GPT_{postboundary\ and\ whole\ word}$, and

Table 6

Word n + 1 and Word n Results of the (Generalized) LME Models for the Untransformed Fixation Duration With the Interaction Between Preview and Experiment (Preview × Experiment)

Measure	Contrast	*b*	*SE*	*t/z*
	Word $n+1$(five characters) versus word n whole word comparison			
$GD_{\text{whole word}}$	Intercept	**314.58**	**13.76**	**22.87*****
	Identical versus nonword	17.21	11.18	1.54
	Related versus nonword	−5.25	7.36	0.71
	Related versus identical	4.18	13.73	0.30
	FF launch site	0.45	2.50	0.18
	Identical: $N+1$ versus N	**145.20**	**14.83**	**9.79*****
	Related: $N+1$ versus N	**156.54**	**15.62**	**10.02*****
	Nonword: $N+1$ versus N	**158.97**	**16.88**	**9.42*****
	$N+1$ versus N: identical versus nonword	13.51	17.49	0.77
	$N+1$ versus N: related versus nonword	3.30	12.99	0.25
	$N+1$ versus N: related versus identical	12.32	20.45	0.60
$GPT_{\text{whole word}}$	Intercept	**314.58**	**13.76**	**22.87*****
	Identical versus nonword	**47.87**	**22.34**	**2.14***
	Related versus nonword	3.38	21.19	0.16
	Related versus identical	**51.55**	**23.55**	**2.20***
	FF launch site	10.72	23.32	0.13
	Identical: $N+1$ versus N	−23.44	7.80	−3.01
	Related: $N+1$ versus N	6.14	9.94	0.62
	Nonword: $N+1$ versus N	20.25	24.75	0.82
	$N+1$ versus N: identical versus nonword	12.22	10.65	1.15
	$N+1$ versus N: related versus nonword	21.58	30.01	0.72
	$N+1$ versus N: related versus identical	11.25	28.68	0.39
$TT_{\text{whole word}}$	Intercept	**586.35**	**30.40**	**19.29*****
	Identical versus nonword	**52.37**	**24.91**	**2.10***
	Related versus nonword	5.82	22.73	0.80
	Related versus identical	47.48	25.81	1.84
	FF launch site	−6.57	5.51	−1.20
	Identical: $N+1$ versus N	**170.99**	**32.17**	**5.32*****
	Related: $N+1$ versus N	**237.05**	**32.32**	**7.34*****
	Nonword: $N+1$ versus N	**207.59**	**11.15**	**15.60*****
	$N+1$ versus N: identical versus nonword	55.75	36.68	1.52
	$N+1$ versus N: related versus nonword	5.44	41.53	0.13
	$N+1$ versus N: related versus identical	67.73	39.52	1.72

Note. Bolded values indicate statistically significant contrast differences. LME = linear mixed effects; GD = gaze duration; FF = first fixation; GPT = go-past time; TT = total time.
* $p < .05$. *** $p < .001$.

$TT_{\text{postboundary and whole word}}$ without significant interaction across the two experiments. Furthermore, the related preview showed significant disruption over the identical preview in the key late measures: $GPT_{\text{postboundary}}$ and $GPT_{\text{whole word}}$, also without significant interaction between the experiments.

This evidence further clarifies the augmented attention allocation hypothesis by demonstrating the different time course for visual and linguistic information. Skilled readers showed the graded effect of word length and delayed morpho-syntactico-semantic effect, and these effects did not interact with each other. Skilled readers process parafoveally visible parts of a longer word faster than length-controlled upcoming word $n+1$, yet the message-level contextual linguistic information affects the target words n and $n+1$ similarly.

Discussion and Conclusion

We investigated whether morpho-syntactico-semantic information can be processed parafoveally. Morphologically related previews were read as fast as the identical previews in early measures but significantly more slowly than the identical previews during later measures across both words $n+1$ and words n. We conclude that the parafoveally visible but illegal case marker in the current study facilitated word-level identification as reflected in early measures but interfered with the incorporation of the target word into the syntactic structure. This interference was observed on GPT for both the word $n+1$ and word n. This pattern contrasts with the pattern found in Stoops and Christianson (2017, 2019). In both previous studies, the parafoveally visible related case marker was legal but ultimately incorrect, that is, replaced with another grammatical target when the eyes fixated the region of interest directly. This manipulation yielded longer fixation durations in both early and later measures because the related grammatical case marker was integrated into the syntactic structure based on parafoveal preprocessing.

We attribute the combined pattern of results obtained from the earlier and the present study to the modulation of the syntactic fit of the related and identical previews. All four experiments examined the processing of an expected object case marker presented either only parafoveally in the earlier work (2017, 2019) or as the identical target in this study. The current experiments clarified that the syntactic fit of the target word operationalized as the Cloze test score for the target grammatical category drove both earlier and current results. If morphosyntactic information activation is blind to the grammaticality of the target word in the sentence stream, a related preview should interfere with the identical condition and result in slower reading times on the target word more so than the no-change preview, due to the mismatch in surface form. Instead, the related preview facilitated the recognition of the target word in the early first-pass measures and interfered only in the second-pass measures. Since the subject in the current sentences had just been extracted from the preceding word, the preview that had the second subject case marker could not be integrated at the message level. As a result, the related preview was read more slowly than the identical only in later second-pass measures, GPT on word $n+1$ and n.

The primarily delayed nature of the processing cost due to ungrammaticality is the most intriguing result of this study. Even though the morphological marking of ungrammaticality was parafoveally available, the syntactic fit only affected delayed processing manifested as an increased reading of the previous text. In other words, the morphosyntactic information is fed into the system early on during the word's parafoveal processing. Yet, its effect is not immediate, instead exerting its cost only later, presumably during the message-level integration process. This conclusion is consistent with earlier self-paced and eye-tracking reading studies (Stoops et al., 2014; Vainio et al., 2008). The morphological agreement effects in modifier-head noun phrases were consistently shown as delayed effects (eye tracking, Vainio et al., 2008; self-paced reading, Stoops et al., 2014). Whereas in the earlier studies participants read manipulated head noun case markings foveally, without parafoveal manipulation, similar to the present authors, Vainio and colleagues and Stoops and colleagues both interpret the results to reflect syntactic-level integration.

There are at least two possible explanations for the weaker findings in the early first-pass measures. The first and most obvious explanation is the low power of the current study. However, we believe this scenario to be unlikely, given that the earlier two studies conducted with a similar number of participants and items revealed robust cost in gaze for the word $n+1$ (Stoops & Christianson, 2017) and on multiple first-pass measures on the postboundary region for the word n (Stoops & Christianson, 2019). Alternatively, on theoretical grounds, the null effect for the related preview in early measures suggests that the related preview initially facilitated recognition of the target word. The nominative case marker preview on the noun that follows a subject with the same case marker could have induced a spaced compound reading analogous to English spaced compounds "man child" or "lady king." English readers show facilitation of the second word in such frequent and common English spaced compounds as "teddy bear," even when the "bear" is two words away from the currently fixated word (word $n+2$), given the intact preview of the first word "teddy" in the word $n+1$ position (Cutter et al., 2014). Evidence from the English spaced compounds additionally stresses the role of lexicality on parafoveal processing. Much further research is needed to fully understand how suffixes influence processing both parafoveally and foveally across diverse contexts in highly inflected languages like Russian.

Our findings provide independent support for the prediction derived from the OB-1 Reader model (Snell et al., 2018); namely, that a word in a grammatical context is processed easier than a word in an ungrammatical context. Moreover, the results obtained in this study along with the results from the earlier work on this topic (Stoops & Christianson, 2017, 2019) allow us to explicitly spell out how the ease/difficulty of word identification looks as a function of the grammatical status of the syntactic fit in the boundary-change manipulation context. More specifically, if the parafoveally previewed inflections/suffixes are not syntactically legal, then there should be a preview cost in the measures associated with the message-level integration of the target word.

Current eye-movement models that seek to model cognitive processes during reading have difficulty accounting for the pattern of results observed in the current and the earlier Russian studies. All models use the Cloze test predictability score of the specific word as proxy for the ease of lexical access without taking into consideration the grammatical fit of the word. The target words in both this and earlier studies have identical low Cloze test scores for the individual words (in the range of 0–0.2). The individual target words are not predictable since we used neutral contexts with the same target words and sentence frames across all studies. We propose that a grammatical category predictability score can be used as a proxy for the syntactic fit of the target word into the message-level stream (cf., Luke & Christianson, 2018). This score is obtained from the same Cloze test measure that all the models currently use as a proxy for lexical word identification and can be quite easily computed along with the Cloze test score for the individual words. Yet in any given language, while the individual word counts are quite large, the number of grammatical categories (parts of speech) is relatively low, and they are subject to the language-specific statistical combinatorial regularities that help arrange groups of words into a given sentence to express a specific thought (see Dingemanse et al., 2015; Monaghan et al., 2005; Onnis & Christiansen, 2008, for the cross-linguistic and English-specific reviews). Thus, current models, by not capturing the sentence-level fit of the target words, are missing a significant informative layer and reducing their own explanatory power.

The novelty of this current work is also one of its limitations, as we can only generalize our conclusions to the morphosyntactic phenomenon under investigation, namely the processing of the subject/object case markings that denote patient/agent roles for feminine nouns in a noncanonical VP-NP-NP word order. Russian morphological system exhibits homonymity, that is, the same forms indicate different meanings of the inflectional cases. For example, the nominative "a" and accusative "y" case markers tested here with the feminine nouns of the first declension type, indicate genitive "a" and dative "y" cases in the nouns of masculine gender in the second declension type. Such homonymity might be potentially counterbalanced by the allomorphy, that is, different forms indicate the same meaning, across the three declension types. For example, the nominative case has different endings that signal the declension type: "a"—first declension type, which includes feminine and masculine nouns ending in a/ja; null, "e," "o"—for the masculine and neutral nouns of the second declension type and soft sign for the feminine nouns of the third declension that end in a soft consonant. How speakers learn and use morphological homonymity and allomorphy is an empirical question. Consequently, boundary-change paradigm studies of the type described here could help map the time course of such interactions and the information activated by these suffixes across different word orders. Predictions laid out here and in our earlier work could be easily tested by either reversing the preview-target case markers on the current items and investigating

VP-NP$_{object}$-NP$_{subject}$ word order or by using the masculine nouns with the accusative and dative cases as targets and previews in the same VP-NP$_{subject}$-NP$_{object}$ word order (e.g., увидела$_{SAW}$ женщина$_{A\ WOMAN}$ мальчик**а**$_{MasculineAccusative\text{-}A\ BOY}$ [target]/ мальчик**у**$_{MasculineDative\text{-}A\ BOY}$ [preview]/A woman saw a boy/).

Another limitation is the relatively small number of participants who were truly monolingual. Our hope is that the subsequent work will remedy this situation and will replicate this work with monolingual participants, who reside in Russia. Finally, our participants all knew English to various degrees of proficiency, which raises additional questions as to the role of second language knowledge in the processing of native language. Although there is limited evidence from one study that English native speakers process derivational morphology parafoveally (Dann et al., 2021), currently there has been no work that examines the processing of English inflectional morphology parafoveally, especially by second language English speakers. Hence, we leave it to future work to determine the interplay of English and Russian morphological systems in English/Russian bilingual readers.

Additional cross-linguistic work has the potential to improve the modeling of message-level processing reflected by eye movements during reading. Such between-word relationships are currently underspecified in existing models of eye movements and require better understanding to improve models (e.g., Reichle, 2020; Snell et al., 2018; Veldre et al., 2020). Most Indo-European languages with rich inflectional morphology systems (e.g., French, Hindi, Spanish, and Ukrainian to name just a few) are either understudied or have not been examined with the boundary-change paradigm. Given that roughly 3.2 billion people or about 46% of the world population speak one of these Indo-European languages as their first language (Indo-European languages, 2020), overlooking the role of inflectional morphology on parafoveal processing leaves a significant gap in the scientific study of reading. More cross-linguistic investigations of message-level morpho-syntactico-semantic processing with the boundary-change paradigm are necessary to deepen our understanding of the exact mechanisms behind message-level integration of morphologically complex words during reading (Nation, 2019; Rastle, 2019).

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Received November 21, 2022
Revision received May 5, 2025
Accepted May 7, 2025 ■