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Parafoveal processing of inflectional morphology in Russian: A within-word boundary-change paradigm☆

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A B S T R A C T

The present study examined whether the inflectional morphology on Russian nouns is processed parafoveally in words longer than five characters while the eyes are fixated on the word. A modified boundary-change paradigm was used to examine parafoveal processing of nominal case markings within a currently fixated word *n*. The results elicited identical preview benefit for both first and second-pass measures on the post boundary and whole word regions. The morphologically related preview benefit (vs. nonword) was observed for first and second-pass measures as early as pre-boundary, post-boundary, and whole word regions. Additionally the morphologically related preview elicited cost (vs. identical) for first-pass measures on the post-boundary region, total time for the whole word, and regressions into the pre-boundary region. The contribution of the study is two-fold. First, this is the first study to use within-word boundary changes to study the parafoveal processing of inflectional morphology in Russian. Second, we provide additional evidence that inflectional morphology can be integrated parafoveally while reading a language with linear concatenative morphology.

1. Background information

Reading is a complex activity (Huey, 1908; Javal, 1878) because multiple cognitive processes need to be completed under biological constraints of the visual and cerebral systems. Vision is most acute in the fovea (approximately central 2 degrees), followed by the parafovea (the rest of the 5° of the central visual field), and drops significantly in the periphery of the visual field beyond the parafovea (see Fig. 1).

It takes time for the images from the printed page to be transmitted through the visual system to the brain for the interpretation. The "eye-mind lag," attributed to the complexities of the signal flow through cerebral structures (a.k.a. the "efference copy") has been suggested to explain perceived gaze stability (e.g., Herdman, Schubert, and Tusa, 2001). Experiments investigating the eye-mind lag have established that it takes around 50 ms (ms) to integrate the visual features from the reflection of the printed page on the retina to the brain (Clark, Fan, & Hillyard, 1995; Foxe & Simpson, 2002; Mouchetant-Rostaing, Giard, Bentin, Aguera, & Pernier, 2000; VanRullen & Thorpe, 2001). Additionally, it takes time to program an eye movement (saccade) to the next location on the page. Attention thus shifts to the saccade target before the eyes fixate it. As a result, information is obtained during any given fixation not only from the word being fixated, but also from a word or, in some cases, two words to the right of fixation, i.e., from the parafovea (Rayner, 1998, 2009; Schotter, Angele, & Rayner, 2012; Sheridan & Reichle, 2016; Vasilev & Angele, 2017) in a left-to-right orthography. Physiological constraints imply that attention could potentially spread within the 5° of the central visual field due to sensitivity of the parvocellular pathways that underlie foveal and parafoveal portions of the visual field (Kaplan, 1991; Merigan & Maunsell, 1993; Norman, 2002; Steinman, Steinman, & Lehmkuhle, 1997). Indeed, accumulating evidence supports the idea of a flexible attentional span within the parafovea due to lexical access (Cutter, Drieghe, & Liversedge, 2014; Häikiö, Bertram, and Hyöna, 2010; Hyöna, Bertram, & Pollatsek, 2004; Juhasz, Pollatsek, Hyöna, Drieghe, & Rayner, 2009) or preceding contextual constraints (Juhasz et al., 2009). Considerable ongoing research is devoted to determining how much and which types of information can be accessed in the parafovea. In the current study, we examine whether inflectional morphology information is available for processing in the parafovea.

For the past few decades, the paradigm of choice for examining information processing in the parafovea has been the gaze-contingent boundary-change paradigm (Rayner, 1975; see Fig. 2). During eye-tracking experiments, researchers place an invisible boundary in the text preceding a target region (e.g., word *n + 1*). Prior to the eyes fixating word *n + 1*, it may appear in some altered form (Fig. 2). As the eyes cross the boundary, the preview word is replaced with a target word. Participants are not aware of this change due to saccadic suppression (Matin, 1974). Disruptions in processing, as measured by

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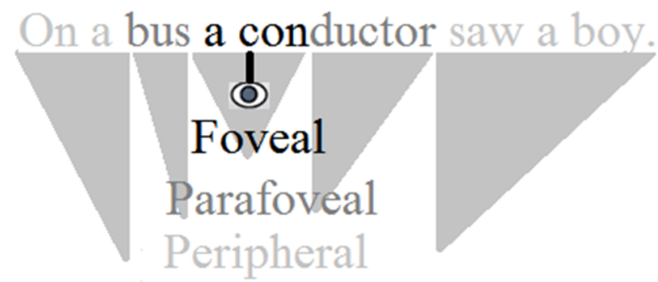

Fig. 1. The foveal, parafoveal, and peripheral regions when three characters make up 1 °of visual angle. The line and the eye icon point to the location of the fixation.
adapted from Stoops & Christianson, 2017

inflated fixation durations on word *n + 1* compared to some baseline, are taken as evidence about the degree to which parafoveal processing was performed on word *n + 1* prior to fixating it. Generally, the fixation time on the target is shorter when the preview was identical to the target or orthographically and/or phonologically related compared to an unrelated word or nonword preview (baseline). The difference between helpful and unhelpful previews in processing time on word *n + 1* is called a *preview benefit effect*. Experiments that place an invisible boundary within word *n + 1*, rather than preceding it, report significantly increased effect size of the preview benefit in the range of 85–100 ms compared to the effect size in the range of 20–40 ms usually reported for between-word boundaries (e.g., Haikio et al., 2010; Hyöna et al., 2004; Juhasz et al., 2009; White, Bertram, and Hyönä, 2008). While the above mentioned studies placed the boundary between two roots of a compound word, Drieghe, Pollatsek, Juhasz, & Rayner, 2010 observed a 225 ms preview benefit when the invisible boundary was placed within shorter (7–9) monomorphemic words, e.g. *fountain-fountaom*. The researchers attributed the observed increase in the effect size to *augmented* attention (spreading of the acute processing within the 5 degrees of the visual field) tied to lexical access of word *n* (the currently fixated word), supporting the idea of flexible attentional allocation within the parafoveal portion of the visual field.

Controversy arises when it comes to the investigation of higher-level linguistic information such as semantic and morphosyntactic information. A semantic preview benefit has been observed in English (e.g., Rayner & Schotter, 2014; Schotter, 2013; Schotter & Jia, 2016; Schotter, Lee, Reiderman, & Rayner, 2015; Veldre & Andrews, 2016a; 2016b, 2016c, 2017, 2018), German (e.g., Hohenstein & Kliegl, 2014), Korean (e.g., Kim, Radach, & Vorstius, 2012), and Chinese (e.g., Li, Wang, Mo, and Kliegl, 2018; Tsai, Kliegl, & Yan, 2012; Yan, Richter, Shu, & Kliegl, 2009; Yan, Zhou, Shu, & Kliegl, 2012; Yang, Li, Wang, Slattery, & Rayner, 2014; Yang, Wang, Tong, & Rayner, 2012), suggesting cross-linguistic stability independent of the writing system and linguistic typology. A word (e.g., *liver*) in a highly predictable semantic context (e.g., *The doctor told Fred that his drinking would damage his liver very quickly*) is skipped significantly less when a preview word is a pronounceable non-word that is different by only one letter (e.g., *liver/livor*) than when the preview is the target word itself. This finding points to a very high degree of letter identification in parafoveal processing (Drieghe, Rayner, & Pollatsek, 2005). In addition to skipping and early first-pass measures associated with lexical word identification stages, a few studies report a preview benefit as late as total time. For example, Veldre and Andrews (2016a) found a preview benefit in total times for semantically plausible and related previews (*insane*) versus semantically plausible but unrelated previews (*modest*) in neutral contexts (e.g. *Melanie thought that the man was psycho*/identical/…). These results suggest that parafoveally previewed words can be processed not only at the level of lexical specificity but also at the sentence level, inferred from effects on later second-pass measures.

For morphosyntactic information, the results are much less clear. The syntactic category of the upcoming word modulates parafoveal processing in English (Brothers and Traxler, 2016); Veldre & Andrews, 2018), Dutch (Snell, Meeter, & Grainger, 2017), Hebrew (Deutsch, Frost, Pollatsek, & Rayner, 2005), and Korean (Kim et al., 2012). The morphology of the upcoming word modulates parafoveal processing in Russian (Stoops & Christianson, 2017), Hebrew (Deutsch, Frost, Peleg, Pollatsek, and Rayner, 2003; Deutsch et al., 2005) and Korean (Kim et al., 2012). Yet, morphological composition of the upcoming word does not seem to affect parafoveal word processing in English (Kambe, 2004; Lima, 1987), Malay (Winskel and Salehuddin, 2014), or Finnish (Bertram and Hyöna (2003); Hyöna et al., 2004). Linguistic typology or writing system peculiarities alone cannot account for the observed differences in findings across languages. Although perceptual bias induced by either non-concatenative morphology in Hebrew or syllabary-alphabetic grouping in Korean could explain the preview benefit reported in these languages, recent findings with the linear concatenative inflectional morphology of Russian challenges this perspective.

Alternatively, the choice of preview in English, Malay, and Finnish experiments (xxxxx or nonword letter combinations used for the baseline condition) could have artificially induced null results (Hutzler et al., 2014; Taft, 2004). The relevant caveat comes from studies that are currently re-examining the mechanism for lexical facilitation. The traditional view maintains that parafoveal information is *integrated* with the foveal information to achieve the acute image in reading (e.g., Pollatsek, Lesch, Morris, & Rayner, 1992; Rayner, 1975). Under this assumption, the baseline of choice is usually the *nonword*, which cannot be integrated into the message being communicated by the experimental sentence. A few researchers question the utility of the nonword baseline because it can induce unnecessary processing *cost* (e.g., Kliegl, Hohenstein, Yan, & McDonald, 2013; Marx, Hawelka, Schuster, & Hutzler, 2015). Emerging evidence suggests that parafoveally available information can *independently* influence the processing of the target either by facilitating (preview *benefit*) or interfering (preview *cost*) with its lexical access (Schotter & Leinenger, 2016; Schotter, Leinenger, & von der Malsburg, 2017). Thus, a nonword baseline that denies any lexical processing is most likely not a good baseline.

It is likely that all of these factors contribute to observed cross-linguistic discrepancies, calling for more targeted language-specific investigations. The majority of Indo-European languages with rich linear

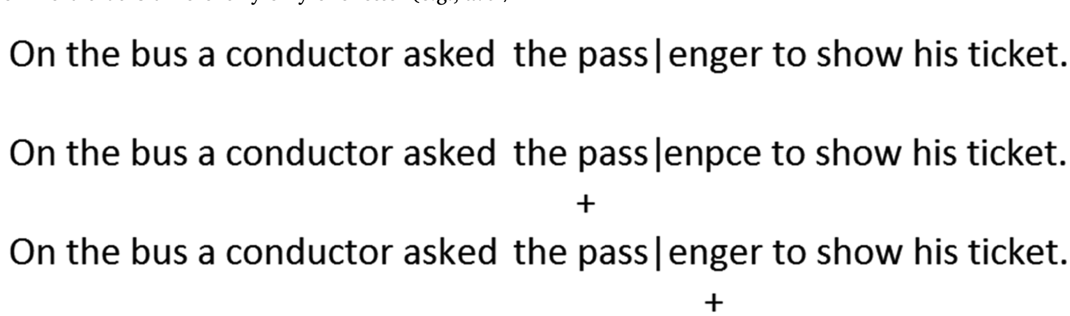

Fig. 2. The + sign shows the location of the eye during a fixation on the line above the + . The vertical line shows the location of the invisible boundary.
adapted from Stoops & Christianson, 2017

Table 1
Example of the declension paradigm for the nouns of 1st class.

Cases	'Traveler'
Nominative	путешественниц**а**/*puteshestvenniţa/*
Genitive	путешественниц**ы**/*puteshestvenniţi/*
Dative	путешественниц**е**/*puteshestvenniţe/*
Accusative	путешественниц**у**/*puteshestvenniţu/*
Creative	путешественниц**ой**/*puteshestvenniţoj/*
Instrumental	путешественниц**е**/*puteshestvenniţe/*

concatenative morphological systems (e.g., French, Italian, Portuguese, Romanian, Russian, Spanish, Ukrainian) allow the use of the same word with different inflectional endings for all three test conditions (identical/related/nonword), thus naturally controlling for limitations of previous studies. Unfortunately these languages have been severely understudied with the boundary-change manipulation paradigm. We therefore have used two baselines (identical and nonword) to contrast morphologically related previews in a previous investigation of Russian (Stoops & Christianson, 2017). Unlike traditional nonword previews of uninterpretable letter strings, nonwords in the 2017 study differed from the identical preview by only one letter (inflection). Moreover, the morphologically relevant preview was a grammatically legal continuation. As a result, we found that, in Russian, morphologically related previews induced a preview cost over the identical preview in gaze duration associated with lexical access, as well as a preview cost in go-past time and total time traditionally associated with message-level integration of the target word. An unanswered question is whether the observed results were only applicable to short (5-letter) nouns that appeared completely in the parafovea (i.e., wholly preceded by the invisible boundary). To answer this question, the present study follows up the initial *n + 1* boundary manipulation with a within-word manipulation on the currently fixated word *n* to get a more complete picture of the role that inflectional morphology plays on word identification processes in Russian. If inflectional morphology facilitates lexical access parafoveally, as reported previously for word *n + 1*, then we should see similar preview costs for the morphologically related preview. By inserting a preview within the currently fixated word *n* and recording pre- and post-boundary reading measures, we might even see traditional identical-nonword preview benefit effects along with typical preview benefits for morphologically related previews during earlier stages of word identification (early measures in the post-boundary region) due to the enhanced attention span associated with lexical access (as suggested by Cutter et al., 2014; Haikio et al., 2010; Hyöna et al., 2004; Juhasz et al., 2009).

1.1. Relevant characteristics of Russian

1.1.1. Inflectional morphology

Russian is morphologically rich, with obligatory inflectional paradigms for nouns, adjectives, verbs, numerals, and pronouns. The declensional paradigm for nouns consists of six cases and is based on grammatical gender with masculine considered a default class taking approximately 46% of the lexicon, followed by feminine (41%) and neuter (13%) (e.g., Akhutina et al., 2001; Comrie, Stone, & Polinsky, 1996). Table 1 illustrates the declension for nouns of the first class singular used in this experiment because the word forms for the agent (subject; word form in the nominative case) and the recipient (object; word form in the accusative case) are equal in length. To ease comparison with our earlier study, only singular feminine nouns were used in this experiment.

Russian verbs consist of a stem and an inflection. The stem reveals semantic information, and the inflection communicates such features as gender, person, and number. To be consistent, we used the verbs in the past-tense singular forms analogous to our previous study (see Stoops & Christianson, 2017; Table 2, p. 4, for a detailed discussion of Russian verbal morphology).

1.1.2. Word order

Russian is a pro-drop language that allows all six basic word orders (SVO, OVS, VOS, VSO, SOV, OSV) but is canonically SVO (Babyonyshev, 1996; but cf. King, 1995). Suffixed nominal case markers convey thematic roles. For example, although the constituent order in both (1a) and (1b) is VP-NP-NP, (1a) asserts that *A traveler asked an interlocutor*, whereas (1b) asserts that *An interlocutor asked a traveler*; the thematic roles are signaled by the nominative and accusative case markers on each noun. (See Stoops & Christianson, 2017, for the distribution of the word order effects according to existing corpora counts). However, corpora counts are computed based on coherent, often scientific or academic texts rather than individual sentences without the context, which are traditionally used in experimental studies.

(1a) Спросила	путешественниц**а**	собеседниц**у**
Asked $_{\text{3rdPsSG}}$	traveler$_{\text{NOM}}$	interlocutor$_{\text{ACC}}$
(1b) Спросила	путешественниц**у**	собеседниц**а**
Asked $_{\text{3rdPsSG}}$	traveler$_{\text{ACC}}$	interlocutor$_{\text{NOM}}$
(1c) Спросила	путешественниц**у**	
Asked $_{\text{3rdPsSG}}$	traveler$_{\text{ACC}}$	

As a pro-drop language Russian allows subject omissions. As a result, sentences such as (1c) are grammatical and quite frequent in colloquial speech (Hofherr, 2006). The exact mechanisms of Russian pro-drop are debated (See Franks, 1995; Gordishevsky & Avrutin, 2004; Hofherr, 2006; Ivanova-Sullivan, 2014; King, 1995; McShane, 2005, 2009; Matushansky, 1998, 1999; Sloussar, 2007 for different proposals). Importantly, all of these approaches would treat the initial VP in the past tense as a sufficient contextual condition to omit the subject. As a result, VO (1c) word order (induced by a morphologically related preview) could be the preferred or most expected continuation in VP-NP word order. Thus, syntactic predictability could have facilitated the integration of the inflectional morphology in our previous study. For the present study we collected additional norming measures to check the syntactic expectations of the target word in the post-verbal position. If the object is more expected than the subject after the verb, then we might see a preview *benefit* for morphologically related previews as early as pre-boundary measures as evidence of syntactic predictability affecting lexical access of the target word. This is the first eye tracking study to examine parafoveal processing in the currently fixated word *n* in Russian (by inserting an invisible boundary within *n*).

1.2. Rationale and predictions

The present study measured eye movements as reflections of cognitive processes during reading. While all current models of eye movement control in reading maintain the importance of parafoveal processing, they differ in the proposed mechanisms. Covert attention that proceeds in a serial fashion accounts for parafoveal processing according to serial models (e.g. E-Z Reader; Reichle, Liversedge, Pollatsek, & Rayner, 2009; Reichle, Warren, and McConnell, 2009). Attention-gradient models of eye movements suggest that several words can be processed in parallel as long as they are within the active attention span (e.g. SWIFT; Engbert, Nuthmann, Richter, & Kliegl, 2005). The important caveat is that the focus on individual words adopted by majority of models makes them agnostic to the processing of syntactic information signaled by inflectional morphology. Such models generate predictions that are applicable mainly to early first-pass measures that are associated with the word identification stages, but largely silent about the effects observed in second-pass measures that are related to the message-level integration of the target (Stoops & Christianson, 2017; Veldre & Andrews, 2016a, 2018). A notable exception is the E-Z Reader 10 model (Reichle et al., 2009), which introduces a postlexical integration stage (I) that begins immediately after the word *n* has been identified (the model's L_2 stage). E-Z Reader 10 predicts that preceding context can facilitate integration of the target word *n* due to semantic or syntactic predictability. According to the model's assumptions, difficulty in the lexical identification of target word *n* and its message-level integration caused by our within word parafoveal manipulations would result in increased reading time and regressions to the earlier parts of the sentence.

An additional challenge is to dissociate the processing of inflectional morphology from orthographic and word-level effects. Analogous to our earlier study, the nonword, identical, and related previews all share the same root and differ only by one final letter (e.g., путешественниц**а**/ путешественниц**у**/ путешественниц**д** [traveler]). Thus, the nonword should prime the lexical word identification of "traveler" analogous to pre-activation observed in masked-priming studies for Russian (e.g., Kazanina, Dukova-Zheleva, Geber, Kharlamov, & Tonciulescu, 2008) but not the role *a traveler* plays in the sentence. The inflectional case markers а vs. у differentiate whether "*a traveler*" is a subject or an object. The nonword inflection д does not communicate any information regarding the role the target word plays in the sentence.

If inflectional morphology in Russian is processed parafoveally, then the pattern of results here should be similar to our previously reported results: a preview cost for morphologically related previews compared to identical previews in early measures, and a preview cost compared to identical and nonword previews in later measures, including TT and regressions into the target word. However studies that employ within-word manipulations suggest augmented attention due to lexical access of the word *n* (e.g. Drieghe et al., 2010; Haikio et al., 2010; Hyöna et al., 2004; Juhasz et al., 2009) that manifests in significantly larger effect sizes for the preview effects. Because we are recording eye movements on pre- and post-boundary regions, we might be able to see a preview benefit for morphologically related previews during the initial stages of word identification. If readers anticipate the syntactic category manifested by the morphologically related preview then morphologically related previews might yield a preview benefit over identical and nonword primes as early as the pre-boundary region, given that this is the beginning of the target word *n*. To sum up, if inflectional morphology is processed parafoveally, then preview benefit effects should be observed in earlier measures followed by preview costs in later cumulative whole word measures.

2. Method

2.1. Participants

Fifty-four Russian native speakers (25 female; mean age = 32; range = 18–69) in the Champaign-Urbana area gave their consent to participate. Six participants were excluded from the analyses; five participants reported during a post-test debriefing session (Appendix B) 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 for their time. 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 IRB.

2.2. 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 5th and 6th character from the end of the target word. This resulted in a five-character post-boundary region, compared to the five-character nouns in Stoops and Christianson (2017). Some words were multimorphemic in addition to the word-final case-marking, but the boundary change was always in the middle of the morpheme immediately preceding the case-marker in these multimorphemic items.

The case-marking inflection appeared in one of three preview conditions (identical, morphologically related, nonword). Examples of the preview manipulations for the target word are provided in (2a–c). Analogous to Stoops and Christianson (2017), which used a word $n + 1$ boundary-change manipulation, the target word was inserted into a VP-NP-NP sentence frame in the post-verbal argument position. The vertical lines indicate the position of the boundary, which was invisible to the participants. As the eyes crossed the invisible boundary, the computer changed the preview character with the correct target character.

(2a) *Identical:* На вокзале спросила **путешестве|нница** собеседницу о расписании поездов.
At the railway station asked **traveler$_{\mathbf{NOM}}$** interlocutor$_{\text{ACC}}$ about the train schedule.
(2b) *Related:* На вокзале спросила **путешестве|нницу** собеседницу о расписании поездов.
At the railway station asked **traveler$_{\mathbf{ACC}}$** interlocutor$_{\text{ACC}}$ about the train schedule.
(2c) *Nonword:* На вокзале спросила **путешестве|нницд** собеседницу о расписании поездов.
At the railway station asked **nonword** interlocutor$_{\text{ACC}}$ about the train schedule.

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

The target noun appeared in post-verbal VSO position. In the control condition the nonword served as the preview. To form the nonword a non-descender inflection (*а*) was replaced with a descender (д). In the test condition, inflections were replaced with a descender (у) indicating the object accusative case. As such, if unchanged the test condition would result in two post verbal objects VOO. Note that the VO continuation is grammatical while the readers are fixating the first argument and becomes ungrammatical only after the second argument has been processed. Items were distributed across three lists in a Latin square design. Due to a limited subject pool of Russian native speakers in the Champaign-Urbana area, this experiment was run concurrently with several other experiments that tested word orders and syntactic categories different from the one reported in this manuscript. All sentences served as fillers for each other, and all sentences in the experiment contained some sort of boundary-change manipulation.

2.2.1. Norming studies

Three norming studies were delivered as online surveys to native Russian speakers residing in Russia who did not participate in the main experiment. Each participant completed only one of the three surveys to avoid cross-survey priming.

2.2.1.1. Semantic plausibility. The plausibility of the sentential arguments as both subjects and objects was assessed in two norming experiments: one kept the non-canonical word order of the experimental stimuli (VSO), and another used the default or most frequent (SVO) word order to assess the thematic relationships between the arguments and the verb and control for any possible effects of syntactic predictability. Two sentences for each of the word orders (VP-NP-NP or NP-VP-NP) were constructed so that the target word was the subject in one and object in another, while the second argument from the experimental sentence was always the opposite argument. For both studies, 180 sentences were divided into two lists to ensure that the two versions of the same experimental sentence were in separate lists. For each study, a different group of 20 Russian native speakers provided plausibility judgments on a 1-to-7 Likert scale for each sentence. 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 ($p > .1$). This result confirmed that the semantic relationship between the arguments in the experimental items was not affected by the non-canonical word order in the sentence frame.

2.2.1.2. Syntactic predictability. A modified version of a traditional Cloze test (Taylor, 1953) was used to access the syntactic predictability of the experimental items. Thirty participants finished 60 experimental sentence beginnings which retained the exact wording of the experimental sentences up to the first argument (На вокзале спросила…/At the railway station asked$_{\text{Past3rdPersonSingularFeminine}}$ …).

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.

Analyses of the participants' responses revealed a clear pattern of grammatical categories that participants chose as possible continuations after the verbs in the experimental items. All six categories are given with the distributional percentage of occurrence of this specific category out of all responses (total 1,800) across subjects and items: S (1%), SO (4%), OS (2%), O (79%), adjunct clause with a null subject (12%), adverb describing the action (2%). The following three categories: O (79%), adjunct clause with a null subject (12%), and adverb describing the action (2%) constitute 93% of responses, showing that participants preferred to postulate null subjects. The seeming discrepancy between corpora word counts and single sentence data observed in this norming study is, however, in line with recent developments in the linguistic theory of Russian pro-drop which stresses the legality of null subjects in Russian (Hofherr, 2006; Ivanova-Sullivan, 2014; Matushansky, 1998, 1999; Slioussar, 2007).

2.2.1.3. Semantic predictability. The Cloze test administered to calculate syntactic predictability also allowed us to compute the semantic predictability of individual experimental lexical items. No exact predictions were made (0%; cf. Stoops, Luke, and Christianson (2014)).

2.3. Apparatus

Eye movements were recorded with an SR Research Eyelink 1000 eye tracker with a 1000 Hz sampling rate and a spatial resolution of 0.01°. Given the sampling rate of the eye-tracker, the display change occurred on average within 8 ms. 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 120 Hz. At this distance, approximately 3.03 characters subtended 1° of visual angle. Head movements were minimized with chin and head rests. Although viewing was binocular, eye movements were recorded only from the right eye.

2.4. Procedure

Participants' eye movements were calibrated using a 9-point calibration procedure (max variance = 0.25°). After 12 practice items, 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. On 25% of the trials a question about the content of the sentence appeared, which participants answered with a mean accuracy of 97% by pressing the corresponding button on the controller. Sentences were presented in a random order for each participant. Participants could take a break after the first 60 sentences. The entire session lasted on average less than 60 min.

3. Results and discussion

3.1. Measures

Because this experiment focused on examining word identification stages and integration of the target word into the sentence, the analyses included five major measures of fixation duration and three probability measures for the three regions of interest (ROIs). First-pass (early) measures were recorded for pre-boundary and post-boundary regions of the target word. Second-pass (late) measures are reported for the cumulative whole word ROI. Probabilities of regressing in and out of all three ROIs (pre-boundary, post-boundary, and cumulative probabilities for the target word) are reported, except for the regression probabilities into the pre-boundary region.

3.1.1. First-pass (early) reading measures

Single fixation (SF). The duration of the fixation on the region of interest (ROI) when only one first-pass fixation on the ROI was recorded.

First fixation (FF). The duration of the first fixation on the ROI regardless of the number of first-pass fixations.

Gaze duration (GD). The sum of all first-pass fixations on the ROI.

3.1.2. Second-pass (late) measures

Go-past time (GPT). Time spent reading the target word and any words prior to that after initially entering the target word until the eyes move past the target word region.

Total time (TT). The sum of all fixations on the target word, including re-fixations after the eyes have moved to other words in the sentence.

3.1.3. Probability measures

First-pass fixation (FPF) probability on the post-boundary region indexes whether this region was fixated in first-pass reading regardless of whether it was later fixated during re-reading.

Regressions out of the ROI to words earlier in the sentence.

Regressions in to the ROI from words later in the sentence.

Fixations shorter than 80 ms and longer than three standard deviations from each participant's mean were excluded from the analyses (1.8% of data). Trials were eliminated if the participant blinked immediately before or after fixating the target word (1.8% of trials) or if the display change completed more than 10 ms into a fixation or was triggered by a saccade that initially landed to the left of the boundary (6.4% of trials). The number of characters per visual angle differs as a function of viewing distance from the monitor and the size of the stimuli being displayed. Therefore, different viewing conditions will generally lead to a different number of letters falling within the perceptual span. Given the parameters of our experiment, the fovea consists of three characters ahead of fixation and three characters behind. Even if the reader was fixating the final character of the pre-boundary region, the fovea would only encompass the first three characters of the post-boundary region. Given that the parafovea extends from 1 to 5 degrees from fixation (i.e. from 3 to 15 characters given the characters per degree), the case marking on the post-boundary region when viewed from the pre-target region fell within the parafovea. Therefore we conclude that the effects reported here can be attributed to parafoveal processing and not to foveal processing. Additionally, to ensure that the preview was available in the parafoveal visual field prior to the eyes crossing the invisible boundary, we excluded any trial that contained a fixation following a saccade that originated from a word prior to the target word (a total of five trials). These exclusions left 2592 trials (90% of the data) available for analysis.

Fixations on the pre-boundary and post-boundary regions and cumulative fixations on the target word were analyzed. Condition means and standard errors for the reading measures are provided in Table 2.

Reading time measures for raw and log transformed data were analyzed using linear mixed-effects (LME) models, and fixation probability measures were analyzed with generalized LMM (GLMM) models using the lme4 package (Version1.1–13; Bates, Maechler, Bolker, Walker, Christiansen, Singmann, Dai, Grothendiek, & Green, 2017) in R (Version 3.2.0; R Core Team, 2015). Two models were run on the data to ensure the orthogonality of comparison: one to estimate the effects of the preview condition with the nonword baseline and the other to estimate the preview effects with the identical preview as a baseline. The

Table 2
Mean (and SE) for Reading Measures on the Target Across Conditions with Related Condition Compared against Identical and Nonword Baselines.

	Identical		Related		Nonword
Pre boundary region (visible preview)					
FF	235 (4.12)		233 (3.75)		238 (4.16)
SF	243 (5.20)		239 (4.68)		250 (5.61)
GD	305 (7.62)		295 (7.62)	*	314 (7.43)
Regressions out	0.19 (0.03)		0.20 (0.03)	*	0.15 (0.03)
Post boundary region (visible target)					
FPF probability	**0.84 (0.02)**	*	0.73 (0.02)	*	0.87 (0.02)
FF	**200 (4.36)**	*	217 (5.23)	*	231 (4.89)
SF	**204 (5.16)**	*	223 (6.05)	*	239 (6.41)
GD	**228 (6.58)**	*	246 (7.28)	*	275 (6.82)
Regressions out	**0.14 (0.02)**		0.16 (0.02)	*	0.24 (0.02)
Regressions in	0.09 (0.07)		0.12 (0.07)		0.12 (0.07)
Whole word					
GD	**448 (11.50)**		431 (11.08)	*	479 (11.75)
GPD	**470 (11.76)**		467 (11.61)	*	514 (11.57)
TT	**765 (23.55)**	*	863 (26.18)		849 (24.11)
Regressions out	0.18 (0.02)		0.22 (0.03)		0.24 (0.03)
Regressions in	0.22 (0.01)	*	0.28 (0.01)		0.25 (0.01)

Note. Significant ($p < .05$) effects are indicated in bold: bolded values for the identical condition indicate significant difference (preview benefit) from the nonword condition; *indicates the difference between the baseline (identical or nonword) and the related conditions.

models were identical in regard to their fixed effects and random structure. The control condition (identical vs. nonword preview) was identical across models except for the sign (±). The test condition allowed us to tease apart preview effects for the related preview as compared to the nonword and identical previews respectively.

For all models, the random effect structure was fitted using likelihood ratio tests; all final models reported below had random intercepts and slopes for participants and items (following Barr, Levy, Scheepers, & Tily, 2013). Although fixation probability models include both slopes and intercepts for both participants and items, some fixation duration models failed to converge. In such cases item random slopes were removed (see Appendix C for the reading measures and Appendix D for the fixation probability). LME models were fitted to untransformed and log-transformed fixation durations. The latter are in agreement with the model assumption of normal distribution of residuals and are reported in Appendix B. Since the pattern of results was identical for raw and log-transformed data, we report only untransformed models to facilitate interpretation. See Table 3 for the summary of models for fixation durations and Table 4 for the summary of the models for fixation probability measures.

3.2. Pre-boundary fixation measures

It is important to note that at this point the previews are visible in the parafoveal visual field. The control condition (identical vs. nonword previews) did not yield any significant differences in any of the collected measures. This result is consistent with Stoops and Christianson (2017). The nonword **путешественниц-д** and the identical preview **путешественниц-а** both have the same root **путешественниц**/*a traveler of a feminine gender/*. The case marking in the identical preview communicates the role the noun plays in the sentence, although this information is not used until later to integrate the target into the syntactic structure. The manipulated case marking in the nonword does not provide any meaningful syntactic information, but its root is just as informative for word identification as the identical preview. The observed pattern of results suggests that this root overlap in the nonword

Table 3
Results of the Linear Mixed-Effects Models for Fixation Duration Measures.

		Nonword baseline			*Identical baseline*		
Measure	Contrast	*b*	*SE*	*t*	*b*	*SE*	*t*
Pre-boundary region (visible preview)							
FF	Intercept	**238.34**	**6.22**	**27.40**	**233.86**	**6.09**	**38.42**
	Control preview	−4.56	5.43	−0.81	4.56	5.43	0.81
	Related preview	−5.69	5.17	−1.10	−1.25	5.15	−0.24
SF	Intercept	**252.06**	**7.73**	**31.82**	**241.70**	**7.51**	**30.79**
	Control preview	−10.39	6.72	−1.55	10.39	6.72	1.55
	Related preview	−12.21	6.96	−1.75	−1.85	7.05	−0.26
GD	Intercept	**312.62**	**13.67**	**22.76**	**300.52**	**13.78**	**21.40**
	Control preview	−12.10	10.28	−1.18	12.10	10.28	1.18
	Related preview	**−22.61**	**9.55**	**−2.37**	−10.52	9.30	−1.13
Post-boundary region (visible target)							
FF	Intercept	**229.84**	**6.58**	**34.92**	**198.63**	**5.21**	**37.75**
	Control preview	**−32.77**	**6.80**	**−4.82****	**32.77**	**6.80**	**4.82****
	Related preview	**−15.04**	**7.17**	**−2.10**	**15.52**	**7.64**	**2.03**
SF	Intercept	**239.66**	**8.46**	**28.32**	**200.01**	**7.25**	**27.64**
	Control preview	**−38.66**	**8.17**	**−4.74****	**38.66**	**8.17**	**4.74****
	Related preview	**−21.55**	**9.32**	**−2.31**	**17.11**	**8.09**	**2.11**
GD	Intercept	**271.66**	**9.47**	**26.73**	**219.66**	**8.55**	**25.68**
	Control preview	**−48.21**	**10.23**	**−4.80****	**48.21**	**10.23**	**4.80****
	Related preview	**−28.84**	**10.23**	**−2.88***	**19.37**	**9.73**	**1.99**
Whole word							
GD	Intercept	**481.85**	**23.39**	**20.55**	**446.76**	**22.37**	**19.95**
	Control Preview	**−35.09**	**16.02**	**−2.19**	**35.09**	**16.02**	**2.19**
	Related preview	**−50.84**	**13.47**	**−3.78****	−15.75	14.76	−1.07
GPD	Intercept	**514.14**	**22.86**	**22.42**	**469.08**	**21.91**	**21.39**
	Control preview	**−45.06**	**16.35**	**−2.76***	**45.06**	**16.35**	**2.76***
	Related preview	**−48.24**	**15.09**	**−3.20***	−3.19	15.07	−0.21
TT	Intercept	**850.71**	**44.41**	**19.16**	**761.29**	**43.56**	**17.48**
	Control preview	**−89.42**	**29.20**	**−3.06***	**89.42**	**29.20**	**3.06***
	Related preview	15.41	29.89	0.52	**104.83**	**30.25**	**3.47***

Notes: Control preview = identical vs. nonword comparison.
Significant ($p < .05$) effects are in bold; *$p < .01$, **$p < .001$.

Table 4
Results of the generalized linear mixed-effects models for fixation probability measures.

		Nonword (baseline)			Identical (baseline)		
Measure	Contrast	b	SE	z	b	SE	z
		Pre-boundary region (visible preview)					
Regression Out	Intercept	**−2.14**	**0.30**	**−7.16**	**−1.77**	**0.28**	**−6.30**
	Control preview	0.37	0.37	1.01	-0.37	0.37	−1.01
	Related preview	**0.72**	**0.36**	**2.04**	0.35	0.36	0.97
		Post-boundary region (visible target)					
FPF Probability	Intercept	**2.50**	**0.30**	**8.29**	**1.90**	**0.25**	**7.59**
	Control preview	**-0.61**	**0.30**	**−2.00**	**0.61**	**0.30**	**2.00**
	Related preview	**−1.15**	**0.30**	**−3.83****	**−0.55**	**0.27**	**−2.03**
Regression Out	Intercept	**−1.39**	**0.20**	**−6.92**	**−2.04**	**0.20**	**−9.98**
	Control preview	**-0.64**	**0.23**	**−2.71***	**0.64**	**0.23**	**2.71***
	Related preview	**-0.67**	**0.24**	**−2.76***	-0.03	0.29	-0.10
Regression In	Intercept	**−3.11**	**0.41**	**−7.51**	**−2.96**	**0.42**	**−7.10**
	Control preview	0.16	0.43	0.38	-0.13	0.43	-0.30
	Related preview	0.42	0.45	0.93	0.30	0.40	0.73
		Whole word					
Regression Out	Intercept	**−1.36**	**0.18**	**−7.42**	**−1.60**	**0.17**	**−9.69**
	Control preview	−0.24	0.19	−1.27	0.24	0.19	1.27
	Related preview	0.01	0.18	0.07	0.26	0.18	1.44
Regression In	Intercept	**−1.29**	**0.20**	**−6.55**	**−1.56**	**0.26**	**5.96**
	Control preview	−0.27	0.21	−1.25	0.27	0.21	1.25
	Related preview	0.17	0.21	0.83	**0.44**	**0.21**	**2.13**

Notes: Control preview = identical vs. nonword comparison.
Significant ($p < .05$) effects are in bold; *$p < .01$, **$p < .001$.

preview facilitated word identification during these early stages of lexical access, whereas effects of the pseudo-case marker are not observed until later measures.

We did not observe the evidence supporting the strongest view of syntactic predictability facilitating the processing of inflectional morphology parafoveally. Although the morphologically related preview revealed reading times numerically faster than the identical preview, none of the pre-boundary first-pass measures (FF, SF, GD) yielded significant preview benefit for the morphologically related over the identical preview. The morphologically related condition yielded a significant GD ($t = -2.37$, $p < .05$) preview *benefit* over the nonword preview, however, followed by a significant ($z = 2.04$, $p < .05$) preview *cost* over the nonword preview in Regressions out of the pre-boundary region. Analogous to our earlier findings for word *n + 1* (Stoops & Christianson, 2017), root + suffix overlap in nonword preview (**путешественниц-д** for **путешественниц-а**) facilitated very early stages of the word recognition process. Since there was no morphosyntactic information communicated by the last letter in the nonword preview, no traditional preview benefit for the identical condition was observed as early as pre-boundary GD or regressions out of the pre-boundary region. When morphosyntactic information was available (**путешественниц-у** for **путешественниц-а**) it yielded preview benefit over the nonword as early as GD. However, it not only facilitated the search for lexical candidates, as the preview benefit alone might suggest. The *cost* over the nonword preview for regression probabilities out of the pre-boundary region suggests that the morphologically related preview was integrated into the message level within the first 295 ms of viewing the pre-boundary region of the target word *n* and required resolution during later processing stages. This result is novel in the literature. The observed GD preview benefit indicates parafoveal-on-foveal effects of the morphological information in the parafovea influencing the processing of information in the fovea. However, because the parafoveal information was located in the target word *n* (i.e. the currently fixated word), the "parafoveal-on-foveal" effects observed here are *qualitatively* different from the classical (and disputed) ones across word boundaries (Kennedy & Pynte, 2005; see Drieghe (2011), for a comprehensive review) which are not fully predicted under E-Z Reader 10 (see Section 1.2 Rationale and Predictions).

3.3. Post boundary fixation measures

These measures reflect processing after the eyes have crossed the invisible boundary and are fixating the target case marking (same as identical preview). The control condition revealed traditional preview benefit effects for the identical preview over the nonword preview across all measures of early word identification: FPF probability ($z = -2.00$, $p < .05$); FF ($t = -4.38$, $p < .001$); SF ($t = -4.74$, $p < .001$); GD ($t = -4.80$, $p < .001$), followed by a preview benefit in regression probabilities out of the post-boundary region ($z = -2.71$, $p < .01$). As expected, the observed preview benefit across all first-pass measures of early lexical access and regressions out of the post boundary region indicate that the nonword preview interfered with the recognition of the target word.

The morphologically related condition also consistently yielded a preview *benefit* over the nonword preview across all early access measures: FPF probability ($z = -3.83$, $p < .001$); FF ($t = -2.10$, $p < .05$); SF ($t = -4.74$, $p < .001$); GD ($t = -2.88$, $p < .01$) and in regression probability out of the post boundary region ($z = -2.76$, $p < .01$). The preview benefit observed in FPF probability for morphologically related previews over both identical and nonword previews provides some support for the weaker syntactic predictability account (see Section 4.2 for a more detailed discussion). When compared to the identical preview, the morphologically related condition yielded significant preview *benefit* in FPF probability ($z = -2.03$, $p < .05$) followed by significant preview *cost* across all the measures of early word identification: FF ($t = 2.03$, $p < .05$), SF ($t = 2.11$, $p < .05$), and GD ($t = 2.00$, $p < .05$). Regression probability out of the word did not differ significantly from the identical preview condition. Regressions into the post-boundary did not yield significant differences for any of the conditions. The observed pattern of result indicates that the object case marker, when visible in the parafovea while the eyes fixated the pre-boundary region, was processed fully from lexical word identification to message level integration. As a result, when participants fixated the post-boundary region, all the first-pass measures for the morphologically related preview were *longer* as compared to the identical preview, but *shorter* in comparison to the nonword preview condition.

3.4. Fixation measures for the whole word

The measures reported in this section reflect processing on the whole word as the ROI (i.e., aggregated processing times for both pre-boundary and post-boundary regions) and are typically associated with later integrative stages of word identification (Pollatsek and Hyönä, 2005). The identical preview revealed a consistent preview benefit over the nonword preview in all the reading measures: GD ($t = -2.19$, $p < .05$), GDP ($t = -2.76$, $p < .01$), and TT ($t = -3.06$, $p < .01$). Regression probabilities out of and into the ROI did not show any significant differences between identical and nonword previews.

The morphologically related preview revealed a preview *benefit* over the nonword preview in first-pass reading measures: GD ($t = -3.78$, $p < .001$) and GDP ($t = -3.20$, $p < .01$), but no difference between the related and nonword previews in TT ($t = 0.52$, $p = .61$) and regression probability out ($z = 0.07$, $p = .95$) or into the word ($z = 0.83$, $p = .41$). This pattern is almost symmetrically reversed when compared to the identical baseline. The morphologically related preview revealed no significant differences from the identical preview in early reading measures, GD ($t = -1.07$, $p = .29$) and GDP ($t = -0.21$, $p = .83$), but a robust preview *cost* in TT ($t = 3.47$, $p < .01$) and regression probability into the target word ($z = 2.13$, $p < .05$). Both morphologically related and identical previews revealed a benefit compared to the nonword preview in the first-pass measures. This suggests that the morphologically related preview facilitated lexical access of the word *n* in first-pass measures similar to the identical preview. Note that this cannot be due to orthographic overlap, as the three preview conditions differed only in the final letter. Yet in later measures (TT and regressions into the target word), the morphologically related condition was not different statistically from the nonword preview and yielded a preview cost compared to the identical preview. This pattern of results implies that the morphologically related form has been identified from low-level orthographic features to the higher levels of word recognition and integrated into the message of the sentence very quickly, and then this early integration needed to be revised when the target morphology was fixated and the entire word had to be integrated into the syntactic structure.

4. Conclusions and general discussion

The experiment reported in this study examined whether parafoveal processing of the inflectional morphology on Russian nouns differs in any way as a function of fixating word *n* versus previously examined word *n + 1*. The results provide a further demonstration that inflectional morphology can be processed parafoveally in an Indo-European language with linear morphology and a shallow alphabetic script.

4.1. Effects of attention: Word n vs word n + 1

Studies that have examined attentional span by comparing the effect sizes of preview benefit for word *n* and word *n + 1* report significant increases in effect sizes. When we compare results reported here with the pattern of results from our 2017 study, we also see evidence that attentional span affected the parafoveal processing of inflectional morphology. The present study reports a traditional preview benefit effect for the control pair (identical vs. nonword) for the first-pass measures for post-boundary and whole word regions that were not observed in our earlier study of word *n + 1*. Both identical and morphologically related preview benefits as compared with the nonword (also not previously observed on word *n + 1*) are within the 15–50 ms range, which is considerably less than preview benefits reported for compound and monomorphemic word *n* (85–225 ms). The observed pattern of results suggests that we were able to capture early word identification stages (pre-boundary and post-boundary) when inflectional morphology in Russian facilitates lexical access, which could not be observed previously on the word *n + 1*.

The considerably smaller effect sizes reported here might reflect only a *quantitative* difference attributed to a subtle preview manipulation of a single letter used in this study. However, effect sizes from earlier studies were obtained by manipulations rather similar to ours that involved two letter changes at the end of the words. An extra letter manipulation usually induces about 5–8 ms difference (e.g. Schotter, 2013) and cannot account for a double preview benefit difference reported by Juhasz et al. (2009) and White et al. (2008). Thus, Juhasz et al. (2009), who used 10 character target words comparable in length to the target words in the present study, report GPT preview benefit of 100 ms for *basketball-basketbadk* versus GPT preview benefit in the range of 45 ms for *путешественница-путешественницд* and 48 ms for *путешественницу-путешественницд* observed in this study. A quantitative explanation would predict preview benefit effect differences in the range of 10–16 ms for the two last letters at the end of the word given the average processing time of 5–8 ms per letter (e.g. Schotter, 2013). Drieghe et al. (2010) observed 225 ms preview benefit for *fountain-fountaom* and 123 ms preview benefit for *bathroom-bathroam*. To compare, we observed GD preview benefit in the range of 48 ms for identical preview (*путешественница-путешественницд*) and 29 ms for morphologically related preview (*путешественницу-путешественницд*). Alternative account of these differences might suggest that the nonword preview in the compound noun and shorter monomorphemic noun studies interfered with a process of lexically identifying the target word from a set of lexical competitors. The interruptions of such process are very costly as revealed by the size of the preview benefit. In the case of inflectional morphology the root of the word is intact even in the nonword target. As a result the lexical access of the concept that corresponds to the target word is not interrupted. The nonword in our study blocks the integration of the target word into the sentence structure by not communicating the thematic role the target word plays in the sentence (i.e. whether it is an actor or the recipient of the action). As a result the effects are less costly in the early measures but are longer lasting and can be observed in the later measures (TT and Regressions into the target word). At this point this is only our conjecture, and more studies are needed to determine whether word identification processes during sentence reading are *qualitatively* different for inflectional morphology, compounding, and/or derivational morphology cross-linguistically.

While first-pass measures demonstrate differences between experiments, comparison of second-pass measures reveals similarities between experiments, especially when examining preview effects for the morphologically related preview. In both cases, the preview cost over the identical preview is quite high (word *n + 1*: 77 ms vs. word *n*: 105 ms). Both of the effects are well outside the usually observed preview benefit effects for the word *n + 1* first-pass measures that are in the range of 20–40 ms, but comparable to the 71 ms identical preview benefit effect for TT reported by Veldre and Andrews (2016a). The pattern of results suggests that later second-pass measures represent a qualitatively different process than what early first-pass measures capture.

4.2. The mechanisms of parafoveal processing in reading

Our study contributes to the growing literature on the *independent* parafoveal processing of the visual input beyond traditional *trans*-saccadic integration of the preview and target (e.g. Hutzler et al., 2014; Kliegl et al., 2013; Marx et al., 2015, Marx, Hawelka, Schuster, & Hutzler, 2017; Risse & Kliegl, 2012, 2014; Schotter & Jia, 2016; Schotter & Leinenger, 2016; Schotter et al., 2017; Stoops & Christianson, 2017; Veldre & Andrews, 2016b, 2017, 2018; Yang et al., 2012, 2014).

Our study provides independent support for the E-Z Reader 10 model, which postulates early and late effects for the target word *n* due to message level integration processing difficulties. The morphologically related preview yielded more regressions out of the pre-boundary region than the identical preview. This type of behavior is expected under scenario 2C (p. 7) within the E-Z Reader 10 model when attention shifts to the earlier parts of the sentence due to an integration difficulty of the target word *n* after the model's lexical access stage (L_2) in parallel with the model's saccadic planning stage (M_1). Moreover, the morphologically related preview incurred a cost over the identical preview in post-boundary measures (SF, FF, GD), while both identical and morphologically related previews yielded a preview benefit over the nonword. The same word with identical semantic features is easier to identify when it differs only by one letter that communicates a different syntactic role.

We did not find unambiguous support for the claim that the anticipatory characteristics conveyed by the preceding word *n-1* (the main verb in this case) modulate early pre-and post-boundary effects. The morphologically related preview benefit over the identical preview was reported only in FPF probability for the post-boundary region. This measure, taken together with the absence of significant effects on early pre-boundary first-pass reading measures (FF and SF) provides evidence for serial word identification in Russian. Morphologically related preview benefit observed on pre-boundary GD, post-boundary measures (FF, SF, GD) and whole word measures (GD, GPT) suggests that linear inflectional morphology is integrated as part of the word identification processing. More studies are needed to understand whether and how preceding syntactic context modulates parafoveal processing of the target words cross-linguistically.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.visres.2019.01.012.

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