Early and late learners decompose inflected nouns, but can they tell which ones are inflected correctly?

Kira Gor,[1] Anna Chrabaszcz[2,3] and Svetlana Cook[1]
[1]University of Maryland | [2]University of Pittsburgh | [3]National Research University Higher School of Economics, Russian Federation

An auditory lexical decision task tests morphological decomposition and sensitivity to violations in inflection in late second language learners, early learners (heritage speakers), and native speakers of Russian. Two datasets compared reaction times and error rates to real Russian inflected nouns and nonce nouns. Two parameters of real nouns were manipulated: case (the nominative, or the oblique case), and inflection (overt or zero). Nonce nouns had (a) real stems and inflections combined in an illegal way (*lemoning*), and (b) inflected nonce stems (*lemosing)*. Results suggest that heritage and late learners process inflectional morphology; however, their processing of inflected words is unreliable: they are willing to accept words with incongruent inflections. While no major differences were found in the processing patterns of early and late learners, a developmental trajectory was observed in both groups of learners: their sensitivity to violations in inflection improved with proficiency.

Keywords: heritage speakers, second language learners, morphology, lexical access, inflection, decomposition, second language processing, nonnative proficiency, lexical decision task, auditory word recognition

1. Introduction

Research on nonnative processing of morphologically complex words has focused on the issue of whether second language (L2) speakers decompose inflected words when they encounter them in the input, and when they store and access them in the mental lexicon. However, there is another question about L2 morphological processing that has not been addressed in experimental studies: Do L2 learners detect morphological violations in inflected words when they encounter them

https://doi.org/10.1075/jsls.17021.gor
Journal of Second Language Studies 1:1 (2018), pp. 106–140. issn 2542-3835 | e-issn 2542-3843

without context, based on their form? The answer to this question is needed not only for the understanding of nonnative word storage and recognition, but also for the understanding of morphosyntactic processing. Indeed, L2 speakers have been reported to show morphosyntactic insensitivity in sentence processing (e.g., Coughlin & Tremblay, 2013; Hopp, 2010; 2013; Jiang, Hu, Chrabaszcz, & Ye, 2015; Tokowitz & MacWhinney, 2005). Whether this insensitivity results from uncertainty about the use of appropriate inflections, problems with building sentence structure, or both, remains largely an open question. The goal of this study is to establish whether early (heritage) and late classroom learners of Russian at different proficiency levels have a robust representation of the inflectional paradigm, and are able to detect violations in the use of case inflections in Russian nouns. This is done by comparing the error rates (ERs) and reaction times (RTs) in an auditory lexical decision task (LDT) to correctly inflected real nouns, and nonwords with real noun stems and inflections combined in an illegal way (e.g., *lemoning*). Inflected nonwords with nonexistent stems (e.g., *lemosing*) served as a control condition. Results offer a richer picture of nonnative processing of inflection that takes into account sensitivity both to complex morphological structure and morphological violations, the role of the early and late onset of language learning, and learners' proficiency level.

The processing of morphologically complex words, and in particular, words with inflectional affixes, remains a matter of controversy (see Gor, 2015 for a review). The positions vary from whole-word storage and retrieval of inflected words (Butterworth, 1983; Baayen, Milin, Filipović Đurđević, Hendrix, & Marelli, 2011) to obligatory decomposition into stem and affix (Marantz, 2013; Taft, 1979; 2004). According to the dual-route, or hybrid position, both the whole-word and decompositional routes are potentially available in word recognition, and the choice of the route will depend on a number of conditions, with lexical frequency being the principal one (Baayen, Dijkstra, & Schreuder, 1997; Caramazza, Laudanna, & Romani, 1988; Taft, 2017). Word recognition is believed to begin with decomposition into stem and affix, or affix stripping, followed by access of the stem and inflection in the mental lexicon, and finally, recombination and checking of the whole word (Taft, 1979). It is at the recombination and checking stage that the main processing costs, as measured by ERs and RTs, are incurred both by native and advanced nonnative speakers (Gor, Chrabaszcz, & Cook, 2017a).

There are also conflicting views regarding how nonnative speakers process morphologically complex inflected words. According to the non-decompositional account, L2 speakers do not analyze morphological structure of regularly inflected words, and treat them as indivisible whole words: this is how they are processed in the input, stored, and retrieved from memory (Clahsen, Balkhair, Schutter, & Cunnings, 2013; Clahsen, Felser, Neubauer, Sato, & Silva, 2010). For example, L2 speakers of English are expected to store regularly inflected *squirrels* and *jumped* as whole words, and not as complex forms with productive inflectional affixes: *squirrel-s* with a plural noun marker, and *jump-ed* with a past-tense verb marker. The non-decompositional account has mainly found support in visual masked priming experiments, when participants see the inflected word, the prime, for a very short time and process it subliminally. The prime is presented for 50 milliseconds (ms) or less, and it is additionally masked by preceding or following hashmarks or other symbols. Despite the fact that participants are unaware of the prime, native speakers are often able to take advantage of the morphological overlap between the prime and the target, and process the target (either the base form or another inflected form of the same word) faster compared to the unrelated condition (Stanners, Neiser, Hernon, & Hall, 1979). L2 speakers, who do not show a robust morphological priming effect in a masked priming task, are likely to experience additional difficulties that are not directly related to morphological decomposition per se, but rather to the task conditions: they may be less experienced with reading the L2 script, and as a result, cannot process longer or less frequent primes. These considerations question the interpretation of the absence of masked priming effects in nonnative speakers as proof of whole-word storage and access.

The proponents of the opposite, decompositional account, provide evidence in support of nonnative decomposition of regularly inflected words. This evidence comes from the priming experiments, which used stimuli presented in different modalities: auditory (Gor & Cook, 2010; Gor & Jackson, 2013), visual masked-priming (Coughlin & Tremblay, 2015; Feldman et al., 2010; Foote, 2015; Voga, Anastassiadis-Symeonidis, & Giraudo, 2014), and cross-modal, with the auditory prime and visual target (Feldman, Kostić, Basnight-Brown, Filipović Đurđević, & Pastizzo, 2010). All these priming studies report morphological facilitation both in native and nonnative speakers. Support for nonnative morphological decomposition also comes from lexical decision experiments, which compare the processing costs (defined as increased ERs and RTs) for different types of inflected words matched on other lexical properties, such as lexical frequency and length (Gor et al., 2017a; Portin, Lehtonen, & Laine, 2007; Portin, Lehtonen, Harrer, Wande, Niemi, & Laine, 2008).

Importantly, while providing evidence in support of nonnative decomposition, these studies also signal differences between native and nonnative morphological processing. First, nonnative speakers are slower than native speakers in word recognition (e.g., Gor & Cook, 2010; Gor & Jackson, 2013), and second, they are more influenced by changes in allomorphy, or changes to the phonology of the morpheme that occur in different inflected word forms, for example, in verb stems in German, French, and Russian (Estivalet & Meunier, 2015; Gor & Jackson, 2013; Neubauer & Clahsen, 2009). And third, nonnative speakers are more sensitive to lexical frequency (Diependaele, Lemhöfer, & Brysbaert, 2013), and accordingly, frequency plays a stronger mitigating role in nonnative morphological processing (Gor & Jackson, 2013; Portin et al., 2007; 2008). For example, lexical frequency interacted with L2 proficiency and form regularity in an auditory morphological priming study, which examined the processing of inflected Russian verb forms with different degrees of regularity (Gor & Jackson, 2013). In processing high-frequency verbs, all tested L2 participants showed facilitation regardless of the degree of form regularity. Conversely, in the low-frequency range, L2 proficiency interacted with verb regularity: only regular verbs led to facilitation at all the proficiency levels, while semi-regular verbs led to facilitation only at two higher proficiency levels, and irregular verbs only at the highest proficiency level. Therefore, while nonnative processing relies on the same decompositional mechanism as native processing, in nonnative speakers, this mechanism does not work as efficiently as in native speakers.

While the role of nonnative proficiency in the processing of inflected words has been addressed in a number of studies (Gor, Chrabaszcz, & Cook, 2017a; Gor et al., 2017b; Gor & Cook, 2010; Gor & Jackson, 2013), the role of the early and late onset of language learning in this domain is yet poorly understood. One population of early learners that is particularly relevant for the understanding of the developmental aspects of inflection are the so-called heritage speakers, or "unbalanced bilinguals, simultaneous or sequential, who shifted early in childhood from one language (their heritage language) to their dominant language (the language of their speech community)" (Scontras, Fuchs, & Polinsky, 2015). Two characteristics of heritage speakers lead to opposite predictions regarding how nativelike their processing of inflectional morphology should be. First, heritage speakers start learning their heritage language since birth. Therefore, the initial exposure to the heritage language is the same as in native speakers, and so are the mechanisms underlying the initial stages of heritage language learning. This early onset of language learning is predicted to lead to nativelike performance, and a processing advantage in heritage speakers compared to late L2 learners. In a masked-priming study with morphologically related prime-target pairs, heritage speakers of Turkish showed significant facilitation for both inflected and derived primes (Jacob & Kirkici, 2016), unlike late L2 learners of Turkish, who showed facilitation only for derived primes (Kirkici & Clahsen, 2013). Yet, the same heritage participants showed facilitation for phonologically overlapping, but semantically and morphologically unrelated prime-target pairs, which opens the possibility that they were sensitive to orthographic overlap rather than morphological structure (Jacob & Kirkici, 2016).

Second, heritage speakers often do not receive schooling in the heritage language, and as a result, miss formal instruction in inflectional paradigms, which helps to develop the awareness of inflection, especially, when inflectional affixes are not salient in the input. For example, in Russian, inflections are often homonymous, and their homonymy is considerably enhanced by the phonological and phonetic reduction processes in unstressed inflections that lead to their increased homophony and decreased salience. Formal schooling helps elementary school children to map the spellings that maintain the morphological contrasts to the appropriate inflections, and thereby develop their morphological awareness (see Gor et al., 2017b, for a discussion). Consequently, the opposite prediction is that heritage speakers will lag behind native speakers, and possibly, late formal L2 learners in their processing of inflectional morphology. To the best of our knowledge, there exists only one study that directly compares the processing of inflection in heritage speakers, late L2 learners, and native speakers (Gor et al., 2017b). The results of the study support the second prediction: heritage speakers lagged behind proficiency-matched late L2 learners in developing sensitivity to case frequency in a cross-modal morphosyntactic priming task.

To summarize, considerable evidence has been accumulated regarding nonnative processing of inflected words with the help of online experimental methods, such as an auditory or visual LDT with or without morphological priming. This evidence suggests that L2 speakers analyze inflected words in terms of morphological structure, rather than storing and retrieving them as whole words. At the same time, nonnative speakers are less efficient at the processing of inflected words than native speakers. Therefore, demonstrating nonnative sensitivity to morphological structure of inflected L2 words is not equivalent to establishing that nonnative speakers have nativelike knowledge of inflection. In fact, this question has not been explicitly addressed in research on word recognition, because only responses to correctly inflected words are normally analyzed. The current study overcomes this limitation and focuses on the processing of nonwords, i.e., incorrectly inflected words, in an auditory LDT. It compares heritage speakers and late L2 learners to native speakers, and thereby examines the role of the early and late onset of language learning.

1.1 Nonnative processing of Russian nominal inflection

The present study compares the processing of inflected Russian nouns vis-à-vis matched nonwords with real noun stems and inflections combined in an illegal way in an auditory LDT. Matching nonwords composed of non-existent stems and real inflections served as a control condition. This section will provide a context for the study by briefly reviewing the Russian nominal inflection and the available research on the processing of Russian inflected nouns by native and nonnative speakers.

Russian nominal inflection is organized in inflectional paradigms, with six cases and two numbers – a total of 12 inflected forms per noun, with several homonymous inflections usually reducing the actual number of resulting inflected forms. The nominative case (in the singular for most nouns) is the citation form of Russian nouns: this is how they are listed in dictionaries. The nominative case is also used for self-standing words and sentence subjects. Russian has three noun paradigms called declensions, with their own sets of inflections. The citation form of the noun clearly specifies its declension type (except for the 3rd declension that will not be discussed because it is not included in the study). Table 1 represents the inflectional paradigms for 1st and 2nd declension nouns used in the study with the cases in the critical conditions represented in bold face, and reports the frequency of each case based on the disambiguated corpus of Russian <http://www.ruscorpora.ru/en/>. As can be seen from Table 1, in the singular, the nominative is the most frequent case, followed by the genitive, which has the highest frequency of all the oblique cases. In the plural, the genitive is the most frequent case in the whole paradigm, followed by the nominative. Thus, overall, the nominative and the genitive are the most frequent cases in the Russian nominal paradigm. The instrumental case is one of the three oblique cases with the lowest frequency. In terms of the type of inflection used in the Russian nominal paradigm, in most cases, an overt inflection is added to the stem (e.g., *sobak-a* 'dog'). However, in two cases, the nominative singular and the genitive plural, nouns may have zero inflections, as explained below (e.g., in *zakon* 'law' and *sobak* 'of dogs').

Two studies, which examined the recognition of Russian inflected nouns by native and nonnative speakers at different proficiency levels, have reported several findings relevant for the present study, and will be briefly reviewed below. The first study (Gor et al., 2017a), an auditory LDT, capitalized on the properties of the Russian nominal paradigm that can be observed in Table 1: 1st declension nouns have a zero inflection in the nominative singular (*zakon*), and the inflection *-a* in the genitive singular (*zakon-a* 'of the law'), while 2nd declension nouns have the inflection *-a* in the nominative (*sobak-a*), and a zero inflection in the genitive plural (*sobak*). In Experiment 1, native and L2 participants showed no additional processing costs for the overt inflection. At the same time, native speakers, but not L2 speakers, showed additional processing costs (longer RTs) for oblique-case nouns compared to the citation form, regardless of the inflection. These additional processing costs were associated with the checking of the recombined word at later stages of morphological processing. Thus, the L2 speakers did not appear to engage in the checking stage of morphological processing – accessing the stem was sufficient for them to decide whether a stimulus was a word or a nonword; no checking of the recombined stem plus inflection form was needed.

Table 1. First-declension masculine nouns, and second-declension feminine nouns: Corpus-based frequency of case inflections

	Case	Singular	Case frequency	Plural	Case frequency
First declension (masculine nouns)	Nominative	**zakon**	0.367	zakon-*ɨ*	0.273
	Accusative	zakon	0.174	zakon-*ɨ*	0.164
	Genitive	**zakon-*a***	0.232	zakon-***ov***	0.349
	Prepositional	zakon-*e*	0.085	zakon-*akh*	0.066
	Dative	zakon-*u*	0.053	zakon-*am*	0.053
	Instrumental	zakon-*om*	0.089	zakon-*ami*	0.096
Second declension (feminine nouns)	Nominative	**sobak-*a***	0.315	sobak-*i*	0.232
	Accusative	sobak-*u*	0.205	sobak-*i*	0.208
	Genitive	sobak-*i*	0.233	**sobak**	0.313
	Prepositional	sobak-*e*	0.107	sobak-*akh*	0.093
	Dative	sobak-*e*	0.051	sobak-*am*	0.044
	Instrumental	sobak-***oj***	0.089	sobak-*ami*	0.110

Note: Case frequency refers to the relative frequency of this case in the paradigm calculated for all nouns in the disambiguated sub-corpus of the Russian National Corpus. Nouns in bold indicate the critical conditions for comparison in Dataset 1. Inflections in bold refer to the incongruent inflections used in nonce nouns in the critical conditions. The symbol "ɨ" corresponds to the high unrounded vowel that is spelled in Russian as "ы", which alternates with "i" after phonologically hard consonants.

This was an efficient strategy given that all nonword stimuli in the experiment had nonword stems. Following the study by Taft (2004), Experiment 2 modified the structure of nonwords and tested native speakers and L2 speakers at several proficiency levels, including the level tested in Experiment 1. In Experiment 2, part of the nonwords with nonword stems were replaced with nonwords composed of illegally combined real stems and inflections. In order to correctly reject such nonwords, it is necessary to check the recombined word form, and not just the stem. Accordingly, in Experiment 2, the processing costs for oblique-case nouns emerged in L2 speakers, and they increased at higher proficiency levels. Therefore, the study demonstrated a developmental trajectory for the processing advantage in the recognition of citation forms in L2 speakers. Overall, the study supported the claim that the nominative case, the citation form, enjoys a special status in lexical access, a position shared with the satellite-entries hypothesis proposed for nominal inflection in the Serbian language (Lukatela, Gligorijevic, Kostic, & Turvey, 1980). According to the satellite-entries hypothesis, the nominative case, the citation form of nouns, serves as the nucleus of the inflectional paradigm, with oblique cases serving as satellites. The special status of the nominative case, interpreted as faster access to nouns inflected in the nominative, was shown for Serbian nouns in a visual lexical decision task (Lukatela et al., 1980).

The next study, a cross-modal morphosyntactic priming task, (Gor et al., 2017b) has addressed two additional issues in the recognition of Russian inflected nouns by native, heritage, and L2 speakers of Russian. The auditory primes were adjectives that had an ambiguous inflection congruent with several oblique cases, but incongruent with the nominative case, the citation form. The visual targets were nouns in one of three cases: the nominative (a case incongruent with the prime), the genitive (a congruent and high-frequency case), and instrumental (a congruent and low-frequency case). Native participants responded the fastest to the citation form, followed by the high-frequency genitive, and the slowest to the low-frequency instrumental case. The difference between two oblique cases emerged only in high-proficiency late L2 learners, and was absent in proficiency-matched heritage speakers. The study demonstrated that the processing advantage for the citation form was present in all three groups even for noun phrases with incongruent case. In addition, L2 learners accessed nouns inflected in a more frequent case faster than nouns in a less frequent case, whereas heritage speakers did not show such a pattern.

The aforementioned studies demonstrated that native speakers of Russian recognized nouns in the nominative singular, the citation form, faster than the same nouns in the genitive, the oblique case, suggesting that the citation-form advantage is a fundamental psycholinguistic property of the Russian nominal paradigm. Such a processing advantage for the citation form gradually emerges in L2 speakers with increasing proficiency. Because both native and nonnative speakers recognize same-case nouns with overt and zero inflections equally fast (there is no measurable additional processing cost for affix stripping per se), the additional processing costs for oblique-case nouns are believed to be incurred not at the initial stage of affix stripping (the cost of processing the overt inflection is low), but later at the recombination and checking stage (the cost of checking a particular case in the paradigm is high). Finally, whereas native speakers are sensitive to the frequency distributions of oblique-case nouns, this sensitivity emerges in L2 speakers only at higher proficiency levels, and is absent in heritage speakers. Although previous studies on the topic of processing of Russian nominal inflection elucidated many issues, some questions remain unanswered. It is unclear how robust nonnative representations of inflections are and how prone they are to break-downs in processing. For example, will nonnative speakers be able to detect morphological violations, or is the nonnative processor less stringent about morphological combinatorics? The answer to this question is needed not only to better understand nonnative storage and access of inflected words, but also to evaluate the role of sensitivity to surface morphology in nonnative processing of morphosyntax, and in particular, case agreement and government. Reports of nonnative problems with case in sentence processing (Slioussar & Cherepovskaia, 2014; Slioussar, Stetsenko, & Matyushkina, 2015) can be better understood, and the source of the problem – processing morphological form or sentence structure – can be clearly identified.

1.2 Processing nonwords and nonnative sensitivity to morphological violations

In a typical LDT, the critical items are real words, but since the task is to decide whether the presented stimulus is a word or a nonword, an equal number of nonwords is added to balance out real word experimental stimuli. However, nonwords can play a significant role in behavioral experiments, including a LDT. First, the properties of nonwords can be manipulated to modify participants' strategies in word recognition (Gor et al., 2017a; Taft, 2004). And second, nonwords, both with inflectional and derivational suffixes, can be used as the critical stimuli to test morphological decomposition (Caramazza, Laudanna, & Romani, 1988; Longtin & Meunier, 2005).

Taft (2004) demonstrated that the use of English nonwords, which consist of real stems and inflections combined in an illegal way, for example, *mirths* and *joying,* as opposed to nonwords with illegal stems, for example, *milphs* and *juxing*, influenced the processing of real inflected words in native speakers of English in a visual lexical decision task. When the nonwords in the task were composed of illegally combined real stems and inflections, they drew participants' attention to the need in checking the inflected word. The study by Gor and colleagues (2017a) capitalized on this property of nonword fillers in a LDT to show the emergence of the processing costs for real Russian nouns inflected in an oblique case in L2 speakers of Russian. Following a number of studies on the processing of morphologically complex words in Finnish and Swedish (Lehtonen & Laine, 2003; Portin et al 2007; 2008), the processing costs were operationalized as increased ER and/or RT in response to nouns depending on their case and the presence and absence of an overt inflection. Lower-proficiency participants did not show additional processing costs for oblique-case inflected nouns compared to the same inflected nouns in the citation form in an auditory LDT when all the nonword fillers had nonword stems and real inflections. They started to show additional processing costs when some of the nonwords were replaced by the ones with illegally combined real stems and real inflections.

The study by Caramazza and colleagues (1988) used nonwords created from real Italian verbs as the critical stimuli. For example, in Experiment 1, the nonword was composed of a real stem *cant-* sing, and a real inflection *-evi*, but the 2nd conjugation inflection did not match the 1st conjugation stem. This type of nonword was contrasted with *canzovi*, with a non-existent stem and inflection, and also *cantovi* with a real stem, but nonexistent inflection, and *canzevi* with a non-existent stem, but an existing inflection. The goal of the study was to demonstrate that depending on the properties of inflected nonwords, they would be easier or more difficult to reject in a LDT. This indeed was the case, with real-stem and real-inflection nonwords (*cantevi)* most difficult to reject, and the ones with non-existent stem and inflection (*canzovi*) the easiest to reject.

One of the advantages of using nonwords is that they do not have lexical entries in the mental lexicon, and thus cannot be retrieved as whole words, but can be processed based on the properties of their morphological constituents. Therefore, they provide a testing ground for research on morphological decomposition. More importantly, the nonwords created by illegally combining real stems with real inflections make it possible to explore nonnative sensitivity to morphological violations. This type of nonwords was used as critical stimuli in the present study.

2. The present study

Previous research on nonnative recognition of Russian inflected nouns has demonstrated that late L2 learners of Russian process morphological structure of inflected nouns rather than store and access them as whole words (Gor et al., 2017a). In an auditory LDT, both native speakers and L2 learners showed additional processing costs for oblique-case nouns compared to the nouns in the citation form. The processing advantage of the citation form was also reported in a cross-modal morphosyntactic priming study for NSs, HSs and L2 learners of Russian (Gor et al., 2017b). At the same time, no additional processing costs were observed for the nouns with the overt inflection *-a* (as in *bumag-a*, 'paper' and *zavod-a* 'of factory') compared to the same nouns with a zero inflection (as in *bumag* 'of papers' and *zavod* 'factory') (Gor et al., 2017a). Given that all the nouns were balanced on lemma and surface frequency, the additional processing costs for the oblique case cannot be explained within the non-decompositional account. If inflected words are stored and accessed undecomposed, and the experimental stimuli are balanced on surface frequency and length, they should take the same time to be recognized. Because the additional processing costs cannot be attributed to the initial decomposition, or affix stripping (Taft, 1979, 2004), they are seen as the cost of checking the recomposed inflected form. The understanding of the locus of the processing costs in the recognition of inflected words is supported by the findings of a neuroimaging and an evoked brain potentials study (Lehtonen, Vorobyev, Hugdahl, Tuokkola, & Laine, 2006; Lehtonen, Vorobyev, Soveri, Hugdahl, Tuokkola, & Laine, 2009).

At the same time, the L2 performance in the study by Gor and colleagues (2017a) differed from the native performance in two respects. First, there was a developmental trajectory in L2 processing costs for oblique-case nouns, with only the highest-proficiency group showing nativelike effects. And second, the additional processing costs for oblique-case nouns were observed in lower-proficiency L2 learners only when the task, and more specifically, the structure of the nonwords (i.e., nonwords with real stems combined with real inflections in an illegal way) required the checking of the recombined inflected noun. These findings can be interpreted in favor of the gradual development of nativelike recognition of inflected words in late L2 learners, with inefficient processing of inflection at lower proficiency. However, this research has left some questions unanswered. Given that, by design, a LDT focuses on accuracy and RTs only in response to real words (while nonwords serve to validate the task, in which participants need to decide if presented words are real words or nonwords), the issue whether nonnative participants are sensitive to violations in inflection, such as in illegally combined stems and inflections, remains beyond the scope of the task. Indeed, sensitivity to violations in inflection can only be tested with incorrectly inflected words, aka nonwords. Furthermore, only a direct comparison of the processing costs incurred in the recognition of nonwords with illegally combined real stems and inflections, and nonwords with nonce stems can single out the role of sensitivity to violations in inflection in word recognition. The information about nonnative sensitivity to violations in inflection is needed to establish whether the reported errors in perception and production of morphosyntactic violations in sentence processing are caused by nonnative problems at the level of inflectional morphology or syntactic parsing (or both). Also, to the best of our knowledge, there has been no research on sensitivity to violations in inflectional morphology in word recognition tasks in HSs.

The present study has been designed to examine sensitivity to violations in inflectional morphology, and to compare three groups of participants: NSs, HSs, and L2 learners of Russian. It also fills the gap in the research concerning decomposition of inflected nouns in HSs, with the only available masked-priming study, which supports decomposition of inflection in HSs of Turkish (Jacob & Kirkici, 2016). However, the authors interpret these findings as ambiguous given that the HS participants also showed facilitation due to orthographic overlap.

This auditory LDT compares the processing costs, as measured by increased error rates and/or RTs to Russian nouns belonging to three categories: (1) nouns in the nominative case, or the citation form, (2) nouns in the genitive case, or an oblique case, and (3) nouns with violations in inflection (nonwords). Crucially, the nouns in the three categories share the same stem, which makes it possible to remove any biases resulting from the semantic characteristics of the nouns in the critical conditions. This requires the use of three presentation lists in order to expose the participants to the same stem only once. The first goal of the study is to compare HSs to late L2 learners, on the one hand, and NSs, on the other, with regard to the processing costs incurred in auditory recognition of the nouns that differ in case (the nominative vs. the genitive) and the type of inflection (overt inflection *-a* vs. zero inflection). We use a Latin square design: both the nominative and the genitive nouns have either an inflection *-a* or a zero inflection, and are balanced on their lexical properties: surface and lemma frequency, and length. For example, in the nominative case, *zakon* 'law' and *sobak-a* 'dog' differ by the presence of the inflection *-a* in *sobak-a*. In the genitive case, *zakon-a* and *sobak* differ by the presence of *-a* in *zakon-a*. Because the same nouns appear on two lists, the lemma frequency is the same for the nouns in two cases, the nominative and the genitive.

The second goal is to examine the processing costs for the nonwords with violations in the inflection. Thus, in addition to *zakon* and *zakon-a*, the third condition has been included: **zakon-oj* (instead of the correct form *zakon-om*). The nonword **zakon-oj* has the inflection of the instrumental singular of 1st declension nouns instead of *zakon-om*, the appropriate instrumental singular for 2nd declension nouns. The fourth critical condition, in which nonwords had nonword stems combined with real inflections, e.g., **zakil-oj* with the stem **zakil-* instead of *zakon-* was needed for the following reason: If nonnative participants engage in morphological decomposition and checking, but do not have robust representations of inflectional paradigms for different declension types, they should take longer to reject a nonword with a real stem and inflection that are illegally combined, and should have a high ER in processing such nonwords. Given that nonwords usually take longer to reject than real words (Coltheart, Besner, Jonasson, & Davelaar, 1979), the fact that nonwords take longer to respond to than real words is insufficient to make claims about nonnative problems with inflection. If nonwords with real stems and incongruent inflections show a higher ER and take longer to process compared to nonwords with nonce stems, this is an indication that nonnative participants have problems with checking the inflection.

The study asks the following research questions:

1. Do HSs of Russian show the same pattern of decomposition of inflected nouns, including the advantage of the citation form, as the one observed in previous studies in late L2 learners and NSs?
2. What is the role of the early and late onset of language learning in sensitivity to inflectional violations?
3. What is the role of proficiency in sensitivity to inflectional violations?

2.1 Method

2.1.1 *Participants*

Thirty-four late L2 learners (M=23.5 years of age; 11 males) and twenty-five early learners, HSs of Russian (M=21.3 years of age; 8 males) took part in the study. Thirty-nine NSs of Russian (M=28.3 years of age; 8 males) participated in the study as a control group. Prior to participating in the study, L2 learners and HSs of Russian filled out a questionnaire with questions about their background and experience of learning Russian, as well as rated their Russian proficiency on a scale from 1 (minimum) to 10 (maximum) in different linguistic domains. In addition, they took a standardized test of linguistic proficiency, a formal Oral Proficiency Interview (OPI), on the basis of which they were assigned the following proficiency levels according to the guidelines of the American Council on the Teaching of Foreign Languages (ACTFL): Intermediate (10 HSs and 12 L2 speakers), Advanced (10 HSs and 16 L2 speakers), and Superior (5 HSs and 6 L2 speakers) levels. These OPI levels correspond to the following levels on the numeric scale used in the Interagency Language Roundtable (ILR) testing: ILR1, 2, and 3. The ILR scale, unlike the ACTFL scale, goes up to the level ILR5, which corresponds to a native speaker. Accordingly, NSs in this study were coded as ILR5, and proficiency was added as a variable to statistical analyses. All participants signed the informed consent form approved by the Institutional Review Board and received monetary compensation for participation in the study. The participant data are presented in Table 2.

Table 2. Participants' language learning history

	Mean (SD)	
Question	**L2**	**HS**
Age at the time of testing	23.5 (3.6)	21.3 (3)
I started learning Russian when I was… years old	16.7 (5.3)	from birth-2
I started learning English when I was… years old	from birth	4.7 (3.1)
I had formal instruction in Russian for at least… years	3.4 (1.9)	4.1 (2.7)
Percent of daily use of Russian (%)	10–30	20–40
Self-rated competency in Russian:		
pronunciation	6.1 (1.4)	7 (1.8)
conversational proficiency	6.1 (1.30)	6.5 (1.9)
listening proficiency	7.1 (1.3)	7.7 (2.1)
reading proficiency	6.5 (1.9)	6.2 (2)
writing proficiency	6 (1.6)	5.2 (2.3)
knowledge of grammar	5.9 (2)	5 (2.3)

2.1.2 *Materials*

The materials consisted of several sets of stimuli (see Table 3), which were counterbalanced across three presentation lists. The conditions in Table 3 are illustrated with examples from the stimulus set that will be further used in reference to the conditions in the text. All real nouns were drawn from the list of 2,000 most frequent Russian words to make sure all participants knew the words used as experimental stimuli. The first set of stimuli (set A in Table 3) included 144 items: 72 real nouns and 72 nonwords matching the critical nouns in inflection. They were subdivided into 4 conditions (18 items each, for words and nonwords) on the basis of a balanced Latin square design with two fully crossed factors, which varied across two levels: inflectional form (citation vs. oblique) x inflection type (zero vs overt). Thus, experimental words could either have a citation form (1st declension masculine singular nouns in the nominative case, *zakon* 'law', and 2nd declension feminine singular nouns in the nominative case, *sobak-a* 'dog'), or be marked for an oblique case (1st declension masculine singular nouns in the genitive singular case, *zakon-a* 'of law' and 2nd declension feminine plural nouns in the genitive plural case, *sobak* 'of dogs'). Note that while the masculine citation form *zakon* has a zero (-*ø*) inflection, the feminine citation form *sobak-a* has an overt inflection (-*a*). When these nouns are used in the oblique form of the genitive case, the masculine noun *zakon-a* receives an overt inflection -*a*, while the feminine noun *sobak* drops the inflection -*a*. Therefore, the case and the type of inflection are disassociated. All experimental nouns were balanced in terms of stem length (in the number of syllables), and surface and lemma frequencies in order to rule out their effect on the outcome variables. We used 1st and 2nd declension nouns with monosyllabic and disyllabic stems (nine monosyllabic and nine disyllabic stems per condition), so that the stimulus length in syllables across the critical comparisons was the same. The critical comparisons were the comparisons of either zero-inflected or overtly inflected nouns in different cases, for example, *zakon* (citation) and *sobak* (oblique). While citation forms in highly inflected languages such as Russian usually have the highest frequency counts compared to other case forms, Russian affords a valuable comparison of citation and oblique forms because of the high frequency of the genitive case forms within the Russian nominal paradigm due to its high functional load in quantification, and especially, expressions with numerals (Gor et al., 2017a). Frequency counts were retrieved from the Frequency Dictionary for Russian by Sharoff (2001, 2006). Nonwords for this stimulus set were constructed by substituting several non-initial letters in the stem of the corresponding critical nouns (e.g., *zakon* → **zakil*, nonce-stem condition) such that they had onsets phonologically overlapping with the target nouns and the same inflections. These nonwords were added to balance the word-to-nonword ratio in the lexical decision task and were not included in the analysis. In contrast, another set of items consisting exclusively of nonwords (set B in Table 3) involved a critical experimental manipulation that had a goal to examine how native and nonnative speakers process words with illegally combined stems and inflections. To construct these nonwords, we took the stem of the target nouns from the set A and combined it with the inflection from a different inflectional paradigm, which resulted in inflectionally incongruent forms (nonce-inflection condition, $n=36$), e.g., the stem of a 1st declension noun *zakon-* was combined with the incongruent inflection that marks instrumental case in the 2nd declension paradigm, *-oj*, as in **zakon-oj* rather than the inflection *-om* that marks the instrumental case in 1st declension masculine nouns. The same procedure was implemented to construct inflectionally incongruent nonwords for 2nd declension feminine nouns (e.g., the genitive plural *sobak-* + *-ov* resulting in **sobak-ov* instead of the zero-inflected *sobak*). Additionally, we constructed matching nonwords by using nonword stems from the stimulus set A and combining them with the same inflections as the ones used to construct inflectionally incongruent nonwords, *-oj* and *-ov* described above, as in **zakil-oj* and **sobur-ov*. This produced 36 unique nonwords with nonword stems but real inflections (nonce-stem condition, $n=36$).

Finally, filler items (both words and nonwords, $n=108$) unrelated to the target words (stimulus set C in Table 3) were added in order to make the critical comparisons less obvious to participants. Filler words included nouns belonging to different declensions and marked for different cases. For example, we used 2nd declension singular nouns in the instrumental case (*vod-oj* 'by water'), 1st declension plural nouns in the genitive case (*dom-ov* 'of houses'), and 1st and 2nd declension singular nouns in the dative or prepositional case (*stol-e* 'to/on table'). Filler nonwords contained nonce nouns of both types: nonwords with nonword stems and nonwords with incongruent inflections.

To summarize, for each noun in a critical condition, there were three forms: citation (e.g., *zakon*), oblique (e.g., *zakon-a*), and illegal (e.g., **zakon-oj*), distributed and balanced across three presentation lists. Additionally, there were nonwords with nonce stems phonologically overlapping with the real words in the stimuli, which had the same inflections as the illegally combined nonwords (e.g., **zakil-oj*). These four forms, two real words and two nonwords, were organized as two datasets for the purpose of statistical analyses. Dataset 1 with the conditions *zakon/sobak-a/zakon-a/sobak* dealt with the issue of decomposition and sensitivity to the difference between the citation form and the oblique case, while Dataset 2 with the conditions *zakon/zakon-a/*zakon-oj/*zakil-oj* and *sobak-a/sobak/*sobak-ov/*soburov* compared the processing patterns for real and nonce nouns, and targeted the differences in the outcomes for two types of nonwords.

Table 3. Materials design

Set	Condition	Lex. status	Inflectional form	Inflection type	Inflection	Example word	N of items per condition	Mean (SD) Length in syllables	Mean (SD) Lemma log freq.	Mean (SD) Surface log freq.
A	experimental	word	citation: nom	zero	-ø	zakon	18	1.5 (0.5)	2.2 (0.2)	1.6 (0.3)
				overt	-a	sobak-a	18	2.5 (0.5)	2.4 (0.3)	1.5 (0.4)
			oblique: gen	zero	-ø	sobak	18	1.5 (0.5)	2.4 (0.3)	1.5 (0.4)
				overt	-a	zakon-a	18	2.5 (0.5)	2.2 (0.2)	1.5 (0.4)
	related fillers	nonword	citation: nom	zero	-ø	*zakil	18	1.5 (0.5)	n.a.	n.a.
				overt	-a	*sobur-a	18	2.5 (0.5)	n.a.	n.a.
			oblique: gen	zero	-ø	*sobur	18	1.5 (0.5)	n.a.	n.a.
				overt	-a	*zakil-a	18	2.5 (0.5)	n.a.	n.a.
Set	**Condition**	**Lex. status**	**Locus of violation**	**Inflectional violation**	**Inflection**	**Example word**	**N of items per condition**	**Length in syllables**	**Lemma log freq.**	**Surface log freq.**
B	experimental	nonword	inflection	2nd gen pl-> 1st gen pl	-ov	*sobak-ov	18	2.5 (0.5)	n.a.	n.a.
				2nd instr sg -> 1st instr sg	-oj	*zakon-oj	18	2.5 (0.5)	n.a.	n.a.
		nonword	stem	n.a.	-ov	*sobur-ov	18	2.5 (0.5)	n.a.	n.a.
				n.a.	-oj	*zakil-oj	18	2.5 (0.5)	n.a.	n.a.
C	unrelated fillers	word	n.a.	n.a.	various	n.a.	66	various	n.a.	n.a.
		nonword	inflection, stem	n.a.	various	n.a.	42	various	n.a.	n.a.

Note: Experimental comparisons are highlighted in light grey.
Abbreviations: nom = nominative, gen = genitive, instr = instrumental, pl = plural, sg = singular; freq. = frequency

The materials were recorded by a female native speaker of Russian in a sound-attenuated booth. There were 324 items per list, the order of presentation of items within a list was randomized across the three stimulus sets.

2.1.3 *Procedure*

Participants were tested in a remote setting using the DMDX program (Forster & Forster, 2003). Prior to the experiment, they performed an online equipment check and reported any issues requiring troubleshooting. After ensuring that the experiment can be reliably conducted on a remote computer, participants received an executable experimental package with detailed written instructions that explained the experimental procedure and the task. They were required to remove all distractions and wear headphones throughout the duration of the experiment. During the experiment, participants heard Russian spoken words and nonwords. Their task was to judge whether a given word was a real Russian word or not. They were instructed to press the right control key on their keyboard to provide a YES response, and the left control key to provide a NO response. Each trial began with a fixation cross '+' presented on the computer screen for 500 ms and immediately followed by a spoken word or a nonword. If the test-taker did not give a response within 4000 ms, the program proceeded with the presentation of the next item. Reaction times were recorded from target onsets. Participants were able to take three self-timed breaks during the test. The experiment was preceded by 10 practice trials to familiarize participants with the nature of the task. After each practice trial, participants received feedback about the accuracy of their decisions. No feedback was provided during the presentation of experimental trials. The whole experiment lasted about twenty minutes.

2.2 Results

2.2.1 *Dataset 1: Real words: Case and inflection*

Dataset 1 focused on the comparisons of the processing costs to different cases in the inflectional paradigm (citation and oblique), and the type of inflections (overt and zero) in three groups of participants: NS, HS, and L2 learners. A logistic mixed-effects model (glm function) was used to analyze the ER data, and a linear mixed-effects modeling approach was used to analyze the log-transformed RT data. We performed and compared a series of fitted mixed-effects regression models via backward testing of fixed effects in order to measure the goodness of model fit without unnecessary parameter overfitting. Only the fixed effects and factorial interactions that improved the fit of the model without overfitting were retained in the models. Random intercepts were included in all models, and random slope effects were included where they could be justified statistically using the Akaike information criterion (AIC) (Akaike, 1974), the criterion recommended for the evaluation of mixed-effects models (Fang, 2011; Vaida & Blanchard, 2005). The initial model included four fixed factors (group: native (NS), heritage speakers (HS), and L2 learners (L2); form: citation, and oblique; inflection: zero, and overt; and proficiency as a continuous variable: ILR 1–5) and all of the interactions between the factors. Levels of the fixed factors were treatment-coded with the intercept estimating a dependent variable (ER or RT) for the citation form with a zero inflection (e.g., *zakon*) in the NS group of participants. All pair-wise comparisons were performed within the corresponding best-fitting model by changing the reference level of the factor. The models' estimated coefficients for each factor and interaction terms, standard errors, degrees of freedom, the t statistic (or z statistic), and the p values are presented in Table A1 in the Appendix. All data analyses were done in R programming environment (R Core Team, 2015), using lme4 package for R (Bates, Maechler, Bolker, & Walker, 2014); degrees of freedom and p-values were generated using lmerTest (Kuznetsova, Brockhoff, & Christensen, 2015).

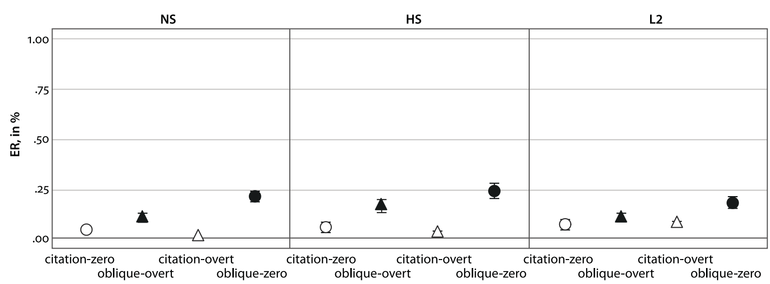
Error rate

The best-fitting model for the ER data includes group, form, inflection, proficiency, and a group by form interaction (AIC = 1370.1). All groups showed statistically significant sensitivity to whether the word was in the citation or in the oblique-case form, performing with minimal error on citation forms and worse on oblique forms (NS: $\beta = 2.16$, SE = 0.410, $z = 5.26$, $p < 0.001$; HS: $\beta = 2.059$, SE = 0.439, $z = 4.69$, $p < 0.001$; L2: $\beta = 0.95$, SE = 0.340, $z = 2.80$, $p < 0.01$) (see Figure 1A). The effect size of form was of comparable magnitude for NSs and HSs ($\beta = 0.10$, SE = 0.542, $z = -0.19$, $p = 0.853$), while being significantly smaller for L2 learners in comparison with both NSs ($\beta = 1.209$, SE = 0.485, $z = 2.49$, $p < 0.05$) and HSs ($\beta = 1.11$, SE = 0.501, $z = 2.21$, $p < 0.05$). Also, a strong effect of inflection was observed, such that words with zero inflections elicited more errors than words with overt inflections. It is reasonable to presume that the effect of zero inflection is primarily driven by the oblique form with zero inflection (*sobak*), which had the highest error rate across all groups; the model, however, did not support the interaction between form and inflection, suggesting that the form of the word had a much greater effect on accuracy regardless of the presence of an overt or a zero inflection.

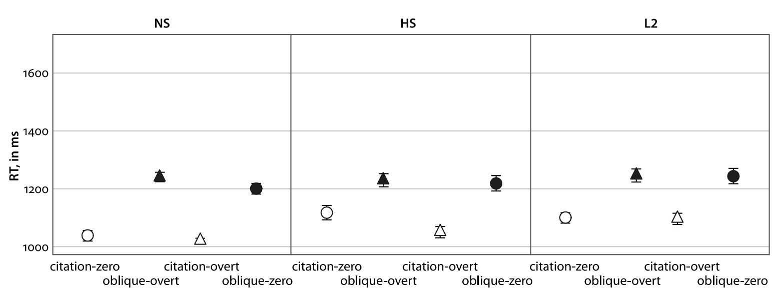
Reaction times

Prior to conducting the RT analysis, incorrect responses as well as the data exceeding 3 SD from the overall group mean were discarded. This procedure resulted in the elimination of 11% and 1.7% of the data respectively. The analysis was performed on the log-transformed RT data. The final model was similar to the model of the ER data and included the same fixed effects: group, form, inflection, proficiency, and a group by form interaction (AIC=1374.0). Two fixed factors – inflection and proficiency – while not being significant predictors in the reported model, were retained in the model based on the results of the model comparisons, which confirmed that the model fit was improved if these factors were included.

Besides the expected difference in the overall speed, with native speakers being overall faster than both nonnative groups, all groups demonstrated sensitivity to form: words in the citation form were processed faster than words in the oblique-case form (NS: $\beta = 0.17$, SE = 0.012, $z = 14.97$, $p < 0.001$; HS: $\beta = 0.132$, SE = 0.015, $z = 9.03$, $p < 0.001$; L2: $\beta = 0.127$, SE = 0.012, $z = 10.32$, $p < 0.001$). The effect of form was most robust in the NSs (vs. HSs: $\beta = 0.039$, SE = 0.018, $z = -2.147$, $p < 0.05$; vs. L2 learners: $\beta = 0.045$, SE = 0.017, $z = 2.666$, $p < 0.01$), while the two nonnative groups did not differ significantly from each other ($\beta = 0.005$, SE = 0.019, $z = -0.261$, $p = 0.794$). The effect of inflection was not statistically significant. See Figure 1B.



A.



B.

Figure 1. Error rates and reaction times in three participant groups for Dataset 1 (real nouns)*Note*: Panel A represents error rates, and panel B represents reaction times.

Summary

Overall, the observed results indicate that both HSs and L2 learners, while being slower, demonstrated the same pattern of RTs as NSs: they showed a processing advantage for the citation form compared to the oblique-case form. This RT difference signals sensitivity to case inflections in all three groups, and more generally, to case hierarchy previously reported for NSs and late L2 learners of Russian (Gor et al., 2017a, 2017b). At the same time, the magnitude of the effect of case in the ER analysis was smaller in L2, and bigger in NSs and HSs. Proficiency was not significant in this dataset, possibly, because the processing advantage for the citation form is a robust effect when the task is conducive to rechecking the whole inflected noun (see Gor et al., 2017a). The effect of inflection observed in the RT analysis – longer RTs for zero-inflected oblique-case nouns, is the same as in the behavioral part of the fMRI study with native Russian participants (Gor et al., 2017c).

2.2.2 *Dataset 2: Real and nonce nouns*

Dataset 2 focused on the comparisons of the processing costs to real nouns in two cases (the word-citation and word-oblique conditions), and nonce nouns of two types: nonwords with illegally combined real stems and real inflections (the nonce-inflection condition), and nonwords with nonce stems (the nonce-stem condition) in three participant groups: NS, HS, and L2 learners. The analyses were conducted separately for 1st and 2nd declension nouns, because they have different properties (e.g., an overt or zero inflection in the cases of interest), and required different manipulations in the nonce-inflection condition. In performing the data analysis, we followed the same procedure for model comparison and selection, as described in the Results section for Dataset 1 above. The initial model included three fixed factors (group: NS, HS, L2; condition: word-citation, word-oblique, nonce-inflection, nonce-stem; proficiency as a continuous variable: ILR 1–5), and all of the interactions between the factors. Levels of the fixed factors were treatment-coded with the intercept estimating a dependent variable (ER or RT) for real words in the citation form (e.g., *zakon* or *sobaka*) in the NS group. As in Dataset 1, all pair-wise comparisons were performed within the best-fitting model by changing the reference level of the factor. The models' estimated coefficients for each factor and interaction terms, standard errors, degrees of freedom, the t statistic (or z statistic), and the p values are presented in Table A2 in the Appendix.

Dataset 2.1: 1st declension nouns

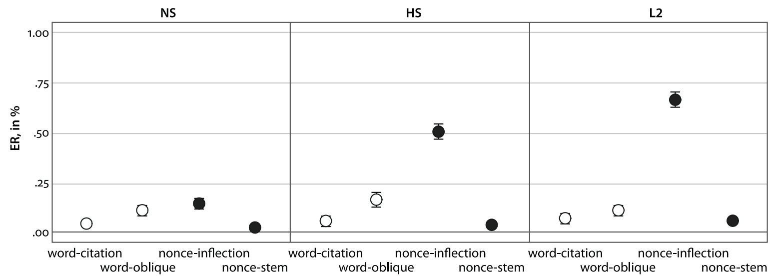
Error rate

The best-fitting model for the data includes group, condition, proficiency, and a condition by proficiency interaction (AIC = 1467.1). Since the model comparisons suggested that proficiency was a better predictor for the model data and did not support the group by condition interaction, the analysis does not show how each of the conditions fared within each group and should be interpreted as a general trend across all groups. The model demonstrated that the nonce condition with the morphologically incongruent inflection (nonce-inflection) elicited the most errors (compared to word-citation: $\beta = 4.42$, $SE = 0.466$, $z = 9.487$, $p < 0.001$; to word-oblique: $\beta = 3.785$, $SE = 0.472$, $z = 8.016$, $p < 0.001$; to nonce-stem: $\beta = 5.22$, $SE = 0.802$, $z = 6.514$, $p < 0.001$). The error rates for the other three conditions – two word conditions and the nonce condition with a nonword stem – were not statistically different from each other and patterned together (see Figure 2A). In addition, unlike other conditions, where the error rate was consistent across all proficiency ranges, nonwords with incongruent inflections (nonce-inflection) showed significant accuracy gains as participants' proficiency increased ($\beta = -0.657$, $SE = 0.145$, $z = -4.504$, $p < 0.001$). Indeed, in the nonce-inflection condition, the lowest-proficiency group, ILR1, or Intermediate, had an extremely high ER of 67.4%, which decreased to 39.4% in the ILR3, or Superior group (see Figure 3). This result is particularly important when interpreted in comparison with the other nonce condition – nonword with nonce stem, which showed no statistically significant effect of proficiency ($\beta = -0.249$, $SE = 0.280$, $z = -0.89$, $p = 0.373$). Nonwords with nonce stems have elicited extremely low error rates even in learners at lower proficiency ranges, while the nonwords with incongruent inflections continued to present a major challenge even for Superior speakers (ILR3).

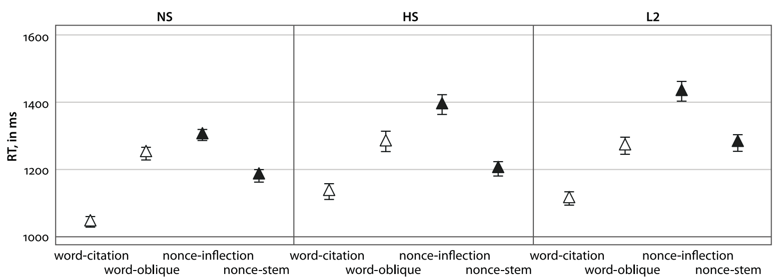
Reaction times

Prior to RT analysis, incorrect responses as well as data exceeding 3 SD from the overall group mean were discarded. This procedure resulted in the elimination of 10.5% and 1.6% of the data respectively. The best-fitting model for the data included group, condition, proficiency, and a condition by group interaction ($AIC = 1007.4$). It did not support the inclusion of factorial interactions with proficiency, and this variable was retained as a covariate only.

In all three groups, real words in the citation form were processed significantly faster than the real words in the oblique form (NS: $\beta = 0.163$, $SE = 0.017$, $t = 9.37$, $p < 0.001$; HS: $\beta = 0.120$, $SE = 0.022$, $t = 5.57$, $p < 0.001$; L2: $\beta = 0.132$, $SE = 0.019$, $t = 7.07$, $p < 0.001$) (see Figure 2B). The citation forms were also processed by all groups significantly faster than the nonce conditions (for nonce-inflection and nonce-stem, respectively: $\beta = 0.129$, $SE = 0.018$, $t = 12.33$, $p < 0.001$ and $\beta = 0.011$, $SE = 0.026$, $t = 4.14$, $p < 0.001$ for NS; $\beta = 0.214$, $SE = 0.022$, $t = 9.67$, $p < 0.001$ and $\beta = 0.017$, $SE = 0.029$, $t = 2.42$, $p < 0.05$ for HS; $\beta = 0.251$, $SE = 0.019$, $t = 13.16$, $p < 0.001$ and $\beta = 0.136$, $SE = 0.027$, $t = 5.06$, $p < 0.001$ for L2). When comparing the nonce conditions, we observed that across all groups, the nonce words



A.



B.

Figure 2. Error rates and reaction times in three participant groups for Dataset 2 (real and nonce nouns)
Note: Panel A represents error rates, and panel B represents reaction times.

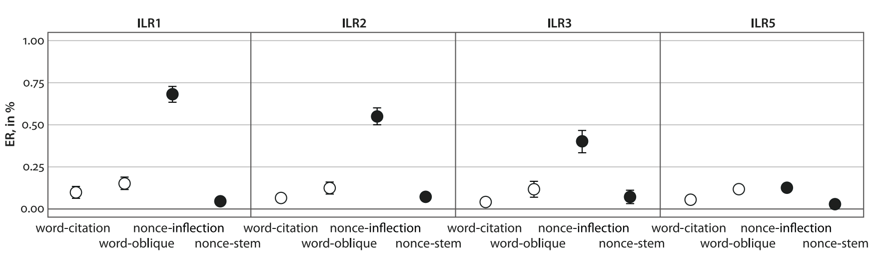


Figure 3. Error rate in response to nonwords: A developmental trajectory
Note: The abbreviations correspond to the following oral proficiency levels:

ILR1 Intermediate
ILR2 Advanced
ILR3 Superior
ILR5 Native Speaker

with morphologically incongruent inflections took longer than the nonce words with incongruent stems (NS: $\beta = 0.111$, SE = 0.026, $t = -4.204$, $p < 0.001$; HS: $\beta = 0.143$, SE = 0.030, $t = -4.824$, $p < 0.001$; L2: $\beta = 0.115$, SE = 0.027, $t = -4.203$, $p < 0.001$).

Dataset 2.2: 2nd declension nouns

Error rate

The statistical modelling for Dataset 2.2 was done in the same way as for Dataset 2.1. The best-fitting model for the data includes group, condition, proficiency, and a condition by group interaction (AIC = 1635.9). Similarly to the results of Dataset 2.1, the model comparisons suggested that proficiency was a better predictor for the model data and did not support the inclusion of the group by condition interaction; therefore, the analysis does not show how each of the conditions fared within each group and should be interpreted as a general trend across all groups. The model demonstrated that the morphologically incongruent nonce-inflection condition elicited overall the highest error rate (compared to word-citation: $\beta = -3.268$, SE = 0.467, $z = -6.984$, $p < 0.001$; to word-oblique: $\beta = -2.572$, SE = 0.297, $z = -8.653$, $p < 0.001$; to nonce-stem: $\beta = -3.470$, SE = 0.486, $z = -7.284$, $p < 0.001$). The lowest-proficiency ILR1 (Intermediate) group had the ER of 62.9% in the nonce-inflection condition, and it decreased to 34.8% in the ILR3 (Superior) group. Proficiency was also a significant predictor of accuracy. The effect of proficiency was statistically significant for word-citation ($\beta = -0.503$, SE = 0.213, $z = -2.359$, $p < 0.05$), nonce-stem condition ($\beta = -0.383$, SE = 0.178, $z = -2.154$, $p < 0.05$), and nonce-inflection condition, where it is the most robust ($\beta = -0.625$, SE = 0.092, $z = -6.760$, $p < 0.001$), indicating that learners' ability to correctly reject nonce words with real stems illegally combined with real inflections increased with proficiency.

Reaction time

Prior to RT analysis, incorrect responses as well as data exceeding 3 SD from the overall group mean were discarded. This procedure resulted in the elimination of 12.3% and 1.7% of the data respectively. The best-fitting model for the data includes group, condition, and proficiency (AIC = 759.31). No factorial interactions were supported by the model.

NSs had marginally faster RTs than HSs ($\beta = 0.121$, SE = 0.064, $t = 1.88$, $p = 0.063$). HSs, in turn, were faster than L2 learners ($\beta = 0.164$, SE = 0.063, $t = 2.609$, $p < 0.05$). The real words in the citation form were processed significantly faster than real words in the oblique form by all participants ($\beta = 0.157$, SE = 0.012, $t = 13.212$, $p < 0.001$) and faster than the nonwords in the nonce-stem and nonce-inflection conditions ($\beta = 0.151$, SE = 0.028, $t = 5.25$, $p < 0.001$, and

$\beta=0.182$, SE$=0.014$, $t=12.872$, $p<0.001$, respectively). The RTs on two types of nonce words did not differ from each other statistically ($\beta=0.031$, SE$=0.029$, $t=1.042$, $p=0.304$).

Summary
The most striking finding across the two datasets of real and nonce nouns is an extremely high ER for nonce nouns with incongruent inflections in the two non-native groups. The ER was higher for nonce nouns with incongruent inflections than for nonce nouns with nonword stems. This effect signals nonnative problems with inflections which result from unfaithful representations of case inflections in the complex nominal paradigm with several inflectional patterns corresponding to different declensions. The high ER was also associated with longer RTs in Dataset 2.1 for 1st declension nouns. Another finding of the analyses of Dataset 2 with nonce nouns is a clear developmental trajectory in nonnative speakers who show a decrease in ER at higher proficiency levels. This outcome is observed in the sample that combines HSs and late L2 learners.

3. Discussion

The main objective of this study has been to document the difficulties with morphological processing that HSs and late L2 learners experience during lexical access of inflected words. The study combines two approaches to the investigation of the processing of inflection in lexical access: it manipulates the properties of real nouns to establish whether morphological decomposition and the checking of recomposed stem-inflection forms takes place (Dataset 1), and manipulates the properties of nonce nouns to show that HSs and L2 learners are uncertain about the correct stem-inflection mappings licensed by the Russian nominal inflection (Dataset 2). Let us review the findings, first, on morphological decomposition, and second, on sensitivity to violations in inflection, and compare HSs and L2 learners to NSs.

The study used the design of a previously reported auditory LDT (Gor et al., 2017a), which teased apart the role of case and overt inflection in the recognition of inflected Russian nouns. It used RTs as a measure of the processing costs incurred in lexical access of nouns that differed by their case (citation or oblique) and the type of inflection (overt, -*a*, or zero). As in the study by Gor and colleagues (2017a), in the present study's Dataset 1, the conditions were fully crossed in a Latin square design, which made it possible to disassociate the contribution of case and inflection to the processing costs.

Following the work of Taft and the logic of the earlier study, and motivated by the findings from neurolinguistics research (Gor et al., 2017a; Gor, Kireev, Chrabaszcz, & Medvedev, 2017c; Taft, 2004; Lehtonen & Laine, 2003: Portin et al., 2007; 2008), it was hypothesized that the locus of processing costs in lexical access of inflected nouns was the late recombination and checking stage rather than the early affix stripping stage. This hypothesis was confirmed for NSs: the presence or absence of the inflection *-a* did not drive the processing costs, while the case of the noun did – longer RTs were observed for oblique-case nouns compared to the citation form, regardless of the presence or absence of inflection. L2 learners showed the same pattern of RTs when the task encouraged the checking of the inflected noun.

The present study asked the question whether HSs, early learners who switched to English as their dominant language when they were children, would show the same processing pattern: additional processing costs for oblique-case nouns. The outcomes of the study confirmed the earlier findings for NSs and late L2 learners, and also showed that HSs were similar to NSs and L2 learners in the pattern of the processing costs: they took longer to recognize the nouns in an oblique case compared to the same nouns in the citation form, regardless of the presence or absence of an overt inflection. Thus, the special status of the citation form in lexical storage and access of Russian nouns has been confirmed for all three groups of participants. This finding supports the claim of the satellite-entries hypothesis that was proposed for Serbian nouns, which have an inflectional paradigm similar to Russian (Lukatela et al., 1980). However, the findings of this study, as well as the one by Gor and colleagues (2017a) do not support whole-word storage and access as the only route available in word recognition: all the nouns in both studies were balanced for surface and lemma frequency, and therefore, the observed additional processing costs had to result from the analysis of the morphological form. While the pattern of the processing costs did not differ across the three participant groups, there was a difference in the ER results: L2 participants showed a smaller difference in the ER for the citation forms and oblique-case nouns compared both to NSs and HSs. This ER pattern indicates that HSs showed nativelike sensitivity to the difference between citation forms and oblique-case nouns, while L2 sensitivity to this difference was less nativelike, even if it was robust in the RT results. This reduced sensitivity to case at the level of ER evokes the results of Experiment 1 in the study by Gor and colleagues (2017a), where L2 learners did not show any preference for the citation form.

The main contribution and the novelty of this study is associated with Dataset 2, which examined the processing patterns for nonce nouns that were created by illegally combining real stems with real inflections. In the past, inflected nonwords with different properties as the critical stimuli were used in a LDT targeting native processing of verbal morphology in Italian (Caramazza et al., 1988). Recently, the processing of nonwords has drawn researchers' attention, because it offers additional insights into word recognition (Yap, Sibley, Balota, Ratcliff, & Rueckl, 2015).

The most striking finding was an extremely high ER for the nonwords with incongruent inflections observed both in HSs and L2 learners (refer to Figure 2A), while the ER in the NS group did not differ from the other conditions. Remarkably, the ER for the nonwords in the nonce-stem condition were low, and did not differ significantly from the real-word conditions in any of the participant groups. Also, there was a strong developmental trajectory in the nonnative groups, with the ER ranging from 67.4% or 62.9%, depending on the subset, in Intermediate proficiency participants to 39.4% or 34.8% in Superior proficiency participants (see Figure 3). Note that the developmental trajectory was similar for HSs and L2 learners, given that there were no group by proficiency interactions in the statistical analyses. Overall, the ER results strongly indicate that both HSs and late L2 learners experience a high level of confusion about what stem-inflection combinations are legal in the Russian nominal paradigm, a finding that has important consequences for the interpretation of nonnative morphosyntactic deficits. Apparently, at least some of the reported insensitivity to morphosyntactic violations in sentence processing, both in L2 and HSs (e.g., Coughlin & Tremblay, 2013; Hopp, 2010; 2013; Jiang, Hu, Chrabaszcz, & Ye, 2015; Montrul, Foote, & Perpiñán, 2008) can be explained by uncertainty about the use of appropriate and congruent inflections, and stem-inflection mappings.

The results of RT analyses for Dataset 2 should be treated with caution given the high ER in the rejection of nonce-inflection nouns in HSs and L2 learners. At the same time, given the low ER for all the other conditions, one can assume that all participants were familiar with the stems and the real words used in the critical conditions. They were quick to reject the nonwords with nonce-stems. Accordingly, despite a reduced number of data points, we treat the RT data on nonce-inflection nouns as informative. The results differed for two subsets. In the 1st declension subset, RTs to nonce-inflection nouns were significantly longer than to nonce-stem nouns, and this pattern was observed across all three participant groups. This finding suggests that all participants processed inflectional morphology – checked the stem-inflection combination for congruence, and thereby incurred additional processing costs compared to the nonwords with nonce stems that could be rejected based solely on the checking of the stem. The 2nd declension subset did not show a difference in RTs for two types of nonwords in any group. The only observed effect was the difference in the speed of responses in three groups: NSs were the fastest, and L2 learners the slowest. HSs were marginally slower than NSs, and significantly faster than L2 learners.

The following observation can be made with reference to Dataset 2: the ER data show a difference across the proficiency levels, and indicate a developmental trajectory in HSs and L2 learners: they make less errors in rejecting the nonwords with incongruent inflections as their proficiency increases. The RT data document a general difference in the speed of word recognition among the participant groups: NSs are the fastest, while L2 learners are the slowest. HSs' response times either pattern with NSs or are marginally slower than those of NSs; however, they are faster than the response times of L2 learners. Therefore, the study supports the HS advantage compared to L2 learners in tasks measuring the speed of auditory lexical access. This HS advantage stands in contrast with the HS disadvantage reported for a visual LDT by Montrul and Foote: HS were slower than late L2 learners in their study (2014). One can attribute the difference to the general advantage of HSs when processing auditory input, and their disadvantage in the processing of visual input, which is related to their language learning background. Indeed, HSs receive early naturalistic input from birth, but typically do not undergo systematic schooling in their heritage language. As a result, they develop nativelike auditory skills, but may have low literacy, which slows them down when processing visual input. Conversely, late L2 learners mostly receive visual input in a formal classroom, and as a result, prefer the visual modality.

In conclusion, the present study reports two sets of findings on early and late learners of Russian: HSs and L2 learners. First, they are sensitive to the case of the inflected noun in auditory word recognition. Therefore, they (a) process inflectional morphology, and (b) show a nativelike pattern of sensitivity to the case hierarchy, and the special status of the citation form in the nominal paradigm. In this respect, the findings support morphological decomposition of inflected words in these two groups of participants. Second, the study reports that both HSs' and L2 learners' accuracy is at chance level when they process nouns with violations in inflection. These two observations suggest that both early and late learners process inflectional morphology, but their processing of inflected words is effortful and unreliable: they are willing to accept words with incongruent inflections. The study also documents a developmental trajectory in early and late learners: their sensitivity to violations in inflection improves at higher proficiency levels. No major differences are observed in the processing patterns of early and late learners; however, overall, HSs are faster in auditory recognition of inflected words. The findings of this study not only inform the debate regarding nonnative morphological decomposition, but are relevant for the understanding of the contribution of morphological sensitivity to morphosyntactic processing.

Acknowledgments

This study was supported by the funding from the Slavic and East European Language Resource Center (SEELRC) at Duke University, and The National Heritage Language Resource Center (NHLRC) at UCLA. The authors express their deep gratitude to Edna Andrews, the Director of SEELRC, and Olga Kagan, the Director of NHLRC, for securing the funding for the project and providing feedback in the course of its development. The author Anna Chrabaszcz was partially supported by the Center for Language and Brain NRU Higher School of Economics, RF Government grant, ag. № 14.641.31.0004.

References

Akaike, H. (1974). A new look at the statistical model identification. *IEEE Transactions on Automatic Control*, 19, 716–723. https://doi.org/10.1109/TAC.1974.1100705

Baayen, H., Dijkstra, T., & Schreuder, R. (1997). Singulars and plurals in Dutch: Evidence for a dual parallel route model. *Journal of Memory and Language*, 37, 94–119. https://doi.org/10.1006/jmla.1997.2509

Baayen, R. H., Milin, P., Filipović Đurđević, D., Hendrix, P., & Marelli, M. (2011). An amorphous model for morphological processing in visual comprehension based on naive discriminative learning. *Psychological Review*, 118, 438–481. https://doi.org/10.1037/a0023851

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2014). lme4: Linear mixed-effects models using Eigen and S4. R package version 1.1-7. <http://CRAN.Rproject.org/package=lme4>

Butterworth, B. (1983). Lexical representation. In B. Butterworth (Ed.), *Language production: Development, writing and other language processes* (pp. 257–294). London: Academic Press.

Caramazza, A., Laudanna, A., & Romani, C. (1988). Lexical access and inflectional morphology. *Cognition*, 28, 297–332. https://doi.org/10.1016/0010-0277(88)90017-0

Clahsen, H., Balkhair, L., Schutter, J-S., & Cunnings, I. (2013). The time course of morphological processing in a second language. *Second Language Research*, 29, 7–31. https://doi.org/10.1177/0267658312464970

Clahsen, H., Felser, C., Neubauer, K., Sato, M., & Silva, R. (2010). Morphological structure in native and nonnative language processing. *Language Learning*, 60, 21–43. https://doi.org/10.1111/j.1467-9922.2009.00550.x

Coltheart, M., Besner, D., Jonasson, J. T., & Davelaar, E. (1979). Phonological encoding in the lexical decision task. *The Quarterly Journal of Experimental Psychology*, 31, 489–507. https://doi.org/10.1080/14640747908400741

Coughlin, C. E., & Tremblay, A. (2013). Proficiency and working memory based explanations for nonnative speakers' sensitivity to agreement in sentence processing. *Applied Psycholinguistics*, 34, 647–647. https://doi.org/10.1017/S0142716411000890

Coughlin, C. E., & Tremblay, A. (2015). Morphological decomposition in native and non-native French speakers. *Bilingualism: Language and Cognition*, 18, 524–542. https://doi.org/10.1017/S1366728914000200

Diependaele, K., Lemhöfer, K., & Brysbaert, M. (2013). The word frequency effect in first- and second-language word recognition: A lexical entrenchment account. *The Quarterly Journal of Experimental Psychology*, 66, 843–863. https://doi.org/10.1080/17470218.2012.720994

Estivalet, G. L., & Meunier, F. E. (2015). Decomposability and mental representation of French verbs. *Frontiers in Human Neuroscience*, 9, Article 4. https://doi.org/10.3389/fnhum.2015.00004

Fang, Y. (2011). Asymptotic equivalence between cross-validations and Akaike information criteria in mixed-effects models. *Journal of Data Science*, 9, 15–21.

Feldman, L. B., Kostić, A., Basnight-Brown, D. M., Filipović Đurđević, D., & Pastizzo, M. J. (2010). Morphological facilitation for regular and irregular verb formations in native and non-native speakers: Little evidence for two distinct mechanisms. *Bilingualism: Language and Cognition*, 13, 119–135. https://doi.org/10.1017/S1366728909990459

Foote, R. (2015). The storage and processing of morphologically complex words in L2 Spanish. *Studies in Second Language Acquisition. FirstView Article.* https://doi.org/10.1017/S0272263115000376

Forster, K. I., & Forster, J. C. (2003). DMDX: A Windows display program with millisecond accuracy. *Behavior Research Methods Instruments and Computers*, 35(1), 116–124. https://doi.org/10.3758/BF03195503

Gor, K. (2015). Phonology and morphology in lexical processing. In J. W. Schwieter (Ed.), *The Cambridge handbook of bilingual processing* (pp. 173–199). Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9781107447257.007

Gor, K., Chrabaszcz, A., & Cook, S. (2017a). Processing of nonnative inflected words: Beyond affix stripping. *Journal of Memory and Language*, 93, 315–332. https://doi.org/10.1016/j.jml.2016.06.014

Gor, K., Chrabaszcz, A., & Cook, S. (2017b). A case for agreement: Processing of case inflection by early and late learners. *Linguistic Approaches to Bilingualism*. https://doi.org/10.1075/lab.16017.gor

Gor, K., & Cook, S. (2010). Non-native processing of verbal morphology: In search of regularity. *Language Learning*, 60, 88–126. https://doi.org/10.1111/j.1467-9922.2009.00552.x

Gor, K., & Jackson, S. (2013). Morphological decomposition and lexical access in a native and second language: A nesting doll effect. *Language and Cognitive Processes*, 28, 1065–1091. https://doi.org/10.1080/01690965.2013.776696

Gor, K., Kireev, M., Chrabaszcz, A., & Medvedev, S. (2017c). An fMRI study of morphological decomposition in the recognition of case-inflected nouns: Dissociation of inflection and case. Paper presented at the 10th International Morphological Processing Conference, SISSA, Trieste, Italy, June 22-24, 2017.

Hopp, H. (2010). Ultimate attainment in L2 inflection: Performance similarities between nonnative and native speakers. *Lingua*, 120, 901–931. https://doi.org/10.1016/j.lingua.2009.06.004

Hopp, H. (2013). Grammatical gender in adult L2 acquisition: Relations between lexical and syntactic variability. *Second Language Research*, 29, 33–56. https://doi.org/10.1177/0267658312461803

Jacob, G., & Kırkıcı, B. (2016). The processing of morphologically complex words in a specific speaker group. *The Mental Lexicon*, 11, 308–328. https://doi.org/10.1075/ml.11.2.06jac

Jiang, N., Hu, G., Chrabaszcz, A., & Ye, L. (2015). The activation of grammaticalized meaning in L2 processing: Toward an explanation of the morphological congruency effect. *International Journal of Bilingualism*, 21(1), 81–98. https://doi.org/1367006915603823

Kirkici, B., & Clahsen, H. (2013). Inflection and derivation in native and non-native language processing: Masked priming experiments on Turkish. *Bilingualism: Language and Cognition*, 16, 776–791. https://doi.org/10.1017/S1366728912000648

Kuznetsova, A., Brockhoff, P., & Christensen, R. (2015). lmerTest: Tests in linear mixed effects models. R package version 2.0-25. <http://CRAN.R-project.org/package=lmerTest>

Lehtonen, M., & Laine, M. (2003). How word frequency affects morphological processing in monolinguals and bilinguals. *Bilingualism: Language and Cognition*, 6, 213–225. https://doi.org/10.1017/S1366728903001147

Lehtonen, M., Vorobyev, V., Hugdahl, K., Tuokkola, T., & Laine, M. (2006). Neural correlates of morphological decomposition in a morphologically rich language: An fMRI study. *Brain and Language*, 98, 182–193. https://doi.org/10.1016/j.bandl.2006.04.011

Lehtonen, M., Vorobyev, V., Soveri, A., Hugdahl, K., Tuokkola, T., & Laine, M. (2009). Language-specific activations in the brain: Evidence from inflectional processing in bilinguals. *Journal of Neurolinguistics*, 22, 495–513. https://doi.org/10.1016/j.jneuroling.2009.05.001

Lukatela, G., Gligorijevic, B., Kostić, A., & Turvey, M. T. (1980). Representation of inflected nouns in the internal lexicon. *Memory and Cognition*, 8, 415–423. https://doi.org/10.3758/BF03211138

Marantz, A. (2013). No escape from morphemes in morphological processing. *Language and Cognitive Processes*, 28(7), 905–916. https://doi.org/10.1080/01690965.2013.779385

Montrul, S., & Foote, R. (2014). Age of acquisition interactions in bilingual lexical access: A study of the weaker language of L2 learners and heritage speakers. *International Journal of Bilingualism*, 18, 274–303. https://doi.org/10.1177/1367006912443431

Montrul, S., Foote, R., & Perpiñán, S. (2008). Gender agreement in adult second language learners and Spanish heritage speakers: The effects of age and context of acquisition. *Language Learning*, 58, 503–553. https://doi.org/10.1111/j.1467-9922.2008.00449.x

Neubauer, K., & Clahsen, H. (2009). Decomposition of inflected words in a second language. *Studies in Second Language Acquisition*, 31, 403–435. https://doi.org/10.1017/S1366728912000648

Portin, M., Lehtonen, M., Harrer, G., Wande, E., Niemi, J., & Laine, M. (2008). L1 effects on the processing of inflected nouns in L2. *Acta Psychologica*, 128, 452–465. https://doi.org/10.1016/j.actpsy.2007.07.003

Portin, M., Lehtonen, M., & Laine, M. (2007). Processing of inflected nouns in late bilinguals. *Applied Psycholinguistics*, 28, 135–56. https://doi.org/10.1017/S014271640607007X

R Core Team (2015). *R: A language and environment for statistical computing*. Vienna: R Foundation for Statistical Computing. <http://www.R-project.org/>

Scontras, G., Fuchs, Z., & Polinsky, M. (2015). Heritage language and linguistic theory. *Frontiers in Psychology*, 6.1545. https://doi.org/10.3389/fpsyg.2015.01545

Sharoff, S. (2001). *The frequency dictionary for Russian*. Available at <http://bokrcorpora.narod.ru/frqlist/frqlist-en.html> (4 December, 2007).

Sharoff, S. (2006). Methods and tools for development of the Russian Reference Corpus. *Language and Computers*, 56, 167–180.

Slioussar, N., & Cherepovskaia, N. (2014). Case errors in processing: Evidence from Russian. In *Formal approaches to Slavic linguistics: The First Hamilton Meeting 2013* (pp. 319–338). Ann Arbor, MI: Michigan Slavic Publications.

Slioussar, N., Stetsenko, A., & Matyushkina, T. (2015). Producing case errors in Russian. In Y. Oseki, M. Esipova, & S. Harves (Eds.), *Formal approaches to Slavic linguistics: The First New York Meeting 2015*. Ann Arbor, MI: Michigan Slavic Publications.

Stanners, R. F., Neiser, J. J., Hernon, W. P., & Hall, R. (1979). Memory representation for morphologically related words. *Journal of Verbal Learning and Verbal Behavior*, 18, 399–412. https://doi.org/10.1016/S0022-5371(79)90219-6

Taft, M. (1979). Recognition of affixed words and the word frequency effect. *Memory and Cognition*, 7, 263–272. https://doi.org/10.3758/bf03197599

Taft, M. (2004). Morphological decomposition and the reverse base frequency effect. *The Quarterly Journal of Experimental Psychology*, 57, 745–765. https://doi.org/10.1080/02724980343000477

Taft, M. (2017). Cross-morphemic transposed letter effects argue against a single decompositional pathway. Paper presented at the 10th International Morphological Processing Conference, SISSA, Trieste, Italy, June 22–24, 2017.

Tockowitz, N., & MacWhinney, B. (2005). Implicit and explicit measures of sensitivity to viola-tions in second language grammar: An event related potential investigation. *Studies in Second Language Acquisition*, 2, 173–204.

Vaida, F., & Blanchard, S. (2005). Conditional Akaike information for mixed-effects models. *Biometrika*, 92, 351–370. https://doi.org/10.1093/biomet/92.2.351

Voga, M., Anastassiadis-Symeonidis, A., & Giraudo, H. (2014). Does morphology play a role in L2 processing? Two masked priming experiments with Greek speakers of ESL. *Lingvisticae Investigationes*, 37, 338–352. https://doi.org/10.1075/li.37.2.10vog

Yap, M. J., Sibley, D. E., Balota, D. A., Ratcliff, R., & Rueckl, J. (2015). Responding to nonwords in the lexical decision task: Insights from the English Lexicon Project. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 41, 597–613. https://doi.org/10.1037/xlm0000064

Appendix

Table A1. Output of the linear mixed-effects model for ER and log-transformed RT as dependent variables in Dataset 1

Model (ER)	**ER~group+form+inflection+proficiency+group* form+(1+form|id)+(1+proficiency|item)**			
Fixed effects	**β**	***SE***	**z value**	***p* value**
Intercept (NS/citation/overt)	−3.780	0.882	−4.29	<0.001
group (HS)	0.007	0.679	0.01	0.992
group (L2)	0.623	0.629	0.99	0.322
form (oblique)	2.160	0.411	5.26	<0.001
inflection (zero)	0.685	0.173	3.96	<0.001
proficiency	−0.204	0.160	−1.27	0.203
group (HS) x form (oblique)	−0.101	0.542	−0.19	0.853
group (L2) x form (oblique)	−1.209	0.485	−2.49	<0.05
Model (RT)	**RT~group+form+inflection+proficiency+group* form+(1|id)+(1+proficiency|item)**			
Fixed effects	**β**	***SE***	**t value**	***p* value**
Intercept (NS/citation/overt)	6.797	0.088	77.64	<0.001
group (HS)	0.122	0.061	2.01	<0.05
group (L2)	0.134	0.059	2.26	<0.05
form (oblique)	0.171	0.011	14.97	<0.01
inflection (zero)	0.006	0.007	0.77	0.443
proficiency	0.024	0.017	1.38	0.170
group (HS) x form (oblique)	−0.040	0.019	−2.15	<0.05
group (L2) x form (oblique)	−0.045	0.017	−2.67	<0.01

Table A2. Output of the linear mixed-effects model for ER and log-transformed RT as dependent variables in Dataset 2

Dataset 2.1: 1st declension				
Model (ER)	**ER~group+condition+proficiency+group* proficiency+(1+condition|id)+(1+proficiency|item)**			
Fixed effects	**β**	***SE***	**z value**	***p* value**
Intercept (NS/word-citation)	−2.590	0.891	−2.91	<0.01
group (HS)	0.058	0.567	0.10	0.918
group (L2)	0.130	0.560	0.23	0.817
condition (word-oblique)	0.636	0.523	1.22	0.224
condition (nonce-inflection)	4.421	0.466	9.49	<0.001
condition (nonce-stem)	−0.804	0.831	−0.97	0.334
proficiency	−0.244	0.203	−1.20	0.229
proficiency x word-oblique	0.100	0.154	0.65	0.515
proficiency x nonce-inflection	−0.657	0.146	−4.50	<0.001
proficiency x nonce-stem	−0.249	0.280	−0.89	0.373
Model (RT)	**RT~group+condition+proficiency+group* condition+(1|id)+(1|item)**			
Fixed effects	**β**	***SE***	**t value**	***p* value**
Intercept (NS/word-citation)	6.786	0.102	66.27	<0.001
group (HS)	0.166	0.073	2.29	<0.05
group (L2)	0.147	0.071	2.08	<0.05
condition (word-oblique)	0.163	0.017	9.37	<0.001
condition (nonce-inflection)	0.219	0.018	12.33	<0.001
condition (nonce-stem)	0.108	0.026	4.14	<0.001
proficiency	0.030	0.020	1.54	0.128
group (HS) x word-oblique	−0.043	0.028	−1.56	0.120
group (L2) x word-oblique	−0.031	0.025	−1.23	0.219
group (HS) x nonce-inflection	−0.006	0.028	−0.20	0.845
group (L2) x nonce-inflection	0.032	0.026	1.22	0.225
group (HS) x nonce-stem	−0.037	0.028	−1.33	0.185
group (HS) x nonce-stem	0.028	0.026	1.08	0.280

Table A2. *(continued)*

Dataset 2.2: 2nd declension				
Model (ER)	**ER~group+condition+proficiency+group* proficiency+(1|id)+(1+proficiency|item)**			
Fixed effects	**β**	***SE***	**z value**	***p* value**
Intercept (NS/ word-citation)	−1.714	0.685	−2.50	<0.05
group (HS)	0.295	0.454	0.65	0.515
group (L2)	0.203	0.446	0.46	0.648
condition (word-oblique)	2.572	0.297	8.65	<0.001
condition (nonce-inflection)	−0.898	0.483	−1.86	0.063
condition (nonce-stem)	−0.696	0.477	−1.46	0.144
proficiency	0.040	0.146	0.28	0.781
proficiency x word-oblique	−0.625	0.092	−6.76	<0.001
proficiency x nonce-inflection	−0.382	0.178	−2.15	<0.05
proficiency x nonce-stem	−0.543	0.192	−2.83	<0.01
Model (RT)	**RT~group+condition+proficiency+(1+condition|id)+(1|item)**			
Fixed effects	**β**	***SE***	**t value**	***p* value**
Intercept (NS/ word-citation)	6.944	0.095	73.27	<0.001
group (HS)	0.121	0.064	1.88	0.063
group (L2)	0.164	0.063	2.61	<0.05
condition (word-oblique)	−0.031	0.029	−1.04	0.304
condition (nonce-inflection)	−0.182	0.014	−12.89	<0.001
condition (nonce-stem)	−0.025	0.013	−1.92	0.058
proficiency	0.029	0.018	1.58	0.119

Address for correspondence

Kira Gor
University of Maryland
Graduate Program in Second Language Acquisition
School of Languages, Literatures, and Cultures
3215 Jiménez Hall
College Park MD 20742
USA
kiragor@umd.edu

Co-author information

Anna Chrabaszcz
University of Pittsburgh
Learning Research & Development Center
anc211@pitt.edu

Svetlana Cook
University of Maryland
The National Foreign Language Center
svcook@umd.edu
svc@umd.edu