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Sentence comprehension in heritage language: Isomorphism, word order, and language transfer

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Abstract
This study examines the role of cross-linguistic transfer versus general processing strategy in two groups of heritage speakers ($n = 28$ per group) with the same heritage language – Russian – and typologically different dominant languages: English and Estonian. A group of homeland Russian speakers ($n = 36$) is tested to provide baseline comparison. Within the framework of the Competition model (MacWhinney, 2012), cross-linguistic transfer is defined as reliance on the processing cue prevalent in the heritage speaker's dominant language (e.g. word order in English) for comprehension of heritage language. In accordance with the Isomorphic Mapping Hypothesis (O'Grady and Lee, 2005), the general processing strategy is defined in terms of isomorphism as a linear alignment between the order of the sentence constituents and the temporal sequence of events. Participants were asked to match pictures on the computer screen with auditorily presented sentences. Sentences included locative or instrumental constructions, in which two cues – word order (basic vs. inverted) and isomorphism mapping (isomorphic vs. nonisomorphic) – were fully crossed. The results revealed that (1) Russian native speakers are sensitive to isomorphism in sentence processing; (2) English-dominant heritage speakers experience dominant language transfer, as evidenced by their reliance primarily on the word order cue; (3) Estonian-dominant heritage speakers do not show significant effects of isomorphism or word order but experience significant processing costs in all conditions.

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I Introduction

Heritage language acquisition is similar to child L1 acquisition in that heritage speakers also acquire their heritage language naturalistically from their caregivers, from birth. The key difference is that heritage language is acquired alongside another (or other) language(s) – either simultaneously or sequentially (e.g. after the enrollment in daycare or school) – in a context where heritage language is not the language of the community. The differences between L1 acquisition and heritage language acquisition are exacerbated over time, because, unlike in a truly bilingual context, heritage speakers rarely receive formal schooling in the heritage language and, therefore, often remain illiterate or have less developed literacy skills in the heritage language compared to the more dominant language (Carreira and Kagan, 2011; Montrul, 2010; Tse, 2001). The heritage language is therefore defined as the minority language of a bilingual who is otherwise considered a native speaker of the language of the community, the majority language (Benmamoun et al., 2013; Montrul, 2010; Polinsky, 2008a; Polinsky, 2018; Polinsky and Scontras, 2020; Rothman, 2009; Scontras et al., 2015; Valdés, 2005). A fair amount of work has focused on describing differences in the linguistic competences between heritage speakers and monolingual native speakers across different linguistic domains, including phonology, morphology, semantics, syntax, discourse and pragmatics. However, the examination of the driving forces behind the divergent performance of the heritage speakers is still ongoing. Among the most commonly identified contributing factors are the natural attrition due to the diminished language practice (a 'use it or lose it' phenomenon); incomplete acquisition due to the onset of bilingualism; inaccurately formed representations due to the qualitatively and quantitatively different input; representational simplification due to the universal tendency of the language towards economical and optimal use (as in the case of creole languages); and transfer from the more dominant language to the minority language (for a detailed discussion, see Meir and Polinsky, 2019; Montrul, 2016; Polinsky, 2018; Polinsky and Scontras, 2020; Scontras et al., 2015). Even when heritage speakers achieve nativelike linguistic competence in their heritage language, the task of performing in the weaker language may be associated with more costly processing demands due to the obligatory retrieval of language-appropriate parsing strategies from memory out of several competing ones. In this case, heritage speakers are not unlikely to resort to nonlinguistic heuristics, such as reliance on real word knowledge and pragmatics, prioritization of analytical forms, and preference of more transparent structures that allow for one-to-one correspondences between the surface forms and the underlying elements. One way to operationalize such heuristics is through structural isomorphism: alignment of a sentence's syntactic structure with the temporal sequence of underlying events (see Isomorphic Mapping Hypothesis in O'Grady and Lee, 2005; O'Grady et al., 2005). Isomorphic sentences are believed to be easier because they maximize processing efficiency. For example, the sentence 'He ate before he read' is considered to be easier than 'He read after he ate' because the clauses in the former sentence align with the order in which the events happened whereas the clauses in the latter do not.

The present study makes an attempt to account for two possible sources of divergent performance in heritage languages: the effect of the dominant language transfer, and the reliance on the general processing strategy defined in terms of isomorphism. To separate the influence of these two factors, we compare two groups of heritage speakers with the same heritage (minority) language – Russian, and typologically different dominant (majority) languages – English and Estonian. While comparing the effects of different contact languages on one and the same heritage language provides a more ecologically valid approach to quantify dominant language transfer as opposed to comparing heritage speakers with the native speaker baseline or the L2 learners (for methodological considerations, see Benmamoun et al., 2013; Montrul, 2010; Scontras et al., 2015), surprisingly, we found only one study that employed this methodology. Kim (2007) investigated binding interpretations with local and long-distance anaphors in Korean by English-dominant and Mandarin-dominant Korean heritage speakers residing in the United States and China, respectively. Although both Korean and Chinese have long-distance binding and English does not, both groups of heritage speakers preferred local binding to long-distance binding regardless of the dominant language. Thus, this preference was not driven by the influence of a specific language; rather, it emerged because memory-intensive phenomena like binding became more costly due to contact with a different language system, whichever it might be. Importantly, had the author decided to test the effect of only one dominant language (e.g. English), the preference for local binding could have been misinterpreted as a transfer effect.

We adopt exactly the same approach as Kim (2007) to separate transfer effects from the more general effects of processing economy. The behavior under investigation is comprehension of sentences with locative and instrumental constructions, in which word order can be reversed in Russian and Estonian, but not in English (e.g. sentences 'I put in the box the bag' or 'I cover with a scarf a hat' are not grammatical in English but grammatical in Russian and Estonian). Therefore, transfer effects should instantiate differently in the two groups of heritage speakers due to the differences in how word order is expressed in the two contact languages. On the other hand, if heritage language processing is inherently more costly, both groups of heritage speakers should rely on similar processing strategies, e.g. preference of isomorphic constructions. Thus, by contrasting linguistic (word order) and nonlinguistic (isomorphism) factors, the goal of this article is to identify which factors play a greater role in sentence comprehension of heritage speakers whose majority and minority languages stand in different relations with each other.

1 Cue interaction during heritage sentence comprehension

In order to interpret language input, comprehenders need to pay attention to the relevant cues and regularities (e.g. semantic, morphological, etc.) in the language. For example, in the sentence 'The dog chases the ball', both 'the dog' and 'the ball' can be possible agents in the sentence. However, the preverbal position and the animacy of 'the dog' contribute to its interpretation as the subject of the sentence. According to the Competition model (Bates and MacWhinney, 1989; Bates et al., 1984) and the more recent Unified model (MacWhinney, 2005, 2008, 2012), there are cross-linguistic differences in the kinds of cues people rely on for sentence comprehension, which is determined by cue availability (how frequently a cue occurs in a given language) and cue reliability (how reliably a cue signals the same meaning). For example, for interpretation of agentivity, English speakers rely overwhelmingly on word order (Bates and MacWhinney, 1989), while Russian speakers, in contrast, rely to a greater extent on case inflections, and German speakers rely on noun animacy (Kempe and MacWhinney, 1999). Heritage speakers are essentially faced with the same task in sentence comprehension as monolingual speakers, but it is further complicated by having to identify which cues are relevant for which language and to apply language-appropriate strategies depending on the linguistic context in a manner that is efficient, flexible and fast. Depending on how the cues in the heritage speaker's majority and minority languages interact, several potential processing strategies can be identified (Janssen and Meir, 2019; Kilborn and Ito, 1989; Liu et al., 1992; MacWhinney, 1987; Pham and Kohnert, 2010):

1. differentiation, when heritage speakers correctly apply language-specific processing strategies in their minority and majority languages, depending on the language mode;
2. dominant language transfer, when heritage speakers incorrectly apply strategies from the majority language to the minority language;
3. amalgamation, which refers to the merging of processing strategies.

Empirical evidence exists supporting different processing patterns used by heritage speakers. For example, child and adolescent speakers (aged 5–13 years) of Spanish and English employed an amalgam of strategies in choosing the agent of a sentence, i.e. they relied on both the subject–verb agreement cue typical for Spanish and the canonical word order cue common to English (Hernandez et al., 1994; Reyes and Hernández, 2006). In another study, Korean-English college-level heritage speakers also used amalgamation strategies for the processing of relative clauses in Korean if they reported language dominancy in Korean or both Korean and English, but used transfer strategies from English if they identified themselves as English-dominant (Kim, 2005). While amalgamation strategies are common in child and adolescent heritage speakers, transfer effects have been noted repeatedly in adult heritage speakers (e.g. Albirini and Benmamoun, 2014; Lee, 2016; Montrul and Ionin, 2012; Moro and Suchtelen, 2017), especially in those aspects of grammar that lie at the interface of syntax and semantics/pragmatics. Much less documented, however, are those instances where heritage speakers perform similar to the native speaker baseline. For example, in the study by Jegerski et al. (2016b) on the processing of temporally ambiguous relative clauses English heritage speakers of Spanish employed language-specific processing strategies in both of their languages, with a preference for high attachment in Spanish and neutral attachment in English. In the subsequent study, the authors provided additional evidence that English heritage speakers of Spanish follow a monolingual-like high attachment strategy during on-line comprehension of Spanish sentences (Jegerski et al., 2016a). Monolingual-like processing by English-dominant heritage speakers of Spanish was also observed by Montrul (2006) in a study of Spanish and English unaccusative and unergative verbs, suggesting that heritage speakers are capable of overcoming at least some of the cross-linguistic influence from the majority language.

The processing strategies that heritage speakers bring to the task of sentence processing may be explained by their linguistic experience, e.g. proficiency in the minority language, quality and quantity of language input, age of acquisition. For example, Liu, Bates and Li (1992) explain the affinity for a certain processing strategy by the age of exposure to the majority language. They found that those Chinese-English speakers who were exposed to the majority language (English) before the age of four used English processing strategies in both English and Chinese (a possible symptom of language attrition), while those speakers who were exposed to English at 6–10 years of age used differentiation strategies (i.e. used animacy cues in Chinese and word order cues in English) and behaved more like monolinguals in both languages. Additionally, different linguistic phenomena can be differentially affected by language interaction, even within the same individuals (Polinsky, 2018). For example, the same heritage speakers reveal monolingual-like preference for high attachment strategy in the interpretation of relative clauses (Jegerski et al., 2016a, 2016b), but show divergent results with regard to the processing of pronominal reference in their minority language (Spanish) (Keating et al., 2016). Finally, heritage speakers may resort to divergent strategies, distinct from those used by the native speakers of either their majority or minority languages (Polinsky, 2018). For example, Polinsky (2008b) observed that adult English-dominant heritage speakers of Russian differed in their performance on Russian object relative clauses from Russian monolingual adults and heritage children, but that they did not transfer word order preferences from English, contrary to transfer-based predictions. This and similar evidence (e.g. Meir and Polinsky, 2019; Scontras et al., 2018) demonstrate that in heritage grammars, which are subject to attrition, dominance and vulnerability, resource-intensive operations may forgo in favor of less memory-costly strategies. Thus, heritage language may be characterized by a restricted set of operations and more economical (therefore, reorganized) grammars, which is evidenced by heritage speakers' preference of short dependencies, difficulty with irregular morphology, increased use of analytical forms and syntactic structures that allow one-to-one correspondences between underlying features and surface forms (for a detailed discussion, see Scontras et al., 2015, 2018). The present study takes this evidence into careful consideration by investigating dominant language transfer vis-à-vis heritage speakers' processing limitations. Specifically, we set out to examine which of the two forces constrain heritage sentence comprehension to a greater extent: reliance on dominant language cues (such as word order) or reliance on a more general heuristic, defined in terms of structural isomorphism.

2 Isomorphism in sentence processing

The term isomorphism refers to the notion of symmetry between meaning and form. It is reflected in the degree of transparency and correspondence between elements of the linguistic structure and elements of experience (Givón, 1991; Ramat, 1995). For the current purposes, we are concerned only with those linguistic phenomena that code temporal contiguity of events. For example, there is a strong tendency for isomorphism in ordering syntactic clauses according to the temporal sequence of events: ‘He opened the door, came in, sat and ate’ rather than ‘He sat, came in, ate and opened the door’ (example is taken from Givón, 1991). Thus, there can be a continuum between complete isomorphism (one form-one meaning relation) and its complete lack (arbitrariness of form-to-meaning mapping). The cognitive basis for isomorphism in language is explained by memory and attentional demands, namely that more transparent, linear formations are easier to parse and require less mental effort for processing (Givón, 1991). An isomorphic mapping between a syntactic structure and its corresponding event is believed to present less difficulty for comprehension, whereas a nonisomorphic mapping leads to increased processing difficulty (the Isomorphic Mapping Hypothesis in O’Grady and Lee, 2005; O’Grady et al., 2005). Indeed, there is a considerable body of literature showing that isomorphic structures are favored over their nonisomorphic counterparts by young children whose parse is not as efficient due to developmental cognitive constraints (Blything and Cain, 2019; Clark, 1971; Cho et al., 1998; Chrabaszcz et al., 2017; de Ruiter et al., 2018; Musolino, 2011; O’Grady, 1997; Slobin, 1985) and by people with linguistic deficits, such as patients with post-stroke aphasia (Dragoy et al., 2016; O’Grady and Lee, 2001, 2005). Specifically, during comprehension and production of clauses with temporal ordering (e.g. ‘He patted the dog after he jumped the gate’), preschool children tend to assume an isomorphic mapping between the sequence of clauses and the sequence of events in the real world (Blything and Cain, 2019; Clark, 1971; de Ruiter et al., 2018). As a result, they tend to interpret isomorphic sentences correctly, but misinterpret nonisomorphic ones. Regarding patient data, O’Grady and Lee tested predictions of the Isomorphic Mapping Hypothesis in Korean- and English-speaking patients with Broca’s aphasia (O’Grady and Lee, 2001, 2005) and found that agrammatic participants performed much better on isomorphic locative constructions (‘Put the crayon on the pencil’) than on nonisomorphic instrumental constructions (‘Tap the crayon with the pencil’) despite the fact that both types of constructions use canonical word order. In isomorphic sentences (‘Put the crayon on the pencil’), the order of events is linear, which is also reflected in the ordering of the NPs. So when one hears an isomorphic sentence, the underlying meaning is constructed linearly: one takes the crayon and puts it on the pencil. In contrast, in nonisomorphic sentences (‘Tap the crayon with the pencil’), the agent first acts on the pencil (takes the pencil), which is then used to act on the crayon (taps the crayon). A similar design of materials was used to examine processing preferences in Korean and Japanese learners of L2 English (O’Grady et al., 2005). It was found that both groups of L2 learners made fewer errors in comprehending sentences with isomorphic mapping, even when the word order was noncanonical and infrequent. To the best of our knowledge, no prior study has examined whether such preference holds true for heritage grammars. Taking into account that heritage speakers often operate with limited cognitive resources due to the systematic pressure from interlanguage competition, greater reliance on nonlinguistic cues, such as isomorphism, is not unlikely.

3 The present study

The current work examines comprehension of locative and instrumental constructions by heritage speakers of the same heritage language (Russian) and typologically different dominant languages (English and Estonian) with the goal to understand whether heritage language comprehension is driven by transfer of processing strategies from the dominant language or by general strategy of processing economy, defined in terms of isomorphism. The originality of the study lies in several areas. First, no previous study on heritage speakers has examined the interaction of linguistic (word order) and nonlinguistic factors (isomorphism) during sentence comprehension. Second, it compares two varieties of the same heritage language developed under the influence of typologically distinct dominant languages: a design that can be highly informative for understanding the effects of dominant language transfer. Third, the study is the first step in expanding the scope of empirical work on the heritage language to new locales (Estonia) and variations of heritage Russian, which so far has been predominantly studied in the U.S., Germany, and Israel. Finally, it extends the ideas put forth in the Competition and Unified models (Bates and MacWhinney, 1989; Bates et al., 1984; MacWhinney, 2005, 2008, 2012) and the Isomorphic Mapping Hypothesis (O'Grady and Lee, 2005; O'Grady et al., 2005) to the population of heritage speakers for the first time.

a Linguistic constructions under examination. Comprehension abilities of heritage speakers are examined in the context of oral comprehension of Russian sentences with locative and instrumental constructions. In previous experiments on comprehension of isomorphic and nonisomorphic sentences, isomorphism cue was confounded with the construction type: isomorphic mapping occurred only in locative constructions while nonisomorphic mapping occurred only in instrumental constructions. The present study is able to avoid this confound because, despite being typologically defined as an SVO language, Russian allows considerable freedom in the order of sentence constituents due to its rich morphological system, which allows to express syntactic relationships with the help of grammatical markers (Bailyn, 1995; Bivon, 1971; Dyakonova, 2004; Thompson, 1977). In Russian, locative and instrumental constructions can be made isomorphic or nonisomorphic by switching around the order of the direct and the indirect/prepositional objects (for the examples of locative and instrumental sentences used in the study, see Table 1). For example, for locative constructions, a direct object followed by a prepositional object yields isomorphic mapping, and a prepositional object followed by a direct object gives nonisomorphic mapping. While the default word order of argument complements in Russian is highly disputable, the preferred word order in sentences with locative constructions is DO followed by PP (e.g. Bailyn, 1995, 2012; Dyakonova, 2009). Therefore, we refer to this order as a 'basic' order, while PP followed by DO is referred to as an 'inverted' word order. Based on such categorization, Russian locative isomorphic constructions have a basic word order, while locative nonisomorphic constructions mark an inverted order. It is more difficult to establish a default word order in double object constructions in Russian, like the instrumental ones in Table 1. Some linguists propose that in the Russian underlying phrase structure, DO is followed by IO (Bailyn, 1995, 2012, but see recent alternative accounts based on Russian scope interpretation in Antonyuk, 2015a, 2015b). In the National Russian Corpus (http://ruscorpora.ru/new) with disambiguated homophony (6,003,398 words), objects in the accusative case precede indirect objects in the instrumental case 1.35 times more often than immediately follow them, suggesting a frequency preference in favor of the

Table 1. Experimental conditions with corresponding examples.

Construction type	Word order	Mapping type	Argument structure	Example sentence
Locative	Basic	I+	DO, PP	Maljchik kladjot sumku v korobku. boy put bag.ACC in box.ACC 'The boy is putting a bag in a box.'
Locative	Inverted	I–	PP, DO	Maljchik kladjot v korobku sumku. boy put in box.ACC bag.ACC 'The boy is putting in a box a bag.'
Instrumental	Inverted	I+	IO, DO	Zhenshchina nakryvajet shapkoj sharf. woman cover hat.INSTR scarf.ACC 'The woman is covering with a hat a scarf.'
Instrumental	Basic	I–	DO, IO	Zhenshchina nakryvajet sharf shapkoj. woman cover scarf.ACC hat.INSTR 'The woman is covering a scarf with a hat.'

Notes. All four types of sentences are grammatically acceptable in Russian. I+ = isomorphic mapping; I– = nonisomorphic mapping; DO = direct object; PP = prepositional phrase; IO = indirect object.

DO > IO pattern (although these counts do not disambiguate different functions of the instrumental case). Based on this and Bailyn (1995, 2012), we refer to the instrumental constructions with nonisomorphic mapping as ones with a basic word order, and the ones with isomorphic mapping as those with an inverted word order (Table 1). Accordingly, in contrast to the locative sentences, word order and isomorphism cues go against each other in the instrumental sentences.

b Predictions for native speakers of Russian. In Russian, case marking serves as the strongest cue in both adult (Kempe and MacWhinney, 1999) and child (Janssen and Meir, 2019) sentence processing. Because adult native speakers of Russian in our experiment are supposed to have a fully-fledged grammatical competence, we expect them to use their grammatical knowledge about case inflections to parse the sentences correctly and show no difficulties in comprehension of locative and instrumental constructions. However, according to the Competition model, various cues may be considered by comprehenders during sentence processing. Alignment of cues helps to arrive at the correct interpretation faster and with lesser processing costs. On the contrary, conflicting cues lead to competition and longer processing times. If Russian native speakers show sensitivity to other cues besides case inflections, such as word order and isomorphism, we expect them to incur the least processing costs in sentences with locative constructions with a basic word order and isomorphic mapping (Basic I+) and the most processing costs with locative constructions in which both cues (inverted word order and nonisomorphic mapping) (Inverted I–) go against the preferred pattern. Native speakers' performance on the instrumental constructions, in which one of the cues goes against the preferred pattern (Basic I–, or Inverted I+), should indicate which of the cues – word order or isomorphism – constrains the parser to a greater extent. Native processing strategy is schematically represented in Figure 1A, in which ranking of the expected processing costs is provided in the order of increased processing difficulty, with 1 being the least difficult and 4 being the most difficult.

A

Expected native strategy		
	I+	I–
Basic	1	2|3
Inverted	2|3	4

B

Reliance on word order		
	I+	I–
Basic	1	1
Inverted	4	4

C

Reliance on isomorphism		
	I+	I–
Basic	1	4
Inverted	1	4

Figure 1. Schematic representation of predicted processing difficulty (shown in the increased order from 1 to 4) for the four types of sentences with locative and instrumental constructions, in which word order (basic vs. inverted) and mapping type (isomorphic, I+ vs. nonisomorphic, I–) are crossed. (A) The order of processing difficulties predicted for the native speaker group. (B) The order of processing difficulty reflecting the strategy of reliance on word order as the main cue. (C) The order of processing difficulty reflecting the strategy of reliance on isomorphism as the main cue.

c Predictions for English-dominant heritage speakers of Russian. Both Russian and English are considered SVO languages, however the two languages differ in the degree of permitted word order flexibility. English is a predominantly analytic language with limited morphological variations and a rigid word order to indicate semantic-syntactic relations (although some variations of topicalization are possible in informal registers) (Bates et al., 1984; Slobin and Bever, 1982). Such word order rigidity does not allow for the transposition of the NPs in sentences with locative and instrumental constructions, with the inverted word order resulting in ungrammatical sentences in English (e.g. * 'The woman is covering with a hat a scarf'). Thus, if heritage speakers transfer processing strategies from their dominant language to their heritage language, we hypothesize that English-dominant heritage speakers will rely more heavily on the word order cue typical for English, i.e. prefer sentences with a basic word order to sentences with an inverted word order. Such strategy is schematically represented in Figure 1B. In this case, English-dominant heritage speakers may incorrectly interpret the post-verbal nouns' thematic role as a direct object in those Russian sentences which have an inverted word order, leading to higher error rate and greater processing times. We should also note that both Russian locative and instrumental constructions translate to a DO followed by a PP in English (see Table 1). Because this is a default pattern for prepositional phrases in English (Halamásková, 2011), Russian instrumental constructions, which do not have a preposition, may present even a greater difficulty because there is no additional disambiguation of the noun's thematic role afforded by the preposition, unlike in the locative constructions.

On the other hand, if heritage sentence processing is primarily driven by the processing economy principle, as discussed above, we expect English-dominant heritage speakers to rely on the isomorphism cue to a greater extent, i.e. show a processing advantage for sentences with isomorphic compared to nonisomorphic mapping, a strategy depicted in Figure 1C.

d Predictions for Estonian-dominant heritage speakers of Russian. Estonian is a Uralic language of the Finnish branch and, similar to Russian, has a rich and complicated system of cases (Russian has 6 productive cases, Estonian – 14, depending on the classification), although there are no direct correspondences between them. For example, unlike Russian, Estonian has 6 locative cases (sometimes called semantic cases) that denote inner ('in') and outer ('on') local relations such as entering, being in/on, or leaving a state or a place (Õispuu, 1999; Valmet et al., 1981). While Russian case inflections are highly fusional and syncretic whereby different grammatical relations (e.g. case, number, gender) may be encoded by the same inflection, Estonian morphology is mostly agglutinative (e.g. number and case markers are attached to stems) (Kaivapalu and Martin, 2007). As one would expect from an agglutinative language, Estonian allows for a large number of word order permutations depending on the pragmatic constraints (Ehala, 2006; Erelt, 2009). Similar to Russian, Estonian also permits reordering of syntactic constituents in the locative and instrumental constructions examined in this study. For example, both of the following sentences are grammatically plausible in Estonian, as shown in (1a) and (1b).

(1) a. Ma katan salli mütsiga.
I cover scarf.GEN hat.COM
'I am covering a scarf with a hat.'
b. Ma katan mütsiga salli.
I cover hat.COM scarf.GEN
'I am covering with a hat a scarf.'

Therefore, we hypothesize that, similar to Russian native speakers, Estonian-dominant heritage speakers will tolerate an inverted word order, which should not detrimentally affect their sentence comprehension. The processing costs associated with different types of sentences are also hypothesized to be similar to those incurred by native Russian speakers (Figure 1A).

On the other hand, if heritage sentence comprehension is intrinsically constrained due to more costly processing demands, as discussed above, Estonian-dominant heritage speakers are expected to show the same preference of isomorphic sentences relative to nonisomorphic ones as English-dominant heritage speakers, consistent with the strategy schematically represented in Figure 1C.

To summarize, if heritage language comprehension is significantly affected by the dominant language, we expect to see differences in the processing of Russian locative and instrumental constructions by English-dominant and Estonian-dominant heritage speakers, with English-dominant speakers showing greater processing costs for sentences with an inverted word order. If, however, heritage sentence processing is driven by the economy principle, we expect both English-dominant and Estonian-dominant heritage speakers to prefer sentences with isomorphic mapping, since isomorphism is believed to reflect not a language-specific, but a domain-general strategy on which people may rely to maximize processing efficiency, especially when they operate with limited cognitive resources. We do not exclude a possibility that heritage speakers are able to achieve differentiation between the processing strategies in their dominant and heritage languages, in which case we should expect to observe nativelike performance in both groups of heritage speakers.

II Methods

1 Participants

A total of 36 native speakers of Russian (mean age = 26.75, SD = 9.44, 26 women/10 men) and 64 Russian heritage speakers were recruited for the study, but 7 participants were excluded from the analysis because the onset of acquisition of their majority language occurred after puberty, and 1 participant was removed from the analysis because he did not complete all parts of the study. As a result, 28 English-dominant[1] (mean age = 21.11, SD = 2.7, 17 women/ 11 men) and 28 Estonian-dominant (mean age = 31.14, SD = 9.39, 16 women/ 12 men) heritage speakers of Russian were included in the analysis. Eleven English-dominant participants were born in English-speaking countries (9 in the U.S., 1 in Canada, 1 in Ghana), 17 were born in Russian-speaking countries (10 in Russia, 3 in Ukraine, 2 in Belarus, 2 in Uzbekistan) to Russian-speaking parents. For the latter, average age when they moved to reside in the U.S. was 4.64 years old (SD = 2.9). At the time of testing, all English-dominant heritage speakers reported having resided in the U.S. most of their lives. All Estonian-dominant participants were born in Estonia and never lived in Russian-speaking countries with the exception of occasional visits. At the time of testing, all native Russian speakers resided in Russia, Estonian-dominant heritage speakers resided in Estonia, and English-dominant heritage speakers resided in the United States. Although assessing sociolinguistic factors on the maintenance of Russian as a heritage language is beyond the scope of the present study, it is necessary to acknowledge that the circumstances under which heritage speakers maintain their Russian in the U.S. and Estonia are quite different due to the cultural, historical and political reasons (e.g. the size of the Russian diaspora, opportunities to practice Russian, perceived language attitude, language policy, etc.) and may affect long-term linguistic outcomes (e.g. see Romanov (2000) and Verschik (2005) on the status of the Russian language in Estonia).

Prior to the experiment, all participants were asked to sign an online consent form, after which native Russian speakers filled out a questionnaire about their demographics and heritage speakers filled out a questionnaire about their language learning experience and completed a cloze test evaluating their global proficiency in Russian. The cloze test was a short fictional story in Russian, in which every seventh word was deleted and replaced with a blank (a total of 25 blanks). Participants were instructed to read the story and fill in the blanks with the appropriate word form. Each accurately supplied response received a score of 1, each inaccurate (semantically or grammatically inappropriate) response or an omission received a score of 0. As evidenced by the score on the cloze test, all heritage participants were literate and were able to read and write in Russian. A summary table of the heritage speakers' language learning background and proficiency scores is provided in Table 2. All participants were recruited through listservs, social media and referrals and tested remotely in their countries of residency. Participants were blind to the experimental design. All procedures were administered in accordance with the ethical principles for conducting research on human participants proposed by the Declaration of Helsinki (World Medical Association, 2013).

Table 2. Linguistic profile of the heritage speakers in the study.

Variable	English-dominant		Estonian-dominant		*t*	*p*
	Mean	SD	Mean	SD		
Experience with Russian:						
Proficiency in Russian (cloze test score, max = 25)	19.68	3.8	19.82	5.6	−0.11	0.91
Use of Russian (%)	57.86	14.55	39.11	17.79	4.24	< 0.001*
Speaking (self-rated)	8	1.83	7.71	1.71	0.59	0.56
Comprehension (self-rated)	8.93	1.33	7.04	1.99	4.1	< 0.001*
Experience with majority language:						
Age when started learning the majority language (years)	3.98	2.75	2.07	2.81	2.52	0.014*
Duration of residency in the country of the majority language (years)	18.09	3.13	30.11	9.6	−6.19	< 0.001*
Use of the majority language (%)	55.54	17.45	63.75	18.21	−1.69	0.096
Speaking (self-rated)	9.68	1.04	9.11	1.14	1.92	0.06
Comprehension (self-rated)	9.75	0.99	8.18	1.91	3.8	< 0.001*

Note. * significant at alpha 0.05. Self-reported responses were given on a scale from 1 (minimal proficiency) to 10 (maximal proficiency).

2 Materials

We constructed 48 sentences with 24 locative and 24 instrumental constructions of the type presented in Table 1. Each sentence represented an action performed by a single actor, always an animate subject, on an inanimate object in relation to another inanimate object (locative constructions) or with the help of another inanimate object (instrumental constructions). All locative constructions had a directional meaning. The directional configuration was expressed with the help of the prepositional phrase with the following prepositions: *в* 'in', *на* 'on', *под* 'under', *над* 'above', *за* 'behind', *перед* 'in front of'. Prepositions 'in', 'on', and 'under' assigned accusative case to the following noun (2a), while prepositions 'above', 'behind', 'in front of' assigned instrumental case (2b). The instrumental constructions always included a direct object in the accusative case and an indirect object in the instrumental case (2c).

(2) a. Zhenshchina stavit tarelku pod kruzhku.
woman put plate.ACC under mug.ACC
'The woman is putting a plate under a mug.'
b. Muzhchina veshaet polku nad zerkalom.
man hang shelf.ACC above mirror.INSTR
'The man is hanging a shelf above a mirror.'
c. Maljchik lomaet palku lopatoj.
boy break stick.ACC shovel.INSTR
'They boy is breaking a stick with a shovel.'

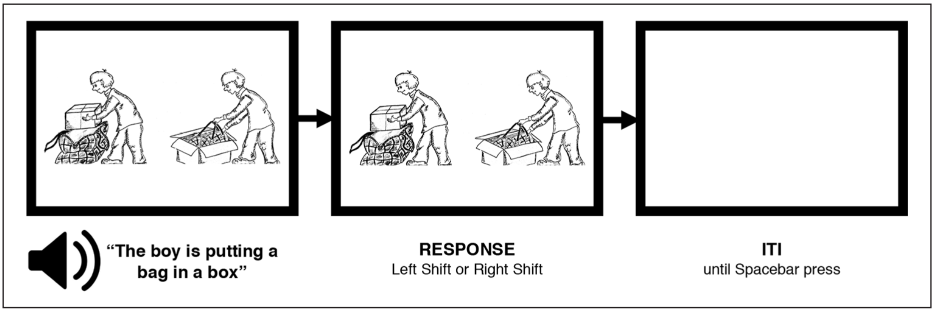

Figure 2. Schematic representation of an experimental trial.
Note. ITI = inter-trial interval.

Thus, while the instrumental case is less frequent in Russian than the accusative case (Kopotev, 2008; Slioussar and Samojlova, 2015), it occurred both in the prepositional phrases of the locative constructions and in the indirect objects of the instrumental constructions, to minimize differences. Moreover, care was taken to match the locative and the instrumental sentences in terms of lexical complexity and length.

The 48 stimulus sentences were constructed such that the word order (basic or inverted) and the mapping type – isomorphic (I+) or nonisomorphic (I–) – were fully crossed, resulting in 12 sentences per each condition: Basic I+, Basic I–, Inverted I+, Inverted I– (see Table 1). All sentences were semantically reversible in that changing the order of the arguments did not disrupt semantic plausibility of the sentence, e.g. (3a) vs. (3b).

(3)	a.	Maljchik	kladjot	sumku	v	korobku.
		boy	put	bag.ACC	in	box.ACC
		'The boy is putting a bag in a box.'				
	b.	Maljchik	kladjot	korobku	v	sumku.
		boy	put	box.ACC	in	bag.ACC
		'The boy is putting a box in a bag.'				

Each sentence was paired up with 2 color images. One image corresponded to the target sentence while the other one corresponded to the semantically reversed counterpart sentence and served as a distractor (Figure 2). For example, for the experimental sentence 'The boy is putting a bag in a box', participants saw a sentence-congruent target picture of a boy putting a bag in a box and a distractor picture of a boy putting a box in a bag. The position of the target and the distractor pictures on the left and the right side of the computer screen was balanced and randomized.

Additionally, 24 filler sentences were added to the experiment. They also included locative and instrumental constructions, but were semantically irreversible, i.e. the argument transformation in these sentences resulted in semantically implausible constructions, e.g. (4a) vs. (4b).

(4)	a.	Maljchik	kladjot	yabloko	v	sumku.
		boy	put	apple.ACC	in	bag.ACC
		'The boy is putting an apple in a bag.'				
	b. *	Maljchik	kladjot	sumku	v	yabloko.
		boy	put	bag.ACC	in	apple.ACC
		'The boy is putting a bag in an apple.'				

Like experimental sentences, filler sentences were also paired up with two color images, targets and distractors. Distractor pictures depicted scenarios, in which the doer used different objects or performed different actions in contrast to the target sentences. For example, for the filler sentence 'The boy is putting an apple *in* a bag', the distractor picture depicted a boy putting an apple *next* to a bag.

All sentences were recorded by a female native speaker of Russian at a normal speaking rate and digitized at a sampling frequency of 44.1 kHz. Experimental sentences were counterbalanced and pseudorandomized across two presentation lists such that no participant received the same sentence in both of its variants (e.g. 'The boy is putting a bag in a box' and 'The boy is putting in a box a bag'); filler sentences were repeated in the two presentation lists. Additionally, all experimental ($n = 48$) and filler ($n = 24$) sentences and their reversed semantic counterpart sentences ($n = 72$) had been rated for grammaticality and plausibility (on a scale from 1 to 5) by native speakers of Russian ($n = 89$, 64 women/ 25 men, mean age = 21) as part of a different study. Using these ratings as a dependent variable, a one-way ANOVA with the sentence condition (Basic I+, Basic I–, Inverted I+, Inverted I–) as an independent variable revealed no significant differences in the ratings between the conditions ($F(3, 140) = 2.19$, $p = 0.1$).

3 Procedure

The experimental task was a sentence-picture matching task, during which participants' response accuracy and reaction times were recorded. The experiment was administered in the remote mode of the DMDX software (Forster and Forster, 2003). Assignment of participants to the presentation lists was random, but recruitment continued until there was the same number of people per list. Participants received a zipped file with the packaged experiment and detailed written explanations of the experimental procedure. They were required to remove all distractions and wear headphones throughout the duration of the experiment. After unpacking the folder, the experiment launched automatically. First, five practice sentences were presented for task familiarization purposes. Accuracy feedback was provided to participants during practice but not during the experiment. On each trial, two pictures (the target and the distractor) appeared on the computer screen while the stimulus sentence was presented auditorily simultaneously with the pictures. Participants were instructed to identify the picture that corresponded to the sentence as fast and as accurately as they could by pressing the right Shift key if they chose the picture on the right or the left Shift key if they chose the picture on the left. Spacebar was used to advance to the next trial. Participants could take self-timed breaks. Reaction times were recorded from the onset of the picture presentation until button press. A total duration of the experiment was about 30 minutes.

4 Statistical approach

Data analysis was performed in R version 3.4.4 (R Core Team, 2019), using packages tidyverse (Wickham et al., 2019) and lme4 (Bates et al., 2015). Degrees of freedom and p-values were generated using lmerTest package (Kuznetsova et al., 2015); pairwise comparisons were estimated with the emmeans package (Lenth, 2020). A series of linear mixed-effects models (lmer function) and logistic generalized linear mixed-effects models (glmer function) with the maximum likelihood estimation were carried out on reaction time and error rate data, respectively. The initial models including the maximal structure of random effects with random intercepts and random slopes (as recommended in Barr et al., 2013) failed to converge; therefore, a reduced random effects structure was used, with by-participant and by-item random intercepts. When determining the structure of the fixed effects, four factors and their interactions were of primary interest: participant group, construction type, word order, and the type of mapping. However, because the levels of the word order (basic and inverted) and mapping (isomorphic and nonisomorphic) variables varied across, but not within, each construction type (e.g. sentences with a basic word order and isomorphic mapping could only occur with the locative, but not instrumental, constructions), this made it problematic to examine the interaction of the four variables at a time without introducing rank deficiencies in the model matrix. To clarify, each experimental condition of the study (Table 1) can be uniquely identified by a combination of any two out of three possible experimental factors (construction + word order, construction + mapping, or word order + mapping). For example, (5) can be defined by the intersection of the levels of any two experimental factors (Locative Basic, Locative Isomorphic, or Basic Isomorphic).

(5)	Maljchik	kladjot	sumku	v	yabloko.
	boy	put	bag.ACC	in	box.ACC

‘The boy is putting a bag in a box.’

Therefore, models with any two of the above factors essentially produce the same marginal means for each experimental condition. Based on such logic, we opted for a model with a three-way interaction of the following fixed factors for modeling each of the dependent variables (DV):

DV ~ mapping * word order * group + (1|participant) + (1|item)

the output of which we report below in Section III. In such a model, the interaction with the construction type is not explicitly included in the model not to introduce rank deficiencies but can be inferred about through pairwise comparisons. For the ease of comparison, the output of an equivalent model with the explicit inclusion of the construction type variable is provided in Appendix 1:

DV ~ construction * word order * group + (1|participant) + (1|item).

The intercept was defined for the native speaker group for the locative constructions with a basic word order and isomorphic mapping (which we hypothesized to be the easiest ones due to the alignment of the word order and the isomorphism cues). For all models, treatment (dummy) coding of contrasts was used. The estimated coefficients generated by the models should therefore be interpreted as a change in the DV brought about by a change of the fixed factor from one level to another. For example, for the native speaker group, a change of the mapping variable from one level to another (i.e. from isomorphic to nonisomorphic mapping) yields a change in the response latency (DV) from 0.53 seconds (for the Basic I+ condition specified in the intercept) to 0.53+0.38 = 0.91 seconds (for the Basic I– condition) (see Table 4 below). All data points were included in the analysis of error, but only correct trials with latencies below 10 seconds were used in the reaction time analysis (resulting in the exclusion of 6.15% of data). Reaction times were calculated by subtracting the duration of the sentence's audio recording from the recorded response latencies (from the onset of the sentence until button press).

III Results

1 Error rate

Analysis of participants' error revealed an overall low error rate in the native Russian-speaking group and the Estonian-dominant heritage group (less than 3%), but an elevated error rate in the English-dominant heritage speaker group (mean = 13%, SD = 1.3). Mean error rates in each participant group and experimental condition are visualized in Figure 3A.

A mixed-effects model with a three-way interaction term for word order, mapping and group yielded a significant word order by group interaction for English-dominant heritage speakers ($\beta = 2.47$, SE = 0.94, $z = 2.64$, $p = 0.008$) (Table 3). A model with a three-way interaction term for construction type, word order and group indicated significant differences in error rate between the native group and the English-dominant group for the instrumental constructions with an inverted word order ($\beta = 2.64$, SE = 1.17, $z = 2.25$, $p = 0.025$) (Table 5 in Appendix 1). Pairwise comparisons generated with the emmeans package (Lenth, 2020) indicated that English-dominant heritage participants made significantly more errors in the instrumental constructions with an inverted word order and isomorphic mapping (Inverted I+) compared to the constructions with a basic word order, both the locative constructions (Basic I+) ($z = 2.73$, $p = 0.006$) and the instrumental constructions (Basic I–) ($z = 2.9$, $p = 0.004$). No significant differences in the error rate were found between sentences with an inverted word order with isomorphic (Inverted I+) and nonisomorphic mapping (Inverted I–); however the latter also did not differ significantly from sentences with a basic word order. Between-group pairwise comparisons showed that English-dominant participants made more errors than Estonian-dominant speakers in each of the four experimental conditions (Basic I+: $z = 2.26$, $p = 0.024$; Basic I–: $z = 2.05$, $p = 0.04$; Inverted I+: $z = 4.25$, $p < 0.001$; Inverted I–: $z = 2.13$, $p = 0.034$), but differed from Russian native speakers only in the conditions with an inverted word order (Inverted I+: $z = 4.55$, $p < 0.001$; Inverted I–: $z = 3.11$, $p = 0.002$). No significant differences in the error rate between different experimental conditions were observed either within or between the Russian native and the Estonian-dominant groups.

To summarize, native Russian and Estonian-dominant heritage speakers made a small number of errors, which was not significantly different across the four experimental

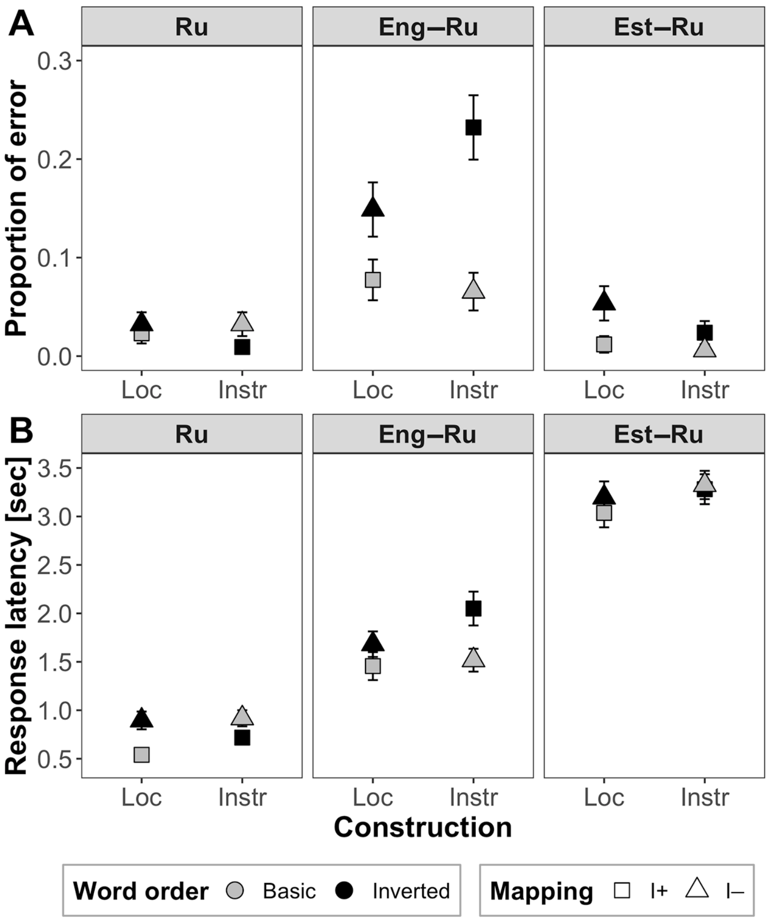

Figure 3. Proportion of participants' error (A) and response latencies (in seconds) (B) across experimental conditions in the three language groups.

Notes. Loc = locative constructions. Instr = instrumental constructions. I+ = isomorphic mapping. I– = nonisomorphic mapping. Eng–Ru = English-dominant heritage speakers of Russian. Est–Ru = Estonian-dominant heritage speakers of Russian. Ru = Russian native speakers.

conditions. English-dominant heritage speakers made significantly more errors compared to native Russian and Estonian-dominant participants, especially in the instrumental sentences with an inverted word order and isomorphic mapping, like (6).

(6)	Zhenshchina	nakryvajet	shapkoj	sharf.
	woman	cover	hat.INSTR	scarf.ACC

'The woman is covering with a hat a scarf.'

Table 3. Summary of the generalized linear mixed-effects model with a three-way interaction between group, word order and mapping type for the analysis of error rate.

Fixed effects	β	SE	*z*	*p*
Intercept (Group: Ru, WO: Basic, Mapping: I+)	−4.13	0.57	−7.19	< 0.001*
Mapping (I–)	0.50	0.72	0.69	0.493
WO (Inverted)	−1.03	0.95	−1.09	0.278
Group (Eng–Ru)	1.19	0.62	1.93	0.054
Group (Est–Ru)	−0.70	0.90	−0.78	0.438
Mapping (I–) × WO (Inverted)	0.93	1.16	0.80	0.426
Mapping (I–) × Group (Eng–Ru)	−0.63	0.76	−0.83	0.408
Mapping (I–) × Group (Est–Ru)	−0.99	1.38	−0.71	0.475
WO (Inverted) × Group (Eng–Ru)	2.47	0.94	2.64	0.008*
WO (Inverted) × Group (Est–Ru)	1.66	1.23	1.35	0.178
Mapping (I–) × WO (Inverted) × Group (Eng–Ru)	−1.39	1.16	−1.20	0.231
Mapping (I–) × WO (Inverted) × Group (Est–Ru)	0.60	1.72	0.35	0.728
Random effects	N	Variance	SD	
ID	92	0.99	0.99	
Item	48	0.81	0.90	

Notes. * significant at alpha < 0.05. Number of data points = 2,208. WO = word order; I+ = isomorphic mapping; I– = nonisomorphic mapping; Ru = Russian native speakers; Eng–Ru = English-dominant heritage speakers of Russian; Est–Ru = Estonian-dominant heritage speakers of Russian.

Table 4. Summary of the linear mixed-effects model with a three-way interaction between group, word order and mapping type for the analysis of reaction time.

Fixed effects	β	SE	*t*	*p*
Intercept (Group: Ru, WO: Basic, Mapping: I+)	0.53	0.21	2.51	0.013*
Mapping (I–)	0.38	0.18	2.08	0.041*
WO (Inverted)	0.18	0.18	0.99	0.325
Group (Eng–Ru)	0.96	0.28	3.36	0.001*
Group (Est–Ru)	2.53	0.28	8.94	< 0.001*
Mapping (I–) × WO (Inverted)	−0.19	0.26	−0.73	0.465
Mapping (I–) × Group (Eng–Ru)	−0.38	0.18	−2.18	0.029*
Mapping (I–) × Group (Est–Ru)	−0.11	0.17	−0.65	0.514
WO (Inverted) × Group (Eng–Ru)	0.45	0.18	2.44	0.015*
WO (Inverted) × Group (Est–Ru)	0.11	0.17	0.64	0.522
Mapping (I–) × WO (Inverted) × Group (Eng–Ru)	−0.16	0.26	−0.64	0.524
Mapping (I–) × WO (Inverted) × Group (Est–Ru)	−0.17	0.25	−0.69	0.489
Random effects	N	Variance	SD	
ID	92	1.03	1.02	
Item	48	0.12	0.35	
Residual		1.38	1.17	

Notes. * significant at alpha < 0.05. Number of data points = 2,072. WO = word order; I+ = isomorphic mapping; I– = nonisomorphic mapping; Eng–Ru = English-dominant heritage speakers of Russian; Est–Ru = Estonian-dominant heritage speakers of Russian; Ru = Russian native speakers.

2 Reaction time

Examination of the processing costs underlying correct sentence-picture matching performance showed that Russian native speakers responded on average within 0.8 seconds (SD = 1.09), while heritage speakers took much longer to select the correct picture corresponding to the target sentence (English-dominant: M = 1.66, SD = 1.71; Estonian-dominant: M = 3.21, SD = 1.96) (Figure 3B). A mixed-effects model with a three-way interaction term for word order, mapping and group supported this observation by yielding significant reaction time differences in the heritage groups compared to the native speaker group (English-dominant: β = 0.96, SE = 0.28, $t = 3.36$, $p = 0.001$; Estonian-dominant: β = 2.53, SE = 0.28, $t = 8.94$, $p < 0.001$) (Table 4). In fact, pairwise comparisons obtained from the model revealed that English-dominant heritage speakers were significantly slower than Russian native speakers in each of the four experimental conditions (Basic I+: $t = 3.32$, $p = 0.001$; Basic I–: $t = 1.99$, $p = 0.049$; Inverted I+: $t = 4.8$, $p < 0.001$; Inverted I–: $t = 2.95$, $p = 0.004$), as were Estonian-dominant heritage speakers (Basic I+: $t = 8.83$, $p < 0.001$; Basic I–: $t = -8.42$, $p < 0.001$; Inverted I+: $t = 9.2$, $p < 0.001$; Inverted I–: $t = 8.19$, $p < 0.001$). Estonian-dominant heritage speakers also incurred significantly greater processing costs in each condition compared to the English-speaking group (Basic I+: $t = 5.15$, $p < 0.001$; Basic I–: $t = 6.04$, $p < 0.001$; Inverted I+: $t = 4$, $p < 0.001$; Inverted I–: $t = 4.89$, $p < 0.001$).

Further, native Russian speakers showed a significant effect of the mapping type (Table 4) (or the construction type for the model with the group × construction × word order interaction, see Table 6 in Appendix 1) (β = 0.38, SE = 0.18, $t = 2.08$, $p = 0.041$) relative to the intercept (defined for the sentences with locative constructions with a basic word order and isomorphic mapping in the native speaker group). Within-group pairwise comparisons revealed that both types of conditions with nonisomorphic mapping – locative constructions with an inverted word order (Inverted I–) and instrumental constructions with a basic word order (Basic I–) – led to longer response latencies compared to locative constructions with a basic word order and isomorphic mapping (Basic I+), which seemed to be processed the fastest ($t = 1.98$, $p = 0.05$ and $t = 2.02$, $p = 0.04$, respectively).

Regarding English-dominant heritage speakers, we obtained a significant interaction of the group by mapping type (β = −0.38, SE = 0.18, $t = -2.18$, $p = 0.029$) and the group by word order (β = 0.45, SE = 0.18, $t = 2.44$, $p = 0.015$) relative to the native speaker intercept (Table 4). This result was driven by significant differences in the reaction times of the English-dominant participants to instrumental constructions with an inverted word order and isomorphic mapping (Inverted I+) compared to constructions with a basic word order, both locative (Basic I+) ($t = 3.02$, $p = 0.003$) and instrumental (Basic I–) ($t = 3.04$, $p = 0.003$) ones, as revealed by pairwise comparisons. Based on this result, reaction time data reflect a similar pattern observed in the analysis of the error rate.

Finally, besides being much slower than the native speaker group and the English-dominant heritage group, Estonian-dominant heritage speakers did not demonstrate any significant reaction time differences between the experimental conditions.

To summarize, among the three participant groups, native speakers incurred the least processing costs while Estonian-dominant heritage speakers showed the longest reaction times, with English-dominant participants falling in between. In the Russian native speaker group, sentences with nonisomorphic mapping led to increased processing time. Sentences, in which both isomorphism and word order cues aligned, were processed the fastest and, therefore, deemed the easiest. In contrast to Russian native speakers, English-dominant heritage speakers experienced processing delays in sentences with an inverted word order, specifically in the instrumental constructions of the type in (6) above, which differed significantly from both types of conditions with a basic word order. Interestingly, Estonian-dominant heritage speakers did not reveal any differences in response times between any of the four experimental conditions.

IV Discussion

Within the framework of the Competition and the Unified models (Bates and MacWhinney, 1989; Bates et al., 1984; MacWhinney, 2005, 2008, 2012), this study set out to identify which cues to sentence parsing are used by heritage speakers during sentence comprehension in their minority language. The stimuli were constructed such that word order (basic or inverted) and isomorphism (isomorphic or nonisomorphic mapping) were fully crossed in a set of locative and instrumental constructions. If heritage speakers inadvertently rely on the cues of their dominant language to process their minority language, we expected English-dominant heritage speakers to rely on the word order cue – the strongest cue in English – for comprehension of Russian sentences. If, however, heritage sentence comprehension is driven by economy constraints, we expected both groups of heritage speakers (English-dominant and Estonian-dominant) to rely on sentence isomorphism, in accordance with the Isomorphic Mapping Hypothesis (O'Grady and Lee, 2005; O'Grady et al., 2005). The obtained data indicate an overall accurate sentence comprehension in the Estonian-dominant heritage speaker group, which was comparable to that of the native speakers of Russian, but a significantly higher percent of comprehension errors in the English-dominant heritage group, consistent with the predictions based on the dominant language transfer. The results of the reaction time analysis provide corroborating evidence in favor of the dominant language transfer in the English-dominant heritage speaker group and offer interesting insights about the role of isomorphism in native language sentence processing.

Turning to the results for the native speaker group, we had originally predicted that locative constructions with a basic word order and isomorphic mapping (Basic I+) should induce the least processing difficulty out of the four conditions examined in the study because both cues align favorably in this condition. This hypothesis was confirmed; indeed, native Russian speakers made their fastest responses in this condition (Figure 3B). We had also predicted that most processing difficulties would be associated with the locative constructions with an inverted word order and nonisomorphic mapping (Inverted I–). This hypothesis was also borne out, however instrumental constructions with a basic word order and nonisomorphic mapping (Basic I–) also elicited similar reaction time delays, suggesting that the nonisomorphic mapping in both types of sentences could have caused greater processing difficulty, thereby providing support for the Isomorphic Mapping Hypothesis. The pattern of the processing costs observed in the native speaker group for each experimental condition is schematically presented in

Constructions		
	I+	I–
Basic	*Мальчик кладет сумку в коробку* The boy is putting a bag in a box	*Женщина накрывает шарф шапкой* The woman is covering a scarf with a hat
Inverted	*Женщина накрывает шапкой шарф* The woman is covering with a hat a scarf	*Мальчик кладет в коробку сумку* The boy is putting in a box a bag

Ru		
	I+	I–
Basic	1	3
Inverted	2	3

Eng–Ru		
	I+	I–
Basic	1	1
Inverted	3	2

Est–Ru		
	I+	I–
Basic	1	1
Inverted	1	1

Figure 4. Schematic representation of observed processing difficulty (shown in the increased order from 1 to 3) in each of the three tested groups of participants for the four types of sentences with locative and instrumental constructions, in which word order (basic vs. inverted) and mapping type (isomorphic, I+ vs. nonisomorphic, I–) are crossed.
Notes. Ru = Russian native speakers, Eng–Ru = English-dominant heritage speakers of Russian, and Est–Ru = Estonian-dominant heritage speakers of Russian.

Figure 4 (bottom left panel). Previously, isomorphism effects were only observed in people with linguistic deficits, such as patients with post-stroke aphasia (Dragoy et al., 2016; O'Grady and Lee, 2001, 2005), or participants with incomplete linguistic competencies, such as children (Cho et al., 1998) or second language learners (O'Grady et al., 2005). This discrepancy could be due to the fact that previous studies only analysed accuracy data. Similarly, we did not observe a significant effect of isomorphism in the error rate data of native speaker participants, it only emerged as reaction time differences. This suggests that while isomorphism does not significantly impact native sentence comprehension, native speakers can still use this information to speed up sentence processing. Therefore, this study provides the first evidence that reliance on structural isomorphism in sentence processing may be characteristic not only of deficient but also mature grammars.

While data from adult native speakers provide support for the Isomorphic Mapping Hypothesis, the two groups of tested heritage speakers demonstrate very different results. English-dominant heritage speakers of Russian did not make significant differences either in the error rate or the reaction times between sentences with isomorphic and nonisomorphic mapping. Instead, they made more errors and responded more slowly to sentences with an inverted word order, specifically to sentences with instrumental constructions with isomorphic mapping (Inverted I+), as in 'The woman is covering with a hat a scarf' (Figure 3). The pattern of the processing costs observed in the English-dominant speaker group for each experimental condition is schematically presented in Figure 4 (bottom middle panel). One explanation of this result could be that heritage speakers tend to overgeneralize most frequent, salient linguistic phenomena, such as canonical word order, and disprefer less frequent phenomena, such as inverted word order. Crucially, we did not observe a similar pattern of results in the Estonian-dominant heritage group. Since there is no reason to believe that one group of heritage speakers would overgeneralize Russian canonical word order and another one would not, we think this result points to the influence of the more dominant (English) language on the weaker (Russian) language. It is now common knowledge that once a monolingual speaker becomes bilingual (or multilingual), the language systems do not exist in isolation; their interaction is constant, dynamic and ubiquitous. Dominant language transfer is the consequence of such interaction, when pre-existing linguistic knowledge of the minority language becomes less accessible or is modified by the presence of the majority language. In the present study, the minority language of the heritage speakers is Russian, a language with rich morphology and a relatively flexible word order. English does not carry as many morphological distinctions and has a rigid word order, which leads English-dominant participants, but not Estonian-dominant participants, to rely more heavily on word order rather than case morphology as the primary cue to sentence parsing and mistakenly apply English cue hierarchy to thematic role assignment in Russian sentences. In this respect it is worth comparing locative and instrumental constructions with an inverted word order (Inverted I– and Inverted I+, respectively). Notice that the latter were associated with the longest reaction times and the highest error rate, but the former did not reach significance compared to the conditions with a basic word order. It is possible that the presence of the preposition in the locative constructions with an inverted word order (Inverted I–) provided a salient cue that the postverbal NP cannot serve as a direct object. In contrast, there is no preposition in Russian instrumental constructions, so the ability to extract the grammatical meaning from the noun's case inflections becomes even more crucial for the correct identification of the noun's thematic roles. For example, if one relies more heavily on the word order cue rather than the case marking in (6) above, the noun following the verb will be interpreted as the theme of the sentence instead of the instrument. If English-dominant heritage speakers of Russian relied on the word order cue in their interpretation of Russian constructions, this explains why such strategy led to particularly longer reaction times and more errors in the instrumental constructions with the inverted word order. Indeed, previous research has shown that reduced sensitivity to grammatical markers in heritage speakers is quite common, which results in the confusion of oblique cases (Isurin and Ivanova-Sullivan, 2008) and the simplification of case system (see Flores, 2020; Polinsky, 1997, 2007, 2018; Polinsky and Kagan, 2007; but see recent contradictory evidence in Łyskawa and Nagy, 2020), with a gradual shift from oblique cases towards the nominative case. Such shift characterizes encoding of major syntactic relations, including the predicate-argument structure. For example, the accusative case is reserved to mark direct and indirect objects, while the nominative case becomes a versatile, multifunctional case that replaces all other case uses. While we did not explicitly test our heritage speaker participants on their knowledge of Russian case inflections, the results of our study indirectly implicate reduced knowledge of case morphology as a culprit of dominant language transfer and the non-nativelike processing.

Now, regarding the results for the Estonian-dominant heritage speaker group, our hypotheses were not borne out. Although the Estonian-dominant participants demonstrated high level of sentence comprehension, similar to the Russian native speaker controls, they experienced significant trade-offs in terms of reaction times, which did not differ significantly across the four experimental conditions (Figure 3B and Figure 4, bottom right panel). Thus, while their comprehension was comparable to the native speaker baseline, the processing costs that they incurred were not nativelike. This is surprising, given that Estonian, similar to Russian, features a sophisticated and complex case system and allows for a flexible word order. We believe that the explanation of the obtained results lies in the differences of how grammatical relations are encoded in the two languages. While both Russian and Estonian case systems are rich and complex, there is no direct correspondence between the cases. For example, the accusative and the instrumental cases in the investigated Russian locative constructions with a directional meaning may map onto two of the six locative cases in Estonian: Illative and Allative (Ōispuu, 1999; Valmet et al., 1981), which have narrower semantics compared to the Russian cases. In Russian, case inflections are highly fusional and syncretic and can express different grammatical meaning (e.g. case, number, gender), which can present an additional challenge for Estonian-dominant heritage speakers, since Estonian morphology is mostly agglutinative (Kaivapalu and Martin, 2007). Another factor that may help to account for the results of the Estonian-dominant participants is the difference in how locative meaning can be expressed in the locative constructions in the two languages. While Russian has prepositions but no postpositions, Estonian can mark locative meaning either with a locative case marker or a postposition, although less frequently and mostly to emphasize the location or the direction, e.g. *autosse.ILLATIVE = auto.GEN sisse.PREP.ILLATIVE* ('in the car') (Valmet et al., 1981). This might have contributed to the overall uncertainty about the correct sentence parse and have slowed down online sentence processing. Importantly, since little is known about the relative contribution of various cues (case markers, word order, postpositions, etc.) to sentence comprehension by native Estonian speakers, we are unable at this point to resolve with confidence which of the above factors have contributed to the increased processing costs observed in the Estonian-dominant heritage group.

To conclude, the present study is the first to examine the role of cross-linguistic transfer versus general processing strategy in a population of heritage speakers. Comparing two groups of heritage speakers with typologically different dominant languages and the same heritage language strengthens our argument in favor of transfer of strong cues from the dominant language during comprehension of the minority language, as is evidenced by reliance of English-dominant, but not Estonian-dominant, heritage speakers on the word order cue during comprehension of Russian sentences. No evidence of reliance on isomorphism as a general strategy to maximize sentence processing efficiency was found in the heritage speaker groups. However, we demonstrate for the first time that reliance on structural isomorphism may be characteristic of native grammars, providing additional evidence in favor of the Isomorphic Mapping Hypothesis.

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Note

1. Preliminary results on the processing of locative and instrumental constructions by early and late English-dominant heritage speakers of Russian are reported in Chrabaszcz and Dragoy, 2017.

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Appendix 1. Additional mixed-effects models.

Table 5. Summary of the generalized linear mixed-effects model with a three-way interaction between group, construction type and word order for the analysis of error rate.

Fixed effects	β	SE	*z*	*p*
Intercept (Group: Ru, Construction: Loc, WO: Basic)	−4.13	0.57	−7.19	< 0.001*
Construction (Instr)	0.50	0.72	0.69	0.493
WO (Inverted)	0.39	0.73	0.54	0.589
Group (Eng–Ru)	1.19	0.62	1.93	0.054
Group (Est–Ru)	−0.70	0.90	−0.78	0.439
Construction (Instr) × WO (Inverted)	−1.92	1.17	−1.64	0.102
Construction (Instr) × Group (Eng–Ru)	−0.63	0.76	−0.83	0.408
Construction (Instr) × Group (Est–Ru)	−0.99	1.38	−0.71	0.475
WO (Inverted) × Group (Eng–Ru)	0.46	0.72	0.64	0.525
WO (Inverted) × Group (Est–Ru)	1.27	1.01	1.26	0.207
Construction (Instr) × WO (Inverted) × Group (Eng–Ru)	2.64	1.17	2.25	0.025*
Construction (Instr) × WO (Inverted) × Group (Est–Ru)	1.37	1.73	0.79	0.429
Random effects	N	Variance	SD	
ID	92	0.99	0.99	
Item	48	0.81	0.90	

Notes. * significant at alpha 0.05. Number of data points = 2,208. Loc = Locative; Instr = Instrumental; WO = word order; Ru = Russian native speakers; Eng–Ru = English-dominant heritage speakers of Russian; Est–Ru = Estonian-dominant heritage speakers of Russian.

Table 6. Summary of the linear mixed-effects model with a three-way interaction between group, construction type and word order for the analysis of reaction time.

Fixed effects	β	SE	*t*	*p*
Intercept (Group: Ru, Construction: Loc, WO: Basic)	0.53	0.21	2.51	0.013*
Construction (Instr)	0.38	0.18	2.08	0.041*
WO (Inverted)	0.37	0.18	2.03	0.046*
Group (Eng–Ru)	0.96	0.28	3.36	0.001*
Group (Est–Ru)	2.53	0.28	8.94	< 0.001*
Construction (Instr) × WO (Inverted)	−0.57	0.26	−2.21	0.030*
Construction (Instr) × Group (Eng–Ru)	−0.38	0.18	−2.18	0.029*
Construction (Instr) × Group (Est–Ru)	−0.11	0.17	−0.65	0.514
WO (Inverted) × Group (Eng–Ru)	−0.10	0.18	−0.57	0.570
WO (Inverted) × Group (Est–Ru)	−0.17	0.17	−0.99	0.323
Construction (Instr) × WO (Inverted) × Group (Eng–Ru)	0.93	0.26	3.64	< 0.001*
Construction (Instr) × WO (Inverted) × Group (Est–Ru)	0.40	0.25	1.61	0.107
Random effects	N	Variance	SD	
ID	92	1.03	1.02	
Item	48	0.12	0.35	
Residual		1.38	1.17	

Notes. * significant at alpha 0.05. Number of data points = 2,072. Loc = Locative; Instr = Instrumental; WO = word order; Ru = Russian native speakers; Eng–Ru = English-dominant heritage speakers of Russian; Est–Ru = Estonian-dominant heritage speakers of Russian.