Journal of Experimental Child Psychology 242 (2024) 105868

Contents lists available at ScienceDirect

Journal of Experimental Child Psychology

journal homepage: www.elsevier.com/locate/jecp

Fine-grained differences in gender-cue strength affect predictive processing in children: Cross-linguistic evidence from Russian and Bulgarian

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ARTICLE INFO

Article history:
Received 14 July 2023
Revised 19 December 2023

Keywords:
Adjective–noun gender agreement
Visual world paradigm
Gender cues
Gender complexity matrix
Fine-grained cross-linguistic differences
Closely related languages

ABSTRACT

We tested predictive gender agreement processing in adjective–noun phrases by 45 4- to 6-year-old Russian- and Bulgarian-speaking children using the visual world eye-tracking paradigm. Russian and Bulgarian are closely related languages that have three genders but differ in the nature and number of gender cues on adjectives. Analysis of the proportion and time course of looks to the target noun showed that only Bulgarian children used gender cues to predict the upcoming noun. We argue that the cross-linguistic difference in the gender cue strength is revealed through the operation of economy, transparency, and interdependence in a gender complexity matrix. The documented advantage for Bulgarian children in gender agreement processing and acquisition underscores the need for a comparative language acquisition approach to typologically close languages.

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https://doi.org/10.1016/j.jecp.2024.105868
0022-0965/

Introduction

Recent cross-linguistic evidence suggests that fine-grained grammatical differences in closely related languages have direct consequences for language processing in development (Christiansen et al., 2022) given that they may influence children's ability to rapidly predict upcoming structures based on multiple cues (Brouwer et al., 2017; Cholewa et al., 2019). Such an approach allows for an investigation of subtle linguistic differences in children's first language (L1) acquisition. Although the calls for comparative language acquisition research are not new (Slobin & Bowerman, 2007), they have intensified in the context of the dominance of research on English and the more general lack of diversity in developmental language research (Kidd & Garcia, 2022).

One of the best studied domains where a comparative approach could reveal important consequences for the course of acquisition and the strength of the predictive abilities of young children is gender agreement.[1] However, due to the scarcity of comparative research on gender acquisition, not much is known about the role of fine-grained differences in the gender systems of typologically close languages. Few publications have adopted a comparative approach and investigated the role of structural (type of gender-marked categories) and distributional (validity of gender cues) factors in the acquisition of gender agreement (Ivanova-Sullivan & Sekerina, 2019; Janssen, 2016; Ševa et al., 2007); however, they did not focus on predictive processing that has dominated reseach in developmental psycholinguistics during the past decade. The same experimental design based on cues across the compared languages in these offline studies facilitates connections between typological research on gender complexity and its acquisition, thereby helping to identify the common sources of difficulties from a learner's perspective. We adopted this experimental design to two typologically close languages, Russian and Bulgarian, but unlike previous comparative studies we specifically focused on children's predictive processing of gender agreement.

We operationalized the typological differences in Russian and Bulgarian through the lens of the complexity matrix developed by Audring (2017, 2019), which evaluates the different domains of gender from a learnability perspective. Specifically, the operation of three principles—*transparency, economy,* and *interdependence*—would help to illuminate the strength of gender cues in gender agreement processing in the developing grammars of Russian and Bulgarian children. The transparency principle applies to the expressions of categories (in our case gender cues) articulated as "one meaning–one form." The economy principle pertains to the number of elements that participate in gender agreement; the smaller their number, the more efficient the acquisition of this system. The interdependence principle considers a system in which all features are independent of each other, less complex than one where they interact.

We explored the impact of these three principles on the typological differences between Russian and Bulgarian such as *structural depth* (i.e., the presence or absence of a determiner), *perceptual transparency* (i.e., the homophony of modifiers' endings), and *functionality of gender cues* in gender agreement processing. We suggested that a learnability perspective applied to the analysis of the nature and direction of this impact allows us to investigate children's ability to use gender cues in their languages predictively. Our results show that this predictive processing ability is modulated by the fine-grained differences in the gender cue strength in Russian and Bulgarian despite the general similarities in their gender systems.

Gender in Russian and Bulgarian

The coarse-grained similarities between the gender systems of Russian and Bulgarian pertain to the presence of three genders, which are marked on nouns, adjectives, pronouns, participles, numerals,

[1] Some linguistic theories make a distinction between agreement and concord (Harley & Ritter, 2002; Norris, 2019). Agreement is the dependency between a head and its argument (syntactic positions are limited), for example, subject–verb agreement for gender, number, and person. The concord is the dependency between a head and its modifier (an adjunct), for example, adjective–noun concord for gender, number, case, and definiteness. Concord may be expressed on multiple elements within the same noun and/or determiner phrase. In this study, we do not distinguish between concord and agreement because both phenomena refer to feature sharing (Corbett, 2003; Preminger, 2014).

quantifiers, and past tense verbs (only in singular because gender distinctions are neutralized in plural). At the same time, the gender systems of the two languages also differ in (a) morphophonological transparency/opacity and distribution of gender assignment and agreement cues, (b) nature and role of agreement targets (i.e., elements participating in gender agreement such as adjectives, determiners, and participles), and (c) interaction of the gender feature with other nominal categories such as number, declension, animacy, definiteness, and grammatical case (Comrie, 1999; Corbett & Comrie, 2003).

The morphophonological transparency/opacity and distribution of gender assignment and agreement cues has different realization in Bulgarian and Russian as a result of two phonological processes—*palatalization* and *vowel reduction.* First, in Russian, palatalization (graphically marked by a soft sign) is the most notable characteristic of opaque gender assignment cues on feminine (FEM) and masculine (MASC) nouns given that it interferes with the probability of regular and consistent associations between noun endings and gender values (e.g., *lopata* 'shovel-FEM', *stul* 'chair-MASC'). In Bulgarian, palatalization is less robust and does not affect stem-final consonants, which reduces the ambiguity of gender cues on noun endings. Compared with Russian, where inanimate opaque nouns are distributed across the three genders (e.g., *krov* 'shelter-MASC', *krov* 'blood-FEM'), their distribution in Bulgarian is limited to a small group of FEM nouns (∼160) that have consonant noun endings (e.g., *pesen* 'song', *sol* 'salt', *krăv* 'blood') instead of the transparent *-a/-ja* endings usually associated with FEM nouns (Nicolova, 2018; Pashov, 1989); there are no opaque MASC or neuter (NEUT) nouns. Such restricted distribution of opaque nouns results in fewer associations between form and meaning, making the Bulgarian gender system arguably more transparent compared with Russian.

Second, transparency/opacity in Russian (but not in Bulgarian) is also affected by vowel reduction in FEM and NEUT nouns. The stem-stressed NEUT nouns (e.g., ózero 'lake-NEUT') trigger a reduction of the unstressed *-o* ending to a schwa sound, pronounced the same way as the unstressed *-a* in FEM transparent nouns (e.g., *méra* 'measure-FEM') (Iosad, 2012), thereby neutralizing the FEM–NEUT contrast in spoken Russian (Rodina & Westergaard, 2017).

The typological differences in the distribution of transparent and opaque cues in gender assignment of nouns in Russian and Bulgarian extend also to gender agreement for adjectives. Whereas all Bulgarian adjectival endings are always transparent, Russian FEM and NEUT adjectival endings vary as a result of the place of stress on the stem (e.g., */krásnəjə/* 'red-FEM') versus the stress on the ending (e.g., */gəlubájə/* 'blue-FEM'). Specifically, the vowel reduction in NEUT and FEM stem-stressed adjectives blurs the FEM–NEUT contrast, making the gender cues on this much larger group of adjectives nontransparent. In contrast, Bulgarian NEUT and FEM adjectives do not feature such neutralization despite the presence of vowel reduction (e.g., */chervénə/* 'red-FEM'–*/chervénu/* 'red-NEUT'). Thus, applying Audring's principle of transparency, gender cues on Bulgarian adjectives (modifiers) are more transparent compared with Russian adjectives, which feature uneven distribution of transparent (ending-stressed) and nontransparent (stem-stressed) gender cues.

The gender system of Bulgarian includes an additional element for gender distinctions, the definite article, which is expressed as an inflectional affix on the head of the syntactic phrase, either noun (Examples 1 and 2) or adjective (Example 3):

1. *moliv*	*moliv-**ăt*** 'pencil'	'the pencil-MASC'
kukla	*kukla-**ta*** 'doll'	'the doll-FEM'
palto	*palto-**to*** 'coat'	'the coat-NEUT'
2. *krăv*	*krăv-**tá*** 'blood'	'the blood-FEM'
3. goljama-**ta**	xubava	kukla
big-FEM-DET	nice	doll-FEM

The definite article attached to inanimate FEM opaque nouns illustrated in Example 2 results in perceptually transparent and unambiguous gender cues due to the form of the FEM determiner *-ta,* which is always under stress. Ostentatiously, the Bulgarian definite article marked for gender violates Audring's principle of economy, making its gender system more complex compared with the Russian one.

At the same time, the definiteness marker provides a more clear form-to-function mapping for opaque nouns, making the Bulgarian system more transparent, in line with the transparency principle.

Table 1summarizes key information about the type (transparent or opaque) and distribution of gender cues on nouns[2] and adjectives in gender assignment and gender agreement in Russian and Bulgarian.

Finally, the interaction of gender with declension, number, case, and animacy in Russian contributes to the polyfunctionality of the Russian gender system, which according to Audring's principle of interdependence exhibits more complexity than a system in which all features are independent of each other. Unlike Russian, Bulgarian does not have a case system for nouns, only pronouns, making the nominal declension paradigm of nouns and their agreeing elements smaller and more transparent compared with Russian.

In sum, despite a learnability drawback of the Bulgarian gender system that is manifested in the more limited evidence with opaque nouns about form–meaning associations (Ivanova-Sullivan & Sekerina, 2019), according to Audring's principle of transparency, Bulgarian is more transparent than Russian in its gender distinctions and its gender agreement should be easier to acquire.

Acquisition of gender in Russian and Bulgarian

Early descriptive work in English provided an initial framework to study the acquisition of morphophonological markers by children (Brown, 1973; Pinker, 1984), described overregularization errors in verb inflections (Ambridge et al., 2011; Maratsos, 2000), and established the critical role of morphology in diagnosing developmental language disorders (Rice & Wexler, 1996). The subsequent scholarship on the acquisition of languages with more complex morphological systems has resulted in empirically rich descriptions of children's production, noting the milestones in the acquisition of morphological markers and simultaneously acknowledging the challenges in establishing a clear matrix of inflectional complexity cross-linguistically (Argus, 2009; Clark, 2017; Voeikova & Dressler, 2002; Xanthos et al., 2011).

Specific types of morphological complexity, such as the higher degree of syncretism between gender and case, have been considered as factors in the slower acquisition of some languages compared with others (Eichler et al., 2013, for German and French). Our study reveals an important contrast in the degree of syncretism in the otherwise closely related Russian and Bulgarian. Whereas Bulgarian adjectives are gender-marked with monofunctional (gender-dedicated) cues, Russian fuses gender and case in its polyfunctional adjectival endings (syncretism). Thus, applying Audring's principle of interdependence, the Russian polyfunctional adjectival endings bearing gender, number, and case cues make the system more complex and challenging for acquisition compared with that of Bulgarian, in which the gender is marked on monofunctional adjectival endings and the definiteness marker.

The presence of a large number of agreeing elements marked for gender also adds to the complexity of the gender system, but from the point of view of acquisition it provides children with richer representation of gender distinctions, greater perceptual transparency, and dedicated gender cues. We view this enhancement of the learnability of the gender system as manifesting the operation of the transparency and interdependence principles (Audring, 2019) and stimulating children to pay close attention to form–meaning relations (see Dressler et al., 2007, for a discussion). By extending the scope of the earlier descriptive accounts to current interest in children's processing of gender, we aim to illuminate the implications of the differences in the Russian and Bulgarian gender systems for acquisition and evaluate the weight of their gender cues using Audring's complexity matrix and its three principles.

Monolingual Russian-speaking children acquire the gender of transparent FEM and MASC nouns by age 2;6 (years;months), as evidenced by the fact that they produce correct adjectival agreement in phrases with FEM nouns ending in *-a* and MASC nouns ending in non-palatalized consonants (Rodina & Westergaard, 2017; Schwartz et al., 2015). The gender assignment of transparent NEUT nouns ending in a stressed vowel is acquired by age 3;0 to 4;0, whereas the gender of opaque NEUT

[2] We focus on inanimate nouns and leave semantic gender aside due to the complex interaction between morphophonological and semantic cues in gender agreement and the possible impact of animacy on gender processing.

Table 1
Gender assignment and agreement in Russian and Bulgarian.

	Russian				Bulgarian	
	Transparent nouns		Opaque nouns		Transparent nouns	Opaque nouns
FEM Opaque Adj.	*krásn**əjə***	*kúkla*	*krásn**əjə***	*krov'*	*tʃɛrvén**ɒ-tɒ** kúkla*	*tʃɛrvén**ɒ-tɒ** krɤv*
	red	doll	red	blood	red-DET doll	red-DET blood
FEM Transp. Adj.	*gəlub**ájə***	*kúkla*	*golub**ájə***	*krov'*		
	blue	doll	blue	blood		
MASC	*krásn**ɨj***	*stol*	*krásn**ɨj***	*gvozd'*	*tʃɛrvén**i-ɤt** stɔl*	none
	red	table	red	nail	red-DET chair	
	gəlubój/	*stol*	*gəlub**ój***	*gvozd'*		
	blue	table	blue	nail		
NEUT Opaque Adj.	*krásn**əjə***	*pal'tó*	*krásn**əjə***	*ózero*	*tʃɛrvéno-**to** palto*	none
	red	coat	red	lake	red-DET coat	
NEUT Transp. Adj.	*gəlub**óje***	*pal'tó*	*golub**óje***	*ózero*		
	blue	coat	blue	lake		

Note. All adjectives in the table are presented in phonetic transcription following the International Phonetic Alphabet. A single quotation mark indicates the palatalization of the preceding consonants (e.g., *gvosʲt'*), a contrastive feature present only in Russian (Padgett, 2003). Adjectival endings are given in bold, and the definite article in Bulgarian is glossed and separated from the ending graphically for the sake of clarity. FEM, feminine; Transp., transparent; Adj., adjective; MASC, masculine, NEUT, neuter; DET, determiner.

nouns with an unstressed vowel happens much later by age 6;0. The ending of opaque nouns in a palatalized consonant does not serve as a reliable indicator of gender assignment and often results in initial delay (up to age 7;0) in the acquisition of these nouns (Ceitlin, 2009; Gvozdev, 1961; Mitrofanova et al., 2021).

Monolingual Bulgarian children acquire the grammatical system of their language by age 3;0, but the scarcity of studies about gender acquisition hinders investigations of the cue strength of different gender markers. Limited naturalistic production data show that alongside error-free gender agreement attested with transparent nouns as early as age 1;6, Bulgarian children produce nontarget feminine opaque forms with the short form of the MASC definite article *–a* such as **zahara* 'the sugar' instead of the correct *zaharta* and **sola* 'the salt' instead of the correct *solta* (Stojanova, 2021). The noncanonical use of the MASC form of the definite article in these cases reflects unstable gender assignment, much like the one attested in Ivanova-Sullivan and Sekerina's (2019) study of the FEM opaque nouns. The strong effect of the transparency of gender cues in Bulgarian was also reported in a study with adults who processed transparent nouns faster than opaque ones in a gender-monitoring task (Andonova et al., 2004).

The importance of the determiner for the gender cue strength in gender acquisition has been documented in studies of other languages, which found that gender agreement on determiners is acquired earlier than gender agreement on adjectives (Eichler et al., 2013; Szagun et al., 2007). However, the distributional strength of the determiner manifested in determiner–noun co-occurrence in these languages is still under debate. Some of the findings support the view that the frequently co-occurring determiner–noun pair provides only probabilistic cues to learners without tapping into syntax proper (Cholewa et al., 2019; Lew-Williams & Fernald, 2010; Melançon & Shi, 2015). It should be noted that this discussion only references free-standing determiners in Romance and Germanic languages. Acquisition data from languages with determiners in the form of bound morphemes, as in Bulgarian, are scarce but would allow us to examine the gender agreement from a grammatical perspective rather than a probabilistic one.

The current study

Evidence about Russian and Bulgarian gender acquisition milestones comes primarily from production studies (Rodina & Westergaard, 2017; Stojanova, 2021), whereas gender comprehension is underinvestigated in Russian and Bulgarian acquisition scholarship despite its different nature and outcomes. Thus, there are still unanswered questions about the comprehension acquisition timeline

and its relation to gender processing. Our study, informed by the comparative approach to language acquisition (Christiansen et al., 2022), aimed to throw more light on these questions by investigating children's ability to predict an upcoming noun modified by a preceding gender-marked adjective in two closely related languages, Russian and Bulgarian, using the visual world eye-tracking paradigm (VWP). We expected that this methodology would reveal how preschool-age children use gender markers online to guide their comprehension and whether the fine-grained typological differences between Russian and Bulgarian have any impact on it.

The small number of earlier VWP studies of gender agreement processing in Russian children show mixed findings, possibly due to the differences in their experimental design (Aumeistere et al., 2022; Sekerina, 2015). What they have in common is the comparison of children and adults as the two endpoints in acquisition. Such a focus does not allow us to evaluate independently the effects of structural and perceptual gender cues on agreement targets and their contribution to predictive processing because of the differences in maturational constraints between adults and children. To overcome such potential limitations, we chose not to compare adults and children but instead conducted a cross-linguistic investigation of gender agreement processing by comparing two groups of children, Russian and Bulgarian children matched on age, using an identical design and method.

As we mentioned earlier, Russian children start producing correct gender agreement at 2 to 3 years of age and demonstrate meta-awareness with respect to gender assignment of nonce words (Mitrofanova et al., 2018, 2021). These findings indicate that there are qualitative similarities between adults and children in acquisition of gender. On the other hand, children show protracted acquisition of neuter nontransparent nouns and some exceptional cases such as *papa*-like nouns, double gender nouns, and FEM nouns ending in *-o* (Rodina, 2008). The differences between adults and children are due to the complexity of special cases and exceptions, the larger vocabulary in adults (providing more material for generalizations), adults' higher general metalinguistic awareness, and adults' faster processing speed. In our study, we tried to take care of the differences by using very simple sentences and words that children are expected to know by 4 years of age.

Our methodology was the VWP, which measures children's ability to employ gender cues in real time (Aumeistere et al., 2022; Brouwer et al., 2017; Sekerina, 2015). We aimed to determine whether the fine-grained differences in the gender systems of these languages described above affect the strength of the gender cues on agreement targets (adjectives) in predictive processing of gender agreement. We chose to focus on adjectives because, unlike freestanding determiners, adjectives do not regularly co-occur with nouns, which helps us to rule out possible probabilistic learning (Bellanger et al., 2017; Grüter et al., 2012). At the same time, the presence of a definite determiner in Bulgarian as an inflectional affix versus case in Russian allowed us to explore the effects of fine-grained typological differences between the otherwise closely related languages on the strength of gender cues in word endings.

To accomplish this, our research question called attention to the ways in which Russian and Bulgarian gender cues on modifiers influence children's ability to predict the upcoming noun. We determined the predictive strength of these gender cues by analyzing their adherence to or violation of the principles of economy, transparency, and interdependence, which organize the typological space of gender (Audring, 2017, 2019). Our analysis of the interaction of these principles in Russian and Bulgarian throws light on the greater strength of specific gender-marked elements as a result of their structural depth, perceptual transparency, and mono- or polyfunctionality. To this end, our research question was the following:

> Do language-specific gender cues on adjectival modifiers have differential predictive effects on gender agreement processing in Russian and Bulgarian because of the fine-grained differences between the gender systems of the two languages?

Null hypothesis

The null hypothesis states that fine-grained differences between Russian and Bulgarian will not have an impact on children's predictive gender processing, and there will be no differences in eye movements between the two groups. Specifically, both Russian and Bulgarian children will look at the target noun earlier in the Informative condition when the two objects (target and competitor)

are of different genders (DIFF condition) compared with the Uninformative condition when they are the same (SAME condition).

Hypothesis 1a

Hypothesis 1a states that Bulgarian-speaking children will be less efficient (i.e., slower) in gender agreement processing than their Russian-speaking peers. This prediction is based on the violation of the principle of economy in Bulgarian because of the redundancy of the gender marker on the adjectival ending (e.g., goljam-a, 'big-FEM') and on the definite determiner suffix attached to that ending (goljama-ta, 'the big one-FEM').

Hypothesis 1b

Alternatively, Hypothesis 1b states that Bulgarian-speaking children will be more efficient than their Russian-speaking peers bearing on the principles of transparency and interdependence. The monofunctional determiner and adjectival endings in Bulgarian provide more salient cues for gender distinctions compared with the Russian polyfunctional adjectival endings, which are simultaneous exponents of gender and case.

Method

Participants

We recruited 23 L1 Russian-speaking children (14 girls; M_{age} = 5;4, range = 3;8–6;8) and 22 L1 Bulgarian-speaking children (16 girls; M_{age} = 5;0, range = 3;11–6;0) in public day cares in Moscow and Sofia located in neighborhoods with average socioeconomic status (i.e., representative of the general population). All participants were monolingual, exposed only to Bulgarian or Russian at home and in the day cares.

The study was approved by the institutional review boards of [University of New Mexico, Bar-Ilan University, and CUNY]. It was carried out in accordance with the ethical principles of the Declaration of Helsinki. Parents signed an informed consent form in Russian or Bulgarian. Children gave oral assent and received a small toy as a thank-you gift after the experiment.

Design and materials

Two weeks prior to the VWP experiment, both groups participated in a picture-naming production task (discussed in Ivanova-Sullivan & Sekerina, 2019). It was necessary to ensure that all participants were familiar with the names of the objects that would be presented to them in the VWP experiment.

Children were presented with a dual-picture screen (Fig. 1) paired with a spoken sentence (Examples 4 and 5) in one of the two conditions based on the gender of the objects—Uninformative (SAME gender) or Informative (DIFF gender)—and were asked to click on the pictures that matched the sentence:

4. RUSS:	*Pokazhi,*	*gde zdes'*	*krasnaja*	*krov'?*
	Show-IMP	where here	red-FEM	blood-FEM
5. BULG:	*Pokazhi,*	*kăde e*	*chervena**ta***	*krăv?*
	Show-IMP	where is	red-FEM-DEF	blood-FEM
	'Show where here is red blood.'			

In Russian, the target nouns included 10 FEM, 10 MASC, and 13 NEUT nouns. We controlled for two factors when selecting them. First, in each gender, half of them were transparent (5 items, e.g., *lopata* 'shovel-FEM', *stul* 'chair-MASC', *peró* 'feather-NEUT') and half were opaque (5 items in FEM and MASC, e.g., *krov'* 'blood-FEM', *remen'* 'belt-MASC'; 8 items in NEUT, e.g., *ózero* 'lake-NEUT'). Second, in the DIFF condition, to avoid a complicated design involving different combinations of three genders, we did not

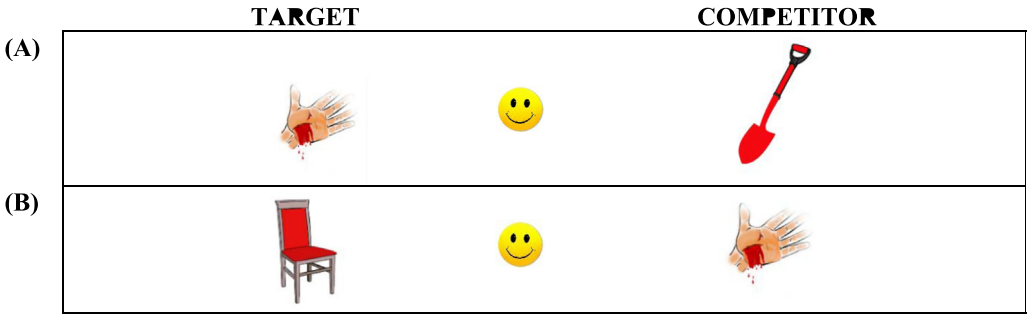

Fig. 1. (A) Uninformative (SAME gender) condition: Target noun *krov'* 'blood-FEM' and competitor noun *lopata* 'shovel-FEM'. (B) Informative (DIFF gender) condition: Target noun *krov'* 'blood-FEM' and competitor noun *stul* 'chair-MASC'. FEM, feminine; MASC, masculine.

use the NEUT nouns as competitors for the FEM and MASC target nouns; that is, FEM targets were always paired with a MASC competitor and vice versa. The NEUT target nouns were paired with either a FEM or a MASC competitor, resulting in three additional pairs (8) than for the FEM and MASC targets. Target nouns were rotated to serve as competitors as well, and several nouns were added to be used exclusively as competitors. The Bulgarian materials contained 11 MASC nouns (all transparent because of the lack of MASC opaque nouns in Bulgarian) and 15 FEM nouns (5 opaque words to match the Russian design and 10 transparent ones). We did not include NEUT nouns and adjectives because they were noninformative of the role of perceptual transparency, unlike the NEUT in Russian. The lack of absolute alignment between the gender of the target items in Russian and Bulgarian resulted in differences in the number of transparent and opaque MASC and FEM nouns in the two conditions cross-linguistically.

In total, there were 59 inanimate target and competitors nouns in Bulgarian and Russian that were matched phonologically, orthographically, grammatically, and semantically whenever possible between the two languages. We were able to use the same words in both languages for 8 items, among which were *traktor* 'tractor-MASC', *kartina* 'picture-FEM', and *kukla* 'doll-FEM'. However, some of the stimuli differed in their phonology (e.g., RUSS *koleno* – BULG *koljano* 'knee-NEUT') or were just different lexical items (RUSS *ladon'* – BULG *dlan* 'palm of the hand-FEM'). In the cases where the gender or the word was different (e.g., RUSS *pedal'*-FEM and BULG *pedal*-MASC, 'pedal'), we needed to replace it with a different lexical item in order to keep the design as balanced as possible. All nouns were of a comparable frequency in the Bulgarian and Russian child speech. The same images were used in both languages wherever possible. The full list of target and competitor nouns and visual stimuli is provided at the Open Science Framework (OSF) repository.

In the current experiment, similarly to previous studies (Aumeistere et al., 2022; Lemmerth & Hopp, 2019), the modifying adjective was always a color adjective in the baseline form: black, white, red, blue, pink, yellow, or brown (see Examples 4 and 5). Color adjectives were chosen because of their high frequency in child-directed speech (Tribushinina et al., 2014) and their ease of visualization. However, it should be noted that most Russian color adjectives are stem-stressed; therefore, FEM and NEUT are ambiguous (e.g., Vorobyeva et al., 2023), and only the adjective *golubój* ('light blue') marks gender information transparently on its ending (see Table 1).

Our design included language (Russian or Bulgarian) and condition (SAME gender or DIFF gender). Thus, there was a 50% chance for participants to predict the gender of the target noun in the Uninformative SAME condition. In Fig. 1A, the target *blood* is FEM and phonologically opaque (i.e., it ends in the palatalized C' -*v'* in Russian and C -*v* in Bulgarian), the competitor *lopata* 'shovel' is also FEM but phonologically transparent (i.e., it ends in -*a*). In this case, the adjective *krasn**aya**/cherven**ata*** 'red-FEM' is compatible with either the target or the competitor. In the Informative DIFF condition, the gender of the target and the competitor noun was different (Fig. 1B). The FEM target *blood* was paired with the MASC competitor *stul* (RUSS) or *stol* (BULG) 'chair'.

In addition, the target noun and its gender in each condition in both languages were matched for stem-final consonants that precede the ending in order to ensure phonotactic compatibility in the two languages. The stem-final consonants used in our study were [d], [t], [r], [l], [v] and [n]. Table 2 provides examples of the stimuli with the coda consonant [n] of transparent and opaque nouns (the gap in MASC opaque in Bulgarian reflects the lack of inanimate opaque nouns in MASC discussed earlier).

The SAME and DIFF conditions were rotated through two lists in Russian and one list in Bulgarian. The smaller number of stimuli in the latter is a result of the exclusion of NEUT adjectives and nouns and the lack of MASC opaque nouns in Bulgarian. Thus, the design in regard to transparent and opaque nouns mirrored the asymmetrical distribution of opaque nouns across gender classes in the two languages, echoing Aumeistere et al.'s (2022) considerations about the transparency-based unbalance of their Russian design.

Procedure

Children were tested individually by the first author, who is a balanced Bulgarian–Russian bilingual, in a quiet room of their day care. They were familiarized with the task and the equipment and were asked for their oral consent. After obtaining their consent, they were seated in front of the stimuli laptop with a remote eye-tracking camera attached to it. A 9-point calibration was performed prior to the study.

The eye movements of the participants were captured by the ETL-500 (ISCAN), a remote free-viewing eye-tracker, and recorded on a digital SONY DSR-30 video tape-recorder. The images (see Fig. 1A and 1B) were presented on a 19-inch HP laptop computer connected to the eye-tracker. Spoken sentences recorded by native speakers of Russian and Bulgarian were played simultaneously with the images during the experiment. The images and corresponding spoken sentences were combined in an interactive PowerPoint presentation, with each slide being advanced as soon as children pointed to one of the images. Each trial started with the presentation of a fixation point in the form of a yellow smiley face blinking for 3 s in the center. Once the smiley face disappeared, two images of the same color appeared on each side of the screen (see Fig. 1) and participants heard the sentences in Example 4 or 5. There were two practice trials to familiarize participants with the design and the task. The experiment lasted about 15 min.

Statistical analysis

The analysis was conducted using R Version 4.1.2 (R Core Team, 2021). To compare the predictive use of gender cues in Russian-speaking versus Bulgarian-speaking children, we fitted a binomial mixed-effects logistic regression model with the target looks as the dependent variable (coded as 1 = look to the target picture, 0 = look to the competitor picture and/or elsewhere) using the "lme4" package (Bates et al., 2015).

The models were built by adding random and fixed variables in a stepwise–step-up procedure, starting with an intercept-only baseline model. The null models included both by-participant random intercepts and by-stimulus random intercepts. With the inclusion of random slopes, the models failed to converge, and therefore random slopes were not included in the final models. First, the fixed effects that were fitted into the models were time (in the form of 33-ms bins set at zero at the adjective ending), language group (Russian or Bulgarian), condition (SAME or DIFF), and two-way and three-way interactions between and among these variables. The models were fitted for the time window of −200 and 800 ms from the adjective ending; thus, the analyzed region included adjective ending, noun, and silence regions. The fitted models were compared in terms of Akaike information criterion (AIC) and Bayes information criterion (BIC), with reduced AIC and BIC values indicating a better model fit. This was supplemented by likelihood ratio tests conducted to determine whether the inclusion of a predictor significantly improved the model fit. The significance level of the main fixed effects was obtained using the analysis of variance (ANOVA) function. We report results from the highest-level model that converged (Barr et al., 2013). Plots were generated using the "ggplot2" package (Wickham, 2016).

Table 2
Examples of experimental stimuli with the coda consonant [n].

	Russian	Bulgarian	Translation
FEM-transparent	*kartina*	*kartina*	'picture'
FEM-opaque	*ladon'*	*dlan*	'palm'
MASC-transparent	*banan*	*banan*	'banana'
MASC-palatalized (opaque)	*remen'*	—	'belt'

Note. FEM, feminine; MASC, masculine.

Furthermore, following Stone et al. (2021) and Ito and Knoeferle (2023), we conducted additional analyses to determine the divergence point between looks to the target in the DIFF and SAME conditions in Russian-speaking and Bulgarian-speaking children. We generated bootstrapped means and confidence intervals (CIs) for each group separately by applying the resampling procedure 2000 times.

Results

Each spoken sentence (Examples 4 and 5) had four regions of interest (ROIs): preamble, adjective onset + adjective ending, noun, and silence (as shown in Table 3). All sentences were of uniform length, and the segmentation of the ROIs was at the same time points in both languages. Following previous VWP studies of gender agreement processing, we predicted that looks to the target noun would emerge in the noun region with a 200-ms delay after hearing the adjective ending (based on the estimated time for programming an eye movement; see Matin et al., 1993). If children used the gender cues in the ending of the adjective predictively, they would identify the target noun faster in the Informative (DIFF) condition than in the Uninformative (SAME) condition.

Our mixed-effects model revealed effects of condition, language, and time as well as a three-way interaction of these variables (Table 4). The presence of the significant three-way Condition*Language*Time interaction indicates that predictive looks toward the target noun were modulated by language and condition, as depicted in Fig. 2. Follow-up pairwise comparisons on the three-way interaction indicated that the difference between the DIFF and SAME conditions was significant in both languages (Russian: β = 0.0808, SE = 0.0293, z = 2.754, p =.0059; Bulgarian: β = 0.1809, SE = 0.0427, z = 4.238, p <.0001), thereby signifying that in both languages children relied on the gender cue.

Subsequently, to answer our research question and further investigate the time course of gender agreement processing in the two languages, we conducted divergence point analyses (Stone et al., 2021) to establish at what point in time the looks to the target noun diverged from the looks to the competitor for both languages and in the two conditions (DIFF and SAME). The results of these analyses are presented in Fig. 3. For Russian-speaking children, the divergent point fell mainly within the silence region (at 772 ms, 95% CI [361, 1021]), indicating only facilitative use of gender information (cf. Brouwer et al., 2017). In contrast, Bulgarian-speaking children exhibited a divergent point much earlier in the noun region, occurring at 461 ms (95% CI [196, 691]). Thus, the divergent point and the split of the condition lines right after the adjective ending indicate both facilitative and predictive use of gender cues.

Taken together, these results suggest that children in both languages used the gender information on the adjectival modifiers to process the sentence, but their efficiency in the SAME and DIFF conditions and their time course varied across the two languages. The mixed results allowed us to reject the null hypothesis because only the Bulgarian children showed an effect of predictive processing. Such a differentiated outcome suggests that the fine-grained typological differences in the gender systems of Russian and Bulgarian affect informativeness of gender cues and have significant impact on children's predictive gender agreement processing.

Table 3
Regions of interest in Russian (Example 4) and Bulgarian (Example 5) spoken sentences.

Region of interest	Preamble	Adj. onset + Adj. ending	Noun	Silence
Russian	*Pokaži, gde zdes'*	*krasn-**aja***	*krov'.*	
Bulgarian	*Pokaži kăde e*	*červen-**ata***	*krăv.*	
	'Show where here	red-FEM	blood-FEM.'	[pointing]

Note. Adj., adjective; FEM, feminine.

Table 4
Mixed-effects analysis of time course and condition in Russian and Bulgarian.

Predictor	Estimate	*SE*	CI	Statistic	*p*
(Intercept)	1.05	0.11	0.85–1.30	0.49	.626
Time	1.00	0.00	1.00–1.00	24.75	**<.001**
Condition [DIFF or SAME]	1.04	0.04	0.96–1.13	1.01	.314
Language [Russian or Bulgarian]	0.72	0.09	0.56–0.92	−2.63	.008
Time × Condition [SAME]	1.00	0.00	1.00–1.00	−3.88	**<.001**
Time × Language [Bulgarian]	1.00	0.00	1.00–1.00	4.68	**<.001**
Condition [SAME] × Language [Bulgarian]	1.08	0.07	0.95–1.23	1.17	.242
(Time × Condition [SAME]) × Language [Bulgarian]	1.00	0.00	1.00–1.00	−3.83	**<.001**
Random effects					
σ^2					3.29
$\tau_{00\ \text{Items}}$					0.23
$\tau_{00\ \text{Participants}}$					0.14
ICC					.10
$N_{\text{Participants}}$					46
N_{Items}					51
Observations					42,540
Marginal R^2 / Conditional R^2					.067/.161

Note. CI, confidence interval; ICC, intraclass correlation coefficient.

Discussion

The mixed findings about the predictive effect of gender agreement cues in processing by Russian-speaking children in the previous research (Aumeistere et al., 2022; Sekerina, 2015) and the lack of such data in Bulgarian provided the original impetus for our study that tested gender agreement processing in preschool-age children in two typologically close languages, Russian and Bulgarian. We focused on gender cues on adjective in order to examine children's use of gender information for predictive purposes and not as an outcome of possible probabilistic learning of frequently co-occurring elements such as freestanding determiners and nouns (Bellanger et al., 2017; Grüter et al., 2012). The presence of gender cues with different strength in the two languages (Bulgarian determiners, Russian case, differences in distribution of opaque and transparent endings, and vowel reduction) allowed us to explore the effects of the fine-grained typological differences by combining Audring's gender learnability approach with a comparative language acquisition approach (Christiansen et al., 2022; Pye & Pfeiler, 2014). Using identical experimental design and methodology across the two languages, our study was able to draw connections between typological research on gender (as represented in Audring's (2017, 2019) complexity matrix) and acquisition patterns, underscoring the importance of the gender cue strength in predictive processing from a child learner's perspective.

In contrast to previous studies (Aumeistere et al., 2022; Janssen, 2016), we reframed our inquiry to include typological aspects of gender cue strength that linked the complexity of gender expression to learnability of gender through the operation of the principles of transparency, economy, and interdependence (Audring, 2017, 2019) that were pitted in Hypotheses 1a and 1b. Our findings support Hypothesis 1b; that is, we found advantages for Bulgarian-speaking children based on transparency

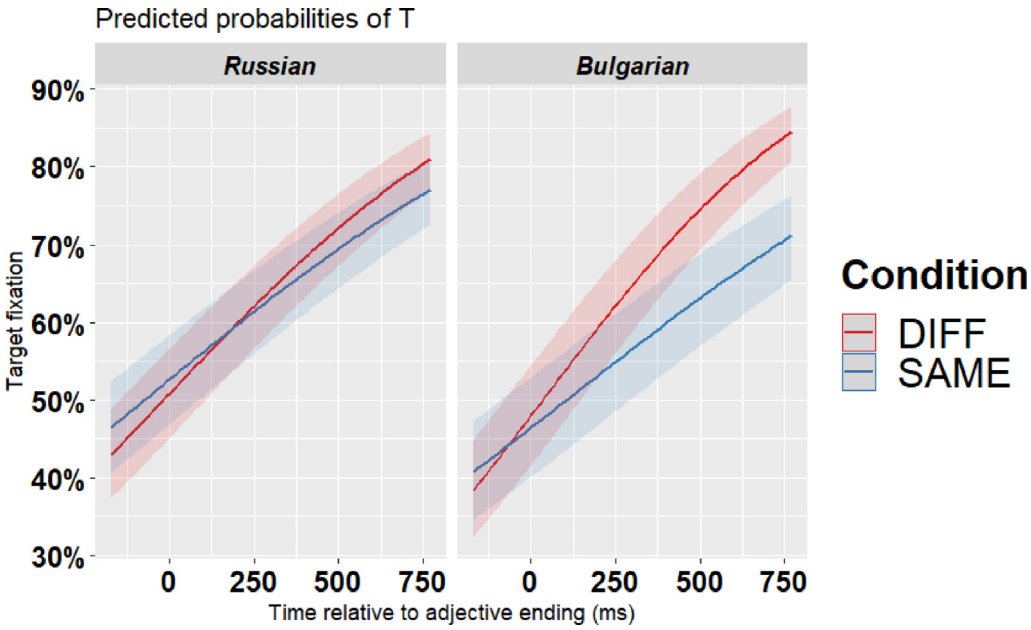

Fig. 2. Predicted probabilities of target noun fixation as a factor of language (Russian or Bulgarian), condition (DIFF or SAME), and time (relative to the adjective ending).

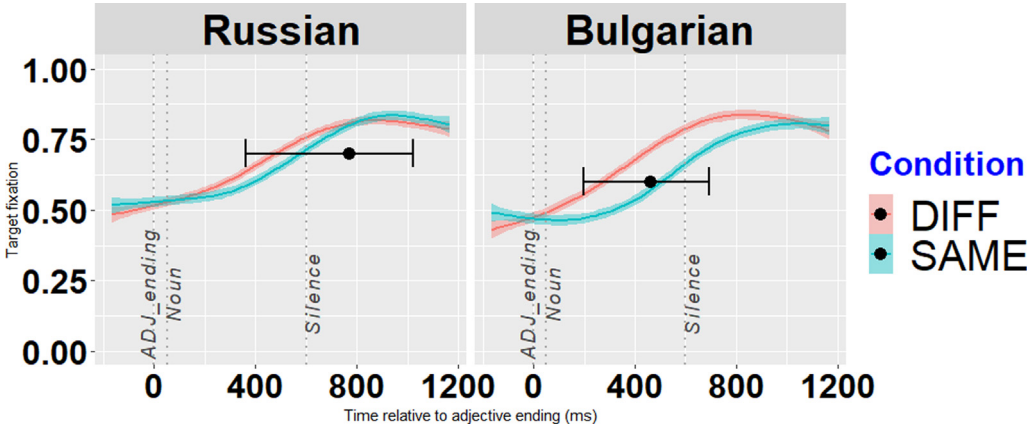

Fig. 3. Divergence points and 95% confidence intervals superimposed on the time course of looks in DIFF condition versus SAME condition for Russian-speaking and Bulgarian-speaking children. Smoothed curves are depicted in the plots, employing a natural spline function with a moderate degree of smoothing. ADJ.

and interdependence of gender-marked modifiers. Only Bulgarian children were able to use the gender agreement cues on adjectives predictively. The Bulgarian determiner enhances children's representation and processing of gender because of its structural depth (i.e., extra functional layer), its perceptual transparency (no homophony of endings in different genders), and its monofunctionality (not fusing multiple grammatical cues). Taken together, the transparency and interdependence of the gender-marked adjectival endings in Bulgarian make this gender cue stronger in the system, which results in faster predictive processing of gender agreement. This is psycholinguistic evidence

of the interaction of the three principles that points to the advantage of the rich and perspicuous gender cues in the acquisition process because they "stand out in the grammar and provide the best evidence for the linguist and for the language-acquiring child" (Audring, 2019, p. 47).

In contrast, Russian children not only were slower in their looks to the target noun but also did not show a difference between the Informative (DIFF gender) condition and the Uninformative (SAME gender) condition early enough to qualify for predictive use of the gender agreement cues. Thus, Russian findings showed only facilitative use of gender agreement information because it took place after the noun was presented (cf. Brouwer et al., 2017, for the distinction between predictive and facilitative processing). Unlike Bulgarian, which provides unambiguous gender cues on adjectives in the form of adjectival endings and articles, the mostly opaque Russian adjectival endings make them weaker cues, which might explain differences in processing in the two languages. Viewed in a larger acquisitional context, the second cue (i.e., gender-marked determiner in Bulgarian, much more tightly integrated in the word due to its inflectional nature), is less prone to probabilistic learning or chunk-like processing that was thought to be operational in determiner–noun pairs in Romance languages (Melançon & Shi, 2015).

In sum, our findings contribute to the growing body of research about the facilitative role of gender cues and their strength on modifiers in gender agreement processing and gender acquisition (Lew-Williams & Fernald, 2010; Smolík & Bláhová, 2019). They also add an important novel angle, that is, a comparative examination of closely related languages to determine the gender cue strength in gender agreement processing and its implications for acquisition. In particular, we showed that the different time course of gender processing in the two languages maps onto the predictive (Bulgarian) versus facilitative (Russian) use of gender information, providing processing evidence for Pickering and Gambi's (2018) suggestion that integration does not facilitate comprehension in the same way that prediction does.

Both Russian and Bulgarian children in our study showed that they could benefit from gender agreement, but only the latter group did it predictively in a time-efficient manner, most likely due to the typological differences that affected the strength of gender cues in the two languages. The faster processing results in the Bulgarian group suggest the greater weight of transparency and interdependency (manifested in the lack of syncretism between gender and other categories) in Bulgarian, underscoring the need for cross-linguistic studies of the nature and operation of gender cues in gender agreement. Our investigation of the strength of gender cues in agreement provides a more refined psycholinguistic approach to gender feature matching that not only complements but also suggests new avenues in the theoretical investigations of gender agreement (see Arsenijević & Borik, 2021, for a detailed overview of existing proposals).

Conclusions and future studies

The current study is a novel contribution to the comparative language acquisition framework (Christiansen et al., 2022) and to the empirical testing of Audring's (2017, 2019) complexity matrix. Our findings showed that fine-grained gender distinctions are processed differentially even in closely related languages such as Russian and Bulgarian. Children in both groups used gender cues to process the gender of the upcoming noun, but the Bulgarian participants did it predictively and were faster than the Russian participants. The application of the principles of economy, transparency, and interdependence (Audring, 2017, 2019) to the gender systems of Russian and Bulgarian showed how the fine-grained differences in gender-marked nouns and their modifiers contribute to the strength of gender cues in the two languages, resulting in a processing advantage for Bulgarian children's comprehension of gender agreement.

Future studies of gender agreement processing should extend the examination of the strength of gender cues by comparing contexts where such cues are present or absent, for example, the processing of gender-marked bare adjectival endings versus those with definite articles in Bulgarian. In addition, a cross-linguistic study of gender processing in the two Slavic languages with definite articles in the form of inflectional suffixes, Bulgarian and Macedonian, would provide insights into the specific ways in which definite articles interact with other gender cues in order to accelerate or delay acquisition of

gender. Whereas the current study focused on processing cues within adjective–noun phrases, future studies should also incorporate the processing of gender cues on verbs as compared with adjectives, thereby enabling us to investigate processing of agreement in comparison with concord.

Data availability

The full list of stimuli and images, the eye-tracking data, and the analysis can be found at the OSF repository. https://osf.io/2gskd/

CRediT authorship contribution statement

Tanya Ivanova-Sullivan: Conceptualization, Data curation, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing. **Natalia Meir:** Conceptualization, Data curation, Formal analysis, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Irina A. Sekerina:** Conceptualization, Data curation, Investigation, Methodology, Project administration, Resources, Validation, Writing – review & editing.

Acknowledgment

Irina A. Sekerina was partially supported by the PSC-CUNY grant #64464-00 52 "Virtual Laboratory: Cross-Linguistic Investigation of Language Grammar". Natalia Meir and Irina A. Sekerina were partially supported by the United States-Israel Binational Science Foundation (BSF), Grant Number 2022245, for the project led by the Principal Investigators Natalia Meir and Irina A. Sekerina.

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