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The Acquisition of Russian Word-Initial Consonant Clusters in a Russian-American English Bilingual Child: An Overview of One Child's Exceptional Production

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ABSTRACT

The majority of approaches to the acquisition of phonology attempt to model discrepancies between child and adult speech, with less attention given to children whose pronunciation is accurate. This is especially true in the acquisition of consonant clusters, where models attempt to explain children's "errors" or non-adult-like production in terms of articulatory difficulty or phonological markedness effects. In this study, dense longitudinal data from one child's third year show exceptional production of Russian word-initial consonant clusters. Though other studies suggest that sonority sequencing plays a central role in consonant cluster acquisition, no support for sonority-based generalizations are found in the naturalistic speech data of a two-year-old bilingual Russian-American English girl, Ulijana. On the contrary, sonority reversals were acquired early, while ideal sonority clines were acquired late. Alternative explanations for observed patterns include frequency effects and the articulatory difficulty of segments.

KEYWORDS acquisition · phonology · consonants · consonant clusters

1 INTRODUCTION

The acquisition of word-initial consonant clusters (#CC) is one of the most long-lasting aspects of a child's speech development, often continuing until the age of eight (McLeod et al., 2001; Vihman, 1996).[1] Crosslinguistically, some two-year-olds are able to produce #CC, though their production is often non-adult-like, with tendencies to reduce clusters to single consonants or, more rarely, to eliminate them through epenthesis, metathesis or other means (e.g. Greenlee, 1974; Jarosz, 2017; Lleó & Prinz, 1996; Ohala, 1999; Schaefer & Fox-Boyer, 2017; Stemberger & Chávez-Peón, 2015). The majority of phonological approaches to the acquisition of word-initial consonant clusters attempt to model discrepancies between child and adult speech. Since a universal sonority hierarchy has been claimed to play a role in determining the structure of complex onsets in all spoken languages, some researchers have tried to explain the speed, order and accuracy of #CC production in terms of the sonority hierarchy. The general claim is that complex onsets obey some version of the Sonority Sequencing Principle (SSP), with a rise in sonority from the beginning of the syllable to the nuclear vowel. For the purposes of this discussion, we adopt the sonority hierarchy in (1) and the SSP in (2) (for critical discussion, see Blevins, 1995; Parker, 2012).

(1) Sonority Hierarchy
most sonorous V > G > L > N > S > T least sonorous

(2) Sonority Sequencing Principle
a. In every syllable there is exactly one peak of sonority in the nucleus,
b. Sonority increases towards the syllable peak and decreases towards its margins.

Given (1) and (2), a prediction is that syllables with onsets that obey the SSP should be acquired more easily and before syllables with onsets that violate the SSP (cf. Barlow, 2003). For example,

[1]Abbreviations used in this paper are: C for any consonant; #CC for initial consonant clusters; O for obstruent; T for oral stop; R for non-syllabic sonorant; S for fricative; A for affricate; L for liquid; N for nasal; G for glide; V for vowel.

Chambless (2006) explains certain aspects of the order and accuracy of #CC production in a corpus of longitudinal data from 5 monolingual English children in terms of Optimality theoretic constraints *COMPLEX ONSET and SONORITY SEQUENCING/MINIMAL DISTANCE: #OR (e.g., /pr/, /pl/, /fr/, /fl/) is acquired before #sC (e.g., /sp/, /st/, /sk/), and produced more accurately, in line with the proposed markedness constraints (Kager et al., 2004). Whereas English does not have initial #RO clusters, Russian does. One clear prediction of the SSP and Chambless's approach is that #OR (e.g., /tr/, /vr/) should be acquired before #sC (e.g., /st/, /sv/) and before #RO (e.g., /rt/, /rv/) in Russian. Our goal in this paper is to highlight data from the acquisition of Russian by one child, Ulijana, that calls into question the role of sonority in determining the order and accuracy of initial consonant cluster production. Ulijana's early and accurate cluster production further highlights the range of variation across children and across languages, presenting challenges for universalist approaches to phonological acquisition.

1.1 RUSSIAN CONSONANTS AND INITIAL CONSONANT CLUSTERS

Russian has a relatively large consonant inventory including 36 phonemes with a robust contrast between voiced and voiceless obstruents as well as between palatalized and non-palatalized consonants (see Table 3 for the full inventory). In consonant sequences, both palatalized and non-palatalized consonants can occur; obstruent clusters agree in voicing with the rightmost obstruent determining the voicing status of the cluster, while sonorants generally do not participate in voicing assimilation.

There are more than 120 biconsonantal #CC types in Russian (McGranahan, 1975). As Table 1 illustrates, even with a minimal sonority hierarchy where we only distinguish obstruents from sonorants, some of these clusters violate the SSP in (2), with sonority reversals (*lgat'* 'to lie', *mgla* 'haze'), and sonority plateaus (*bdenie* 'vigil', *sfera* 'sphere', *mnogo* 'a lot', *spat'* 'to sleep').[2] With the more nuanced scale in (1), violations of the SSP are those in the shaded cells of Table 1.[3]

C2 / C1	Stop	Affricate	Fricative	Nasal	Liquid	Glide
Stop	bd	ptʃ	pʃ	gn	bl	p^(j)j
Affricate	tʃt	—	ʦv	tʃm	tʃr	tʃj
Fricative	ʒd	ftʃ	sf	zn	zr	sj
Nasal	mgl	mtʃ	mʃ	mn	ml	nj
Liquid	lg	rʦ	rv	lʲn	—	lʲj
Glide[4]	vd	—	vz	vn	vl	vj

Table 1: Sonority sequencing in Russian #CC: shaded cells violate SSP

1.2 EARLIER STUDIES

There is limited information on the order of acquisition of consonants and #CC in children learning Russian in monolingual and bilingual settings. The available data is represented mostly by diary studies that vary in the time and focus of observation of a child's language development (e.g. Gvozdev, 1981; Eliseeva, 2008). The sources of information about Russian consonant acquisition include: a study based on the recordings of children's speech taken at a single time point with various recording lengths (Žarkova, 2005); the longitudinal and cross-sectional studies of Russian monolingual and Russian-Finnish bilingual children (a picture-naming task; Nenonen, 2016); and a cross-sectional study of Russian monolingual and Russian-Dutch bilingual children (a picture-naming task; Rešetnikova & Tomas, 2019).

[2] Using frequency dictionaries from written corpora, Proctor (2009) finds that 71.5% of Russian #CC are sonorant final, 28.5% are obstruent-obstruent, and only 1.06% are sonorant-obstruent.

[3] We list affricates separately from stops and fricatives, though the position of affricates on the scale in (1) is debated.

[4] The sonority status of /v/ is problematic (e.g. Padgett, 2002). Although it behaves as a fricative in undergoing final devoicing as in *brov'* [brofʲ] 'eyebrow' and regressive voicing assimilation as in *vkus* [fkus] 'taste'), it patterns with sonorants in not triggering regressive voicing assimilation (e.g., *svežest'* [ˈsvʲeʒəsʲtʲ] 'freshness').

The data on acquisition of consonants by Russian monolingual children reviewed in Table 2 show a great variability in the time and order of acquisition of consonants by different children. However, despite a glaring variability, there are particular trends that are comparable to cross-linguistic findings (McLeod & Crowe, 2018). First, the initial period of Russian consonant production starting from 15 to 24 months of age is characterized by an abundance of stops and a dearth of fricatives. Second, Russian monolingual children demonstrate difficulty in acquisition of the fricatives, affricates, liquids, and trills. Those are the groups of sounds that are among the latest to be acquired by children cross-linguistically.

Studies that investigate acquisition of Russian consonants in bilingual settings reveal that bilingual children acquire some Russian consonants later than their monolingual peers. Rešetnikova & Tomas (2019) report that 27 Russian-Dutch 2;7- to 5;3-year-old children acquired an accurate production of /zʲ, sʲ, t, z, l, tʃ/ later than their Russian monolingual peers. Nenonen (2016) reports that, on a par with the fricatives and affricates, among the hardest Russian consonants for Russian-Finnish 3- to 7-year-old bilinguals were /r/ and /s/. These occurred in a list of non-acquired consonants in all participants of her study.[5]

		Age in years				
Data	Child (Gen.)	1;3–1;6	1;7–2;0	2;1–2;08	3;0–4;0	4;1–6;0
Diary Eliseeva 2008	Liza (F)	/p, kʲ, j, b, tʲ, dʲ, k, nʲ, g, gʲ, zʲ, xʲ/	/m, bʲ, sʲ, x, t, n, d, s, v, vʲ/		/f, ʧʲ, mʲ, pʲ, z, ʦ, l, lʲ, ʃʲː/	/ʃ, ʒ, r, rʲ, tʃ/
Diary Gvozdev 1981	Ženja (M)	/m, mʲ, b, p, pʲ, dʲ, tʲ, nʲ, lʲ, sʲ, k, kʲ, g, x, j/	/bʲ, n, t, d, f, ʧʲ, vʲ, s/	/v, l, ʦ, r, zʲ, z, rʲ, ʃ, ʒ, ʃʲː, tʃ/		
Diary reported in Gvozdev 2004	3 children (M)	—	/b, bʲ, p, pʲ, m, mʲ, dʲ, tʲ, nʲ, sʲ/	—	—	—
Diary reported in Zharkova 2005	Nataša1 (F)	/k, b, n, d, j, tʲ, m, dʲ, nʲ, t, sʲ/	/zʲ, mʲ, pʲ, x, ʧʲ, v, bʲ, g, s, p, xʲ, gʲ, kʲ, ʃ, tʃ, l, vʲ, lʲ, z, f, ʒ, r/	—	—	—
Diary reported in Zharkova 2005	Nataša2 (F)	/k, g, n, m, t, b, tʲ, s, p, v, dʲ, sʲ, nʲ, zʲ/	/j, x, bʲ, lʲ, r, mʲ, rʲ, kʲ, pʲ, gʲ, vʲ, f, ʧʲ, ʒ/	—	—	—
Cross-sectional Rešetnikova & Tomas 2019[6]	35 children (12 M)	—	—	/p, bʲ, kʲ, dʲ, zʲ, m, f, t, d, pʲ, n, z/	/j, k, nʲ, g, sʲ, mʲ/	/tʲ, v, ʧʲ, s, l, tʃ, b, gʲ, x, vʲ, ʦ, ʃʲː, lʲ, ʒ, ʃ, rʲ, r/

Table 2: Age of acquisition of consonants by Russian monolingual children. *Note*: The consonants within a cell are ordered from earliest to latest with the exception of the data from three children. An em dash indicates the absence of data.

Less is known about the patterns of #CC production. Both Gvozdev (2004) and Eliseeva (2008) report that, at the age of two, Russian monolingual children reduce #CC to singletons, and that some cluster reduction patterns are quite uniform across children in comparison to other phonetic phenomena in children's speech at this age. For example, Gvozdev (2004) reports that in stop-liquid clusters, stops are retained in 95% of the observed cases, while in fricative-stop clusters, the stop is retained in 92% of cases. The only clusters that occurred early in Ženja's speech and did not undergo reduction were /pl/ and /kl/ clusters. Eliseeva's daughter, Liza, started to produce most #CC closer to 3 years and even at that age, did not produce any clusters containing fricatives, affricates, or trills

[5]The results of Nenonen's (2016) longitudinal study revealed a language interference effect that was evidenced in five out of six children and that manifested itself in the non-discrimination of contrast opposition in voicing and palatalization as well as in the transfer of language-specific sounds from children's dominant language (Finnish for some children and Russian for the others). Gildersleeve-Neumann & Wright (2010) also report that Russian-English bilingual children between the ages of 3;3–5;7 sometimes carried over a trilled /r/ into their production of English words. Another early feature of Russian pronunciation they found in their subject's English word-production task was consonant palatalization.

[6]Rešetnikova & Tomas's (2019) study reports that all consonants are acquired by Russian monolingual children much later than reported in previous studies. The authors suggest that an increased number of dysarthria cases in young children could be the cause. However, this suggestion should be considered with caution. The newly obtained data of monolingually developing children were compared with the data based on observation of a single child, Liza, reported in Eliseeva (2008). Moreover, Rešetnikova & Tomas (2019) and Eliseeva's (2008) studies differ in methodological approaches (cross-sectional picture-naming task vs. longitudinal diary study, respectively) as well as in criteria applied to determine the age of acquisition of consonants.

because she had not acquired these sounds yet. Data collected from non-word repetition tasks for 13 typically developing Russian monolingual children between 4;10–10;6 highlight the difficulty of consonant production mastery: for this group, production of simple C onsets was 72% accurate, while complex onsets were produced at 69% accuracy (Kavitskaya & Babyonyshev, 2011; Kavitskaya et al., 2011). However, in contrast to Gvozdev's (2004) findings for young children where 95% of simplification of #TR is to #T, in these older children, simplification of #TR was always to #R, and there was no clear bias towards producing clusters conforming to the SSP.

1.3 THIS CASE STUDY

This case study is based on the *Ulijana* dense longitudinal corpus of naturalistic speech collected during the third year of Ulijana's life (age 2–3). Direct observation of Ulijana showed early linguistic awareness of Russian vs. English, fast acquisition and accurate production of most Russian vowels and consonants, as well as many consonant clusters. Scientific study of Ulijana's speech during the third year is of interest for several reasons. First, though Russian has a relatively large consonant inventory and a wide range of #CC, there are very few longitudinal studies of the acquisition of consonants and #CC in the early speech of children acquiring Russian. Second, unlike many languages, Russian allows initial #OR, #RO, #OO and #RR clusters. A careful study of the acquisition of clusters, then, should reveal whether the SSP plays a clear role in the order, speed and/or accuracy of #CC production. Finally, Ulijana shows an exceptional path of early phonological development, with adult-like consonant production at an early age. A case study of Ulijana's development should deepen our understanding of the range of variation in phonological production patterns, especially where complex sound patterns, like those of Russian, are being acquired.

2 METHOD

The nature of the phonetic data and means of coding it are briefly outlined here. For more details, see Kistanova (2018).

2.1 THE DATA

The current database of the *Ulijana* corpus contains: (a) weekly day-long recordings (about 450 hours of naturalistic speech data, in total) collected by means of LENA^{TM} (The Language ENvironment Analysis System; Richards et al., 2008);[7] (b) 18 one-hour long transcribed samples of parent-child interactions with 3 to 7 days interval for the first 8 hours and the remaining 10 one month apart; (c) the MacArthur-Bates Communicative Development Inventories for Russian (CDI-Rus; Eliseeva et al., 2017) filled out by Ulijana's mother twice, first, when Ulijana was 23 months old, and the second time when she turned 3.

In *Ulijana*, the adult utterances are transcribed orthographically. The child's utterances are transcribed phonetically, in a broad IPA transcription, and are followed by comment lines with orthographic transcription of the utterances, linguistic notes, and contextual information for disambiguation. All interactions are transcribed in full, including false starts, hesitations, repetitions and the child's self-made songs and nonsense utterances (referred to here as "Language Play"). Each word in the corpus is coded as belonging to one of five categories: *Russian*, *English*, *Ambiguous*, *Unintelligible*, and *Nonsense*.[8]

[7] The LENA system measures the early language development of children aged 2 to 48 months and the linguistic environment offered by their caregivers. The LENA system consists of a digital recorder designed to be worn by a child; the LENA software that transforms the audio recordings into quantitative data estimating adult word counts, child vocalizations, and conversational turns between the child and her caregivers; and a cloud-based system for data storage and management (Richards et al., 2008).

[8] *Ambiguous* words include those that express agreement/disagreement (e.g., *okay*, *mhm*, *aha*, etc.), English proper nouns used in Russian utterances, and English words used with Russian morphological markings. *Unintelligible* words are those produced in distant and/or noisy environments. The child's words that do not have obvious meaning are coded as *Nonsense* (see Kistanova, 2018 for details).

2.2 CODING AND ANALYSIS

The Russian adult words containing #CC were extracted from the transcriptions automatically by a program specially written for this project and coded for Session, specific #CC (e.g., [krʲ]), #CC type (e.g., stop-liquid, fricative-stop, etc.), and sonority characteristics (after Stemberger & Chávez-Peón, 2015): sonority-reversed clusters (e.g., [rv, rt, sp...]), sonority plateaus (e.g., [kt, mn, fs...]), rising-sonority clusters with smaller sonority differences (e.g., [sn, ml, lʲj...]), and rising-sonority clusters with large sonority differences (e.g., [kr, kn, xl, bj...]).

All Russian words (excluding onomatopoeia) containing #CC attempted by Ulijana were extracted from the transcriptions manually and coded for Session, Age (in months), #CC, #CC-type, Sonority profile, Word Length (defined in the number of syllables), and the binary variables indicating if the first syllable received Stress, if there was a Palatal segment in the cluster, and if the word was a Function word. The alignment of the child's IPA with the target IPA allowed to code the cluster production for accuracy (Correct: 0-no, 1-yes) and simplification strategies: C1 deletion, C2 deletion, Non-target C (e.g., substitution, retraction, fronting, palatalization, gliding, lateralization), Vowel Epenthesis, and Other (e.g., metathesis), where 0-no, 1-yes.

To determine whether the SSP is a significant predictor of accuracy, a logistic regression using a Generalized Estimating Equation (GEE) model was performed. Since many of the words in the corpus occurred numerous times, GEE was chosen for the analysis because it can treat words as a random effect variable, modeling the non-independence of the data produced by repeated occurrences of the same word. In the model, SSP was represented as an integer on a scale ranging from -2 (a fall in sonority) to +4 (a high rise in sonority). Also included in the model were several covariates: the child's mean-centered Age in months, the base-10 logarithm of the Input Frequency of the cluster type, mean-centered Word Length, and three binary variables indicating if the first syllable received Stress (0-no, 1-yes), if there was a Palatal Segment in the cluster, and if the word was a Function Word.[9]

3 RESULTS

Given length constraints, only a subset of results is reported here. Since the focus is the potential role of sonority in #CC production, the discussion focuses on patterns that could be used to support or discredit sonority-based accounts.

3.1 VOCABULARY DEVELOPMENT AND CONSONANT PRODUCTION

According to the parental questionnaires (CDI-Rus), at the age of 23;1, Ulijana's Russian vocabulary and grammar development was below the monolingual norms of her age group. Just before her 2nd birthday, there was a big gap between her passive (355 words) and active (176 words) vocabulary, though by the age of 3, her active vocabulary included 646 words, or 93.5% of the total CDI-Rus vocabulary list.

Despite her small Russian active vocabulary, Ulijana's acquisition of Russian consonants was very fast. At the age of 24;1, she produced 28 consonants in different syllable positions (Table 3). A week later, all labiodentals and dentals were attested. The plain trill appeared at 24;1 in [kr] of *kroška* 'a crumb', though it was produced as /l/ or /j/ in other words. By 28 months Ulijana acquired the production of almost all consonants.[10] However, the trill was still unstable in production.

How can we explain the speed and accuracy of Ulijana's production of Russian consonants? At the individual level, Ulijana appears to be gifted at carrying out complex articulations. Whereas most children cannot produce #CC at age 2, Ulijana produced initial [spʲ], [ʃt], and [mnʲ] in Russian words just after her 2nd birthday. As for frequency effects, despite the common absence of external stimuli in Russian, Ulijana was often found practicing her own articulatory routines. In the measures, this

[9]The approach and the subset of control variables follows a recent empirical study investigating acquisition of complex onsets in Polish (Jarosz, 2017). A Palatal Segment in the cluster was included based on empirical observation that some palatalized consonants are acquired by young children earlier than their non-palatalized counterparts (e.g., Gvozdev, 2004; Žarkova, 2005: also see data in Table 2).

[10]Words with /xʲ/ were not encountered in the transcribed corpus.

is coded as "Language Play", data which constitute as much as 25% of her production across the entire period of study. While careful study of the Language Play data has yet to be carried out, an analysis of consonants in the first two hours where Language Play accounts for more than 45% of Ulijana's speech, shows the following composition: 51% stops; 21% fricatives; 9% nasals; 7% glides; 6% liquids; and 5% affricates. Ulijana is clearly gifted, but she may also show accelerated production of Russian consonants due to her own articulatory practice routines in the course of language play.[11]

Place/ Manner	Bilabial		Labiodental		Dental		Alveolar		Palatal	Velar	
Stop	p	pʲ			t	tʲ				k	kʲ
	b	bʲ			d	dʲ				g	gʲ
Affricate					ʦ			tʃ			
Fricative			f	fʲ	s	sʲ	ʃ	ʃʲː		x	xʲ
			v	vʲ	z	zʲ	ʒ				
Nasal	m	mʲ			n	nʲ					
Liquid					l	lʲ					
Trill							r	rʲ			
Glide									j		

Table 3: The consonant inventory of Russian with Ulijana's consonants highlighted. *Note*: Consonants produced at 24;1 are in light grey. Consonants produced at 24;8 are in grey. Consonants produced at 28;2 are in dark grey.

3.2 WORD-INITIAL CONSONANT CLUSTER PRODUCTION

In total, there were 64 different #CCs attempted by Ulijana in the 18 hours transcribed from a total 241 word-types and 1,042 word-tokens with #CC. Table 4 shows Ulijana's frequency of accurate and non-target-like production of clusters with examples of each, where "accurate" required matching of each segment in the cluster with adult pronunciation. Overall, by these criteria, Ulijana produced initial clusters accurately 63.9% of the time.[12] When Ulijana did not produce #CC accurately, the most common productions (26%) were those where one of the consonants was not produced (or inaudible). Other non-target realization of clusters accounts for 10% of cluster production in total.

The criteria of 100% adult-like production of cluster type in one sample followed by a 100% adult-like production in consecutive samples allowed us to establish the age at which Ulijana started to produce clusters accurately in a roughly constant manner. The sequence of #CC acquisition starts with perceptually salient and relatively frequent /s/-stop and /ʃ/-stop clusters (e.g., *škola* 'school'; and variants [ʃto]/[tʃo]/[ʃo]/[ʃe] of *čto* 'what') and with one high frequency sonorant-sonorant cluster (e.g., *mne* 'to me'). These were produced accurately starting from the first session (24;1). Obstruent-/v/ (e.g., *dvor* 'yard') and SR (e.g., *smotret'* 'to look') are acquired by the age of 29 months. Stop-stop clusters (e.g., *kto* 'who') were acquired latest, at the age of 32 months. This can be attributed to a feature of child-directed speech: many tokens of the high frequency words *gde* 'where' and *kto* 'who' had articulatory simplified #CC in *adult pronunciation*. Not surprisingly, these same clusters were simplified by the child during the entire year. Moreover, starting from the age of 29 months, Ulijana showed conscious manipulation of early "baby" (inaccurate) and late "grown-up" (accurate) forms of these frequent function words when addressing her parents in different contexts.

One noticeable pattern was a delay in accurate production of #TR clusters with /r/ as C2. In this case, the cause appears to be late mastery of the fine motor control required for articulation of the trilled rhotic. Table 5 provides data tracing the development of #Tr clusters in Ulijana's Russian, with the mean length of Ulijana's Russian utterances (MLU) provided to show her progress from the 1-word to 2-word stage and beyond. Meanwhile, mastering the trill involves a system of replacements

[11] Determining whether Ulijana's articulatory routines play a significant role in her accurate production of particular sounds is complicated by the fact that similar routines in children at this age range are usually not transcribed.

[12] This is striking, given that normally developing monolingual Russian children ages 4;10–10;6 produced complex onsets in nonce-words at 69% accuracy (Kavitskaya & Babyonyshev, 2011; Kavitskaya et al., 2011).

Accuracy	Freq.	Target/gloss	Target IPA	Ulijana IPA	Age
Accurate	63.9%	*spit ‘(he) sleeps’*	[spʲit]	[spʲit]	24;01
		mne ‘to me’	[mnʲe]	[mnʲe]	24;25
		glazkami ‘by eyes’	[ˈglaskəmʲɪ]	[ˈglaskamʲi]	32;01
No evidence for C1	14.6%	*vsë ‘all/that’s it’*	[fsʲo]	[sʲo]	24;11
		gde ‘where’	[gdʲe]	[dʲe]	24;11
		rvat’ ‘to tear’	[rvatʲ]	[vatʲ]	28;02
No evidence for C2	11.5%	*slyšiš’ ‘(you) hear’*	[ˈslɨʃɨʃ]	[ˈsɨʃɨʃ]	24;11
		tvoja ‘yours’	[tvʌˈja]	[toˈja]	24;11
		prygaju ‘(I) jump’	[ˈprɨgəjʊ]	[ˈpʲikʲiju]	25;11
Non-target C	6.2%	*prjač’ ‘hide’*	[prʲatʃ]	[pʲjatʃ]	24;08
		dva ‘two’	[dva]	[dʲuˈa]/[dlʲa]	24;11
		škola ‘school’	[ˈʃkolə]	[ˈskola]	26;14
Open transition	0.8%	*plačet ‘(he) cries’*	[ˈplatʃɪt]	[iˈplʲatʃit]	25;07
		prjamo ‘stright’	[ˈprʲamə]	[pʲiˈjama]	25;16
		l’ëtsja ‘(it) flows’	[ˈlʲjoʦə]	[lʲiˈjoʦa]	28;02
Other	3.0%	*što ‘what’*	[ʃto]	[tsʲto]	24;11
		spjat ‘(they) sleep’	[spʲat]	[zpʲiˈjat]	24;11
		slučilos’ ‘happened’	[slʊˈtʃiləsʲ]	[ˈptʃilasʲ]	29;09

Table 4: Ulijana’s #CC production: error types and frequencies

such as [j] > [lʲ] > [l] > [rʲ] > [r], with some months of good production followed by less accurate productions. Note that the period of good production coincides with the semi-steady two-word stage and ends when Ulijana enters the three-word stage, suggesting trade-offs in production difficulties.

Age	MLU	br	pr	prʲ	dr	tr	trʲ	gr	grʲ	kr	krʲ
24	1.29			plʲ/pʲj		t				**kr**/klʲ	kʲ/kj
25	1.41		pʲ	plʲ/pʲij		t	tʲlʲ/tlʲ				
26	1.76			pʲ/pʲj	dj	t			gʲj	**kr**	kʲ
28	2.37		p/pj	pʲ	**dr**/d					**kr**/k/kj	
29	2.52		p	pʲ	d		tuvʲ/tvʲ			**kr**/k	
30	2.35		**pr**/pl	**prʲ**/pʲ					gʲ	k	
31	2.49	**br**		**prʲ**	**dr**	**tr**				**kr**/k	
32	2.51		**pr**	**prʲ**/pvʲ	**dr**	**tr**	**trʲ**			**kr**	
33	2.59		**pr**	**prʲ**		**tr**				**kr**	
34	3.49		**pr**/pl	**prʲ**/pl/∅	**dr**		**trʲ**			**kr**/kl	**krʲ**
35	3.27	**br**/bl	**pr**/pl	**prʲ**/pl/plʲ	d/dl		tʲ	gl		**kr**/kl/klʲ	

Table 5: The course of Ulijana’s stop + trill production over the year. *Note*: The accurate production of clusters is in bold. The dashed lines and shaded rows indicate the period of good performance.

3.3 THE ROLE OF SONORITY IN #CC PRODUCTION

To determine whether the SSP is a significant predictor of production accuracy, we performed a logistic regression using a Generalized Estimating Equation (GEE) model. The results of the statistical analysis are shown in Table 6.

With regard to covariates, results show a significant effect of Age (greater odds of correct production as age increases), Stress (greater odds of correct production when the syllable is stressed), and Function Word (lower odds of correct production in a function word). Word Length and Input Frequency were not significant, nor was Palatal Segment, although there was a tendency for clusters to be produced more accurately when they did not contain a palatal segment.

The model shows SSP to be a highly significant predictor, but it is not the case that higher rises in sonority are predictive of higher production accuracy. In fact, the negative coefficient for SSP in the model indicates the opposite: sonority reversals were produced most accurately, followed by clusters with small sonority differences, while sonority plateaus and SSP clusters with large rises were

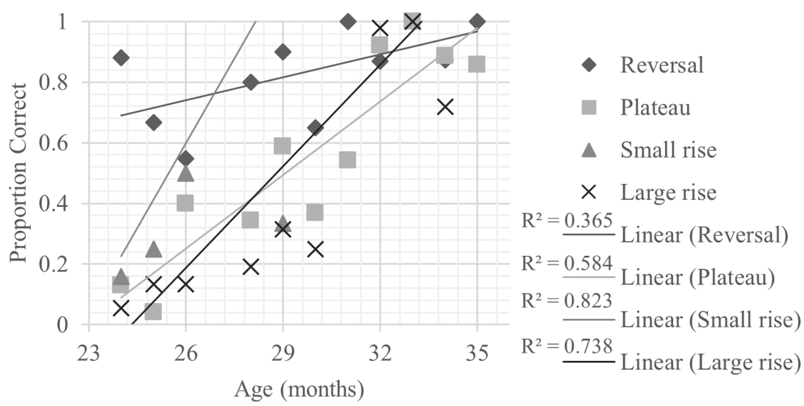

Figure 1: Accuracy of Ulijana's #CC production as a function of age and sonority profile

produced less accurately. Figure 1 shows Ulijana's accuracy by age for different types of sonority contours. Clusters with large sonority rise and sonority plateaus were less accurately produced across almost the entire year. Figure 1 also shows that the change in accuracy across age was steeper for these cluster types than for sonority reversals. This is reflected in the model's significant interaction of SSP by Age.

	β[13]	SE	Wald z	p (>|z|)
Intercept	1	0.41	2.45	0.014*
Age centered	0.35	0.04	8.16	0.000***
Word Length centered	−0.23	0.25	0.93	0.35
Input Frequency centered	−0.01	0.37	0.03	0.976
Stress	1.08	0.35	3.05	0.002**
Function Word	−1.72	0.65	2.66	0.008**
Palatal Segment	−0.59	0.37	1.59	0.112
SSP	−0.45	0.09	5.29	0.000***
SSP * Age centered	0.04	0.02	2.17	0.030*

Table 6: GEE logistic regression model predicting cluster production accuracy.
*, **, and *** indicate significance at $p < 0.05$, $p < 0.01$, and $p < 0.001$ respectively.

3.4 POSSIBLE FREQUENCY EFFECTS

Why do we see the production patterns in Figure 1 at the earliest stages of initial cluster production? Could frequency effects play a role? In order to answer this question, we estimated the distribution of words with #CC in Ulijana's input and output based on corpus counts. Table 7 shows the word-type and word-token frequency estimates and the percentages of Ulijana's correct production of cluster type (%Cor) as well as Ulijana's total accuracy for the particular sonority profile under study.[14]

Table 7 reveals a strong interdependence between input and output: while the word-types with #CCs obeying the SSP and showing large sonority rises are a plurality compared to other profiles (input: 54.2%; output: 46.1%), their word-token counts are less frequent (input: 28.9%; output:

[13]The coefficients of the regression (the β's) are in log-odds units. The Intercept of the regression represents the log-odds of correctly producing a cluster when all of the predictor variables are 0. That corresponds to the following combination: average Age (mean-centered age is 0 when the child's age is the average age), average Word Length, average Input Frequency of the cluster, no Stress, not a Function Word, no Palatal Segment in the cluster, and SSP with the value 0 (a sonority plateau). The β of the Intercept, 1.00, corresponds to odds of 2.72, which corresponds to a probability of 0.73 that the cluster will be produced correctly.

[14]Note that for this analysis, we separated oral stops (T) from oral affricates (A), assuming that, independent of sonority, affricates might create articulatory difficulty when produced in #CC clusters.

		Ulijana's Input				Ulijana's Output					
		Type	%	Token	%	Type	%	Token	%	%Cor	%Total
Sonority Reversal	RT	1		1		0		0		n/a	
	RS	2	21	3	34	2	26	2	33	0	83
	SA	1		9		1		1		0	
	ST	102		816		59		342		83.6	
Sonority Plateau	TT	8		195		7		153		32	
	SS	50	12	241	20	18	12	71	25	78.9	54
	NN	3		55		3		32		100	
Small Sonority Rise	TS	20		130		11		61		59	
	AS	6	12	24	17	3	17	5	13	60	66
	SN	35		260		25		70		74.3	
	RG	0		0		1		2		0	
Large Sonority Rise	TN	10		26		3		12		33.3	
	TL	218	54	596	29	85	46	246	29	48	47
	TG	1		1		0		0		n/a	
	SL	41		83		23		45		66.7	
Total		**498**		**2,440**		**241**		**1,042**			

Table 7: Word-type and word-token frequencies by sonority profile and cluster type in Ulijana's input and output

29.1%) than SSP reversals (input: 34.0%; output: 33.1%). It seems to be the case that frequent occurrence of reversals in Ulijana's input shaped the composition of Ulijana's "favorite" lexicon from the age of 2 on.[15] During the first recording, she produced 3 types, 19 tokens of /s/- and /ʃ/-stop clusters with 90% accuracy, and 3 types and only 4 tokens of stop-liquid and fricative-liquid clusters (3 types) with 0% accuracy. Moreover, at the age of 24 months (5 sessions, in total) fricative-stop clusters were a majority in Ulijana's speech. There were 6 types, and 75 tokens of fricative-stop clusters produced with 88% accuracy. The fricative-liquid clusters (3 types, 20 tokens) were produced with 30% accuracy, while stop-liquid (6 types, 18 tokens) and stop-nasal (1 type, 4 tokens) were produced with 5.6% and 0% accuracy, respectively.

The percentages of accurate cluster type production in Table 7 also show that the early appearance and successful production of fricative-initial clusters determined accurate production of fricative-initial clusters across the entire year: almost all fricative-initial clusters were produced with more than 60% accuracy. In contrast, infrequent occurrence or even absence of liquid-obstruent, liquid-glide, and stop-glide clusters in Ulijana's input is mirrored by her non-use or infrequent unsuccessful performance in producing these cluster types.

4 DISCUSSION

Ulijana acquired the ability to accurately produce nearly all Russian consonants by the age of 28 months, and produced initial clusters [spʲ], [ʃt], and [mnʲ] just after her second birthday. Ulijana seems to have a special gift for complex articulations, but preliminary analysis of her Language Play suggests that she also spent much time practicing her Russian pronunciation. An analysis of Ulijana's #CC production shows the opposite of what sonority-based models predict: clusters with sonority reversals are produced early and accurately, while those with large sonority rises are not. Since #Cr clusters are a subset of the large sonority rise class, part of the effect is likely due to Ulijana's difficulty with the production of /r/. However, the study of input vs. output frequency for #CC cluster types

[15] At 24 months, Ulijana produced different inflected/derived forms of *spat'* 'to sleep' 57 times. This is the most frequent content word in her speech at this age and could be considered one of her favorite words. The role of favorite words in early speech production cannot be underestimated: frequent production routines can lead to entrenched motor functions which can both enhance speed and accuracy of words with the same routines, while inhibiting articulations that are similar, but not the same.

suggests that input frequency also plays a role in determining the order and accuracy of Ulijana's #CC production.

Our analysis of Ženja at 19–36 months, based on Gvozdev (1981), shows a distinct pattern: clusters with large sonority rises were produced more accurately across the entire year, while sonority reversals came later and had delayed accuracy. The late appearance and infrequent use of #ST can be partly explained by Ženja's late acquisition of fricatives and affricates.[16] While both Ulijana and Ženja can accurately produce four or five distinct #CC by age 2, individual differences in the acquisition of specific consonants play a role in each child's distinct pattern of cluster acquisition.

While one might disregard Ulijana's early acquisition of #ST clusters and her accuracy in producing them as an individual idiosyncrasy, this pattern has parallels in other studies of early child cluster production. In her argument for the role of the SSP in #CC acquisition, (Chambless, 2006:57) admits that: "While there is evidence from several surveys of cluster acquisition that the earlier word-initial clusters to be acquired tend to be those in which sonority distance is maximized ... this finding is not uniform across children. Other orders have been identified as well, for example, the earlier acquisition of s-stop clusters with respect to obstruent-approximant clusters."[17] Phoon et al. (2015) looked at acquisition of syllable initial CC-clusters in Chinese-influenced Malaysian English speaking children from 3–7 years old. In their study production was most accurate for /s/ + C clusters, with accuracy decreasing (in order) for Cw, Cj, Cl, and Cr. A more controlled study of sonority reversals is that of Syrika et al. (2011), where the acquisition of #sT and #Ts cluster production in 60 Greek children 2–5 years showed greater accuracy for #sT clusters than #Ts clusters.

The exceptional speed and accuracy of Ulijana's production of Russian consonants and consonant clusters provides us with another data-point in the range of variation among normally developing children. At the same time, it suggests that clusters which adhere to the SSP have no special status in speech production, that trills can be hard for even the most phonetically advanced children, and that production accuracy of particular clusters may correlate with the frequency of those clusters in child-directed speech and in the child's own early favorite words.

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[16] Our analysis of Ženja's words in the diary revealed that he acquired /s/ at the age of 22 months, /zʲ, z/ – at the ages of 25 and 27 months, respectively. The voiced palatal labiodental fricative was acquired at the age of 28 months. The fricatives /ʃ, ʒ, ʃʲː/ were acquired at the age of 30 months and /tʃ/ one month later.

[17] Counterexamples to predictions of the SSP result in suggestions that /s/ is an adjunct (not part of the onset), while variation invokes reference to frequency: "... A more frequent order of acquisition is driven by the greater frequency of particular structures in the ambient (i.e. adult) language" (Chambless, 2006:58).

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