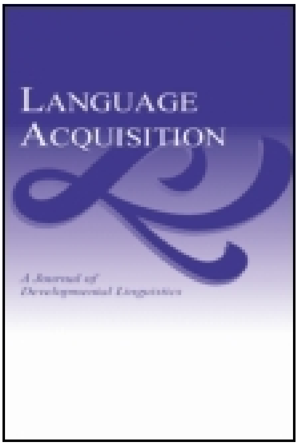

Language Acquisition
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/hlac20

Phonological Universals in Early Childhood: Evidence from Sonority Restrictions

Iris Berent [a], Katherine Harder [a] & Tracy Lennertz [a]
[a] Northeastern University

Available online: 26 Sep 2011

Language Acquisition, 18:281–293, 2011

ISSN: 1048-9223 print/1532-7817 online
DOI: 10.1080/10489223.2011.580676

Psychology Press
Taylor & Francis Group

BRIEF ARTICLE

Phonological Universals in Early Childhood: Evidence from Sonority Restrictions

Iris Berent, Katherine Harder, and Tracy Lennertz
Northeastern University

Across languages, onsets with large sonority distances are preferred to those with smaller distances (e.g., *bw>bd>lb*; Greenberg 1978). Optimality Theory (Prince & Smolensky 2004) attributes such facts to grammatical restrictions that are universally active in all grammars. To test this hypothesis, here we examine whether children extend putatively universal sonority restrictions to onsets unattested in their language. Participants ($M = 4;03$) were presented with pairs of auditory words—either identical (e.g., *lbif→lbif*) or epenthetically related (e.g., *lbif→lebif*)—and asked to judge their identity. Results showed that, like adults, children's ability to detect epenthetic distortions was monotonically related to sonority distance (*bw>bd>lb*), and their performance was inexplicable by several statistical and phonetic factors. These findings suggest that sonority restrictions are active in early childhood, and their scope is broad.

A large body of research demonstrates the sensitivity of young children and adults to the sound-pattern of novel linguistic forms that they have never heard before. Infants as young as nine months of age, for instance, favor syllables like *blif* over *lbif* despite no experience with either (e.g., Friederici & Wessels 1993). But while the productivity of language is widely recognized, its source is contentious. Some authors attribute linguistic generalizations to domain-general mechanisms, including statistical learning, articulatory, and auditory preferences (e.g., Blevins 2004; Bybee & McClelland 2005; MacNeilage 2008). Others, however, assert that productivity might be constrained, in part, by grammatical principles that are potentially specific to language (e.g., Jakobson 1968; Prince & Smolensky 1993/2004; de Lacy 2006a). In this view, all phonological grammars include a universal set of grammatical well-formedness restrictions called markedness constraints. Markedness constraints, for example, disfavor syllables such as

Correspondence should be sent to Iris Berent, Department of Psychology, Northeastern University, 125 Nightingale Hall, 360 Huntington Ave., Boston, MA 02115-5000. E-mail: i.berent@neu.edu

lbif over *blif*. Because the variant *lbif* incurs a more severe violation of markedness constraints, grammars are less likely to admit this marked variant compared to its unmarked counterpart, *blif*. Consequently, marked structures are less likely to emerge in typology, they are disfavored as the output of active phonological alternations, and they are more difficult to master in language acquisition. And while marked syllables, such as *lbif*, are typically ones that are also harder to articulate and perceive on purely phonetic grounds, by hypothesis, grammatical markedness constraints are independently represented in the grammar, irreducible to their analog phonetic precursors (de Lacy 2006b). Moreover, markedness restrictions apply universally, irrespective of whether such sequences are present or absent in a learner's linguistic experience.

The hypothesis of universal phonological constraints has been supported by a growing body of experimental findings demonstrating adult speakers are sensitive to putative universal restrictions that are unattested in their linguistic experience (e.g., Moreton 2002, 2008; Davidson 2006; Wilson 2006). Far less is known, however, about the developmental trajectory of grammatical markedness. Although universality is sometimes equated with innateness, these two questions are logically distinct: universal grammatical restrictions could be either present at birth, or emerge only later in life, shaped by a confluence of genetic factors and universally available phonetic cues that might trigger the representation of markedness restrictions in all grammars (e.g., Hayes & Steriade 2004). Moreover, once represented in the grammar, the effect of markedness constraints will depend on their ranking relative to faithfulness constraints—constraints that require grammatical outputs to be identical to the input. The English ban on syllables like *lbif*, for example, is due to the ranking of markedness constraints against *lbif* above relevant faithfulness restrictions, whereas its tolerance in Russian reflects the opposite ranking. Consequently, an input such as *lbif* will be faithfully represented by the Russian grammar, whereas in the English grammar, such outputs will typically emerge unfaithfully—they will be repaired as less-marked outputs, such as *lebif*, for example. Because such grammatical repair can selectively alter only one of the multiple representations available to the language learner (e.g., surface phonological form), leaving others (e.g., phonetic and auditory forms) intact (Berent et al. 2009), and because its application is probabilistic, grammatical repair does not fully obliterate the faithful representation of marked inputs even if markedness constraints are highly ranked in the initial state of all grammars (see Smolensky 1996; Jusczyk et al. 2002). Accordingly, given sufficient experience with such inputs, marked systems such as Russian will be eventually be learned, resulting in the demotion of markedness pressures relative to faithfulness constraints.

The critical role of experience in the ranking of markedness constraints, and possibly their phonetic triggering, raises the question of when in development does grammatical markedness manifest its effect. A handful of studies suggest that putatively universal markedness restrictions might be active in early development (e.g., Jusczyk et al. 2002; Bergelson & Idsardi 2009; studying 4.5- and 8-month-olds, respectively). Here, we further investigate their role in the grammar of 4-year-old children.

Our case study concerns the sonority restrictions on onset structure (e.g., *bl* in *block*). Across languages, syllables that begin with a consonant are preferred to those beginning with a vowel, and simple onsets (e.g., *ba*) are preferred to complex ones (e.g., *bla*; Prince & Smolensky 1993/2004). But within each onset type—simple or complex—certain onset consonants are systematically preferred to others. Simple onsets that begin with a stop are preferred to those beginning with a liquid (e.g., *ba*>*la*; Clements 1990; Prince & Smolensky

1993/2004). Similarly, complex onsets comprised of stop-liquid combinations are preferred to those with liquid-stop sequences (e.g., *bl*>*lb*; Greenberg 1978).

Such preferences have been attributed to sonority—a scalar phonological property that correlates with the intensity of segments (e.g., Clements 1990; for phonetic analysis, see Parker 2008). Vowels are more sonorous than consonants, and among consonants, glides and liquids (e.g., *y*, *w*, *l*, *r*) are more sonorous than nasals (e.g., *n*, *m*), which, in turn, are more sonorous than obstruents (e.g., *b*, *p*, *f*). Sonority distinctions indeed capture the cross-linguistic preference for syllables like *blif* over *lbif*: *blif* manifests a large rise in sonority, whereas in *lbif*, the onset falls in sonority. Similarly, simple obstruent onsets (e.g., *ba*) manifest larger sonority rises compared to sonorant ones (e.g., *la*). Put generally, there is a preference for syllables to abruptly rise in sonority from the onset to the nucleus—the larger the rise, the less marked the syllable (e.g., Clements 1990; Smolensky 2006). Accordingly, simple onsets consisting of obstruent-vowel combinations are preferred to those with more sonorous consonants—nasals and liquids. And within complex onsets, onsets with large sonority distances are generally preferred to those with smaller distances. In particular, the large rise in *blif* is preferred to a smaller rise, in *bnif*; *bnif*, in turn, is preferred to the sonority plateau in *bdif*, and least preferable are syllables that fall in sonority, such as *lbif*.

Numerous studies are consistent with the possibility that early grammars encode sonority restrictions. Consider, for example, the pattern of onset simplification. It is well known that words including complex onsets (e.g., *please*) are reduced into simple ones in a manner that maximizes sonority distance (as [piz], rather than [liz]; e.g., Pater 1997; Ohala 1999; Barlow 2003; Pater & Barlow 2003; Gnanadesikan 2004; Barlow 2005; Yavas et al. 2008). But whether these patterns are indeed due to universal sonority restrictions is difficult to ascertain. First, the choice of the surviving segment is affected by numerous factors unrelated to sonority, both grammatical (e.g., manner of articulation and its syllabic role as a head vs. adjunct; e.g., Barlow 2001; Goad & Rose 2004) and extra-grammatical factors (e.g., phonetic factors; Demuth & McCullough 2009), and frequency (Levelt et al. 1999), whose contribution varies across children and ages. Moreover, because such reductions concern onsets that are all attested in the child's language, they do not allow one to determine whether the relevant knowledge (sonority-related or otherwise) concerns principles that are language particular or universal.

To test for the scope of sonority-universals in early grammars, one might examine whether they generalize to syllable structures that are unattested in the child's language. Two pioneering studies have addressed this question, but their results are not entirely clear. An early study by Pertz & Bever (1975) examined the responses of adolescents and 9- to 11-year-old English-speaking children to novel words including unattested clusters. These stimuli were presented in both printed and aural forms, and participants were instructed to sound them out and then "choose, on a simplicity criterion ('easier, more likely, or more usual'), which one of two words has the initial sound cluster used in more languages in the world" (153). Results showed that children were sensitive to two of the onset-contrasts examined in the study (i.e., *mb*>*mp*; and *nd*>*ng*). In another study, Ohala (1999) observed that the sonority of unattested clusters affected their reduction by younger children (mean age = 2;07; e.g., *bwa*→*ba*; rather than *wa*).

Although these two studies suggest that children are sensitive to the structure of onsets that do not exist in their language, it is unclear whether this pattern is specifically related to sonority universals. In fact, the *nd*-*ng* distinction observed by Pertz & Bever (1975) cannot possibly be related to sonority, as these onsets are matched for their sonority profile. Moreover, generalizations in both studies were limited in scope—Pertz & Bever's participants failed to differentiate four of the six tested contrasts, and children in Ohala's (1999) study extended sonority-related preferences only to clusters analogous to the ones attested in English. Finally, because these studies relied on articulatory tasks, one cannot rule out the possibility that performance was modulated by the articulatory demands of marked onsets, rather than their grammatical markedness per se.

In the present study, we address these concerns by gauging children's sensitivity to a broad range of onset clusters using a purely perceptual task. Our work builds on past research, demonstrating that adults experience difficulties in the discrimination of marked CCVC monosyllables from their disyllabic CəCVC counterparts—the worse-formed the onset, the harder the discrimination (Berent et al. 2007; Berent et al. 2008). Specifically, discrimination was less accurate and slower given onsets of falling sonority (e.g., *lbif-lebif*) compared to sonority plateaus (e.g., *bdif-bedif*), which, in turn, were harder to distinguish from unattested sonority rises (e.g., *bwif-bewif*). The observation of these findings among speakers of various languages, including Korean, a language that arguably lacks onset clusters altogether, rules out the possibility that the difficulty with marked onsets is due to lexical analogies (Berent et al. 2008). The generality of these misperceptions with respect to stimulus modality—for both aural and printed materials (Berent et al. 2009; Berent & Lennertz 2010)—further demonstrates that misperceptions are not due to the inability to register the surface phonetic form of marked clusters. Together, these findings suggest that epenthetic distortions have an abstract grammatical source: because highly-marked onsets (e.g., *lbif*) severely violate grammatical constraints on sonority sequencing, such clusters are unlikely to be faithfully computed by the grammar. Accordingly, they are systematically repaired as better-formed disyllables by schwa-epenthesis (e.g., *lbif*→*lebif*)—a process that is widely active in loanword adaptation, for instance (e.g., Kenstowicz in press). Crucially, repairs are differentially affected by the sonority distance of onsets that are all unattested in participants' language, an observation suggesting that adult grammars universally represent the entire *bn*>*bd*>*lb* hierarchy irrespective of linguistic experience. To the extent such constraints are active in early development, we expect children to exhibit similar distortions in the identification of ill-formed onsets.

Our experiment examined this possibility using an identity-judgment task. Participants watched two characters engage in an imitation game: one character uttered a CCVC monosyllable with an unattested onset, either a better-formed onset (e.g., *bwif*) or a worse-formed counterpart (e.g., *lbif*). The second character attempted to imitate it, producing either precise imitations (e.g., *lbif*→*lbif*) or epenthetic distortions (e.g., *lbif*→*lebif*). The child's role was to determine whether the imitation was accurate. Our main prediction concerns the child's ability to detect such distortions: if the child's grammar represents the markedness of clusters along the sonority hierarchy, then children should be better able to discriminate among nonidentical items, including unmarked onsets, compared to ones with marked onsets.

To further assess the scope of these markedness distinctions, we varied the type of marked and unmarked structures across three counterbalanced lists presented to three groups of participants (see Table 1). In one group, marked onsets comprised the worst-formed onsets of falling sonority, whereas unmarked ones were best-formed onsets with sonority rises; in a second group, the same unmarked onsets of rising sonority were compared to the more marked sonority plateaus, whereas in a third group, sonority plateaus were compared to sonority falls—the

TABLE 1
Experimental Design

	Onset Type	
Contrast	*Unmarked*	*Marked*
Rise-Fall	*bwif-bewif*	*lbif-lebif*
Rise-Plateau	*bwif-bewif*	*bdif-bedif*
Plateau-Fall	*bdif-bedif*	*lbif-lebif*

most marked structure on the sonority hierarchy. Across groups, items were matched for their rhyme, and their onset structure was manipulated (e.g., *bwif*, *bdif*, *lbif*). If children are sensitive to the fine-grained distinctions along the universal sonority hierarchy, then performance with unmarked onsets with larger sonority distances should surpass performance with their marked counterparts in each of these three comparisons.

1. METHOD

1.1. Participants

The results are based on data from 18 participants aged 3;03–5;07 ($M = 4;04$; $SD = 0;10$). Participants were enrolled in preschools in the Boca Raton, FL and Boston, MA areas.[1] Twenty-two additional participants were tested, but their data were excluded, 5 for failing to pass the practice to criterion, 2 for distraction, 9 for opting out, 5 for giving the same response across all trials, and 1 due to an experimental error.

1.2. Materials

The materials consisted of audiovisual displays. Each such display featured two characters uttering two auditory stimuli in succession. The auditory stimuli were 48 $C_1C_2VC_3$ monosyllables (see Appendix A) and their $C_1əC_2VC_3$ disyllabic counterparts, sampled from items used in past research with adult speakers (Berent et al. 2007). Monosyllables had an onset cluster that is unattested in English—either a sonority rise, a sonority plateau, or a fall in sonority (e.g., *bwif*, *bdif*, *lbif*). There were 16 such triplets, matched for their rhyme and varied with respect to the structure of their onsets.

These monosyllable triplets were next divided into three lists. Each such list included two types of monosyllables that contrasted on the markedness of their sonority profile, along with their disyllabic counterparts. In list 1, monosyllables consisted of sonority rises and falls; in list 2 there were sonority rises and plateaus; and in list 3 there were sonority plateaus and falls. Within each list, the items were arranged in pairs; half identical (e.g., *lbif-lbif*; *lebif-lebif*) and

[1]Information on second-language experience was available for 12 of the 18 participants. Nine participants spoke exclusively English at home, and the remaining 3 were all exposed to languages whose onset structure is either comparable to or less marked than English (i.e., Spanish, German).

half nonidentical (e.g., *lbif-lebif*, *lebif-lbif*, with order counterbalanced). Each list was balanced for the 2 onset type × 2 identity × 2 order combinations. To assure that any single participant experienced each item with either the identity or nonidentity condition (but not both), we further divided each of the three major lists into two sublists (balanced for the onset type × identity × order variables), resulting in a total of six sublists. In three of those sublists, identity trials corresponded to the odd-numbered trios in Appendix A, whereas nonidentity items corresponded to the even-numbered items (these three sublists are provided in Appendix B). In the remaining three sublists, even-numbered items were presented in the identity condition, and odd-numbered items were assigned to the nonidentity condition. Each of the six sublists was presented to three participants, and the order of the trials was randomized. The materials were delivered aurally, using a recording of a native Russian-speaking female (because Russian allows all three types of clusters, they could be produced naturally by the talker).

These auditory materials were presented to participants as part of an imitation game. Each trial featured images of two characters—one character uttered an auditory word and the second attempted to imitate it. The characters were two baby apes—a chimpanzee and a gorilla (Kiki and Koko)—matched for size and overall appearance and balanced for order of presentation across conditions.

To familiarize participants with the task, we also presented them with a brief practice session. The practice consisted of four pairs of items that did not appear in the experiment (half were identical, half were nonidentical). All displays were presented in PowerPoint using "slide show" mode, and auditory files were delivered using Altec Lansing Multimedia ACS5 computer speakers.

1.3. Procedure

Children were tested individually in a quiet area of their preschool. Each session began by obtaining the child's assent to participate in the "computer game." Children were next introduced to Kiki and Koko. The child was told that "Kiki and Koko are trying to copy what each other are saying," but "sometimes they don't say exactly what the other one had said" because "they are only little monkeys," "they are just learning English," and "they still can't speak very well." The experimenter next asked the child to help the apes by telling them whether "they are copying each other exactly."

Each child was given a practice session, repeated until the child had attained the minimum performance criterion,[2] or a total of three times. Once the child had reached the criterion, (s)he proceeded to the experimental session. All children received a sticker as a reward for taking part in the experiment.

Each trial began with a message indicating the trial number. Once the child looked at the screen, the experimenter activated the trial, triggering the appearance of one character and the presentation of an auditory stimulus. After a 1-second delay, the second character appeared

[2]The minimum criterion in the rise-fall comparison was set to 50%, as all practice items were unattested. It soon became evident that some of the children did not understand the task because of the use of nonwords, and for this reason, subsequent testing of the rise-plateau and plateau-fall comparisons replaced two of the practice trials with existing words (e.g., *please-police; blow-below*) and elevated the cutoff criterion to 75% correct (across the four trials).

TABLE 2
Response Accuracy to Nonidentical Trials

Comparison	Mean Better-Formed (% Correct)	Mean Worse-Formed (% Correct)	Multi-Level Logit Analysis β	z	p <
Overall	38.67	20.83	−.98	−4.43	.001
Contrast Type					
Rise-Fall (e.g., *bwif-bewif* vs. *lbif-lebif*)	53.75	25.00	−1.33	−4.12	.001
Rise-Plateau (e.g., *bwif-bewif* vs. *bdif-bedif*)	54.17	35.42	−.82	−2.72	.01
Plateau-Fall (e.g., *bdif-bedif* vs. *lbif-lebif*)	8.33	2.08	−1.84	−1.97	.05

and uttered another auditory stimulus—either identical to the first or epenthetically related. The child was asked to determine whether the imitation was accurate, and her response was coded. On rare occasions in which a child attempted to articulate the words overtly, the experimenter gently discouraged her from doing so. After each trial, the experimenter praised the child for her effort (e.g., "good job"), but provided no feedback on accuracy.

2. RESULTS

Children were quite accurate in their responses to identical pairs ($M = 90\%$), a result that is only expected given that such pairs consisted of identical tokens whose relationship could be easily discerned by attending to their acoustic properties. Our main interest concerns response to nonidentical trials—trials pairing monosyllables with their epenthetic counterparts (e.g., *lbif-lebif*).

Table 2 depicts response accuracy as a function of the markedness of the monosyllabic counterpart. An inspection of the means suggests that children experienced greater difficulty detecting epenthetic distortions of marked onsets compared to distortions of their unmarked counterparts. This conclusion is confirmed by a 2 (marked-unmarked) × 3 contrast type (rise-fall/rise-plateau/plateau-fall) logit analysis. The overall effect of markedness was highly significant (see Table 2), and it was not further modulated by the type of contrast (for the interaction, $\beta = .289$, $z = 1.01$, $p > .30$).[3]

Additional analyses demonstrated the difficulty with marked onsets obtained for each of the three contrasts of interest. Specifically, epenthetic distortions were detected significantly more accurately for pairs including sonority rises (e.g., *bwif-bewif*) compared to pairs including either sonority falls (e.g., *lbif-lebif*) or plateaus (e.g., *bdif-bedif*). Moreover, onset structure modulated response even in the most marked comparison—for sonority plateaus (e.g., *bdif-bedif*) vs. falls (e.g., *lbif-lebif*). Although, as expected, performance in this condition was poor, accuracy was

[3]In view of the large variability in participants' age, we gauged the effect of age by performing a median split. An inspection of the means suggested that performance was similar for younger (M = 3;10) and older (M = 4;10) participants. Marked onsets yielded more accurate responses compared to less marked ones for both younger ($M = 35.69\%$, $M = 20.83\%$, for unmarked and marked onsets, respectively) and older children ($M = 42.36\%$, $M = 21.92\%$, for unmarked and marked onsets, respectively).

significantly higher with sonority plateaus compared to falls. Thus, children were sensitive to the sonority distance of a wide range of onsets that are all unattested in their language, and their performance converged with the behavior of adults and mirrored the distribution of these clusters across languages.

3. DISCUSSION

Our experiment examined whether 4-year-old children are sensitive to putatively universal grammatical restrictions on onset structure. We gauged the effect of markedness from children's ability to detect epenthetic distortions. Past research with adults suggests that marked onsets undergo epenthetic repair (e.g., *lbif→lebif*)—the greater the markedness, the more likely the repair (Berent et al. 2007; Berent et al. 2008; Berent et al. 2009). For this reason, adults tend to misidentify marked onsets as identical to their epenthetic counterparts. The present results demonstrate similar misidentifications among 4-year-olds. Overall, children were less likely to detect distortions of marked onsets compared to distortions of their less marked counterparts, and this effect obtained for each of the three contrasts under investigation. Specifically, sonority falls (e.g., *lbif*) were more likely to be distorted than plateaus (e.g., *bdif*) or rises (e.g., *bwif*), and plateaus (e.g., *bdif*), in turn, were more likely to be distorted relative to rises (e.g., *bwif*).[4]

Why do children misidentify ill-formed onsets with small sonority distances? One possibility is that misidentification is a grammatical reflex triggered by the markedness of such clusters. Because marked onsets severely violate sonority restrictions, they will be less likely to be faithfully represented by the grammar, and consequently, they will be systematically recoded as better-formed structures that separate the marked onset consonants by an epenthetic schwa (e.g., *lbif→lebif*).

Misidentification, however, could also occur due to a host of non-grammatical pressures that correlate with sonority profile. One possibility is that children fail to identify marked onsets because their statistical properties differ from those of onsets attested in English—more so than the less marked onsets. Another explanation attributes the misidentification of ill-formed onsets to their phonetic properties. In this view, children misidentify marked monosyllables as disyllables because the acoustic properties of these items resemble typical disyllables.

We examined these explanations through several analyses of the statistical and phonetic properties of these materials. We first evaluated the possibility that misidentification reflects greater unfamiliarity with marked onsets. To this end, we calculated several statistical properties of the items in adult English, including their segment probability, biphone probability, the number of neighbors, and neighbor frequency (for explanation, see Berent et al. 2007). We

[4]Interestingly, the identification of any given onset type was modulated by its experimental context. Sonority falls, for example, yielded higher accuracy when they were mixed with sonority rises ($M = 25.00\%$) relative to their mixing with sonority plateaus ($M = 2.08\%$). Similarly, sonority plateaus were more readily discriminated from their disyllabic counterparts in the context of sonority rises ($M = 35.42\%$) compared to sonority falls ($M = 8.33\%$). These findings suggest that discrimination accuracy was determined not only by the absolute markedness of the cluster but also by its markedness relative to the other structures presented in the experimental list. As the overall markedness of the list increased, misidentification was more prevalent, and consequently, children were more likely to treat monosyllables as identical to their epenthetic counterparts. The effect of relative markedness presents a special case of list-context effects, which have been amply documented in the psycholinguistic literature (e.g., Stone & Van Orden 1993).

TABLE 3
Step-Wise Linear Regression Analyses Examining the Contribution of Statistical Properties (Number of Neighbors, Neighbor Frequency, Segment Frequency, and Biphone Probability) and Phonetic Properties (Burst Duration and Intensity) on the Misidentification of Marked Onsets

Last Predictor	*Predictor Forced in Previous Steps*	R^2_{change}	F_{change}	df	p <
a. Statistical Properties	Markedness	.063	1.83	4, 89	.13
b. Phonetic Properties-Monosyllables	Markedness	.083	2.125	2, 44	.14
c. Phonetic Properties-Disyllables	Markedness	.025	2.82	1, 92	.10
d. Markedness	Statistical Properties	.05	5.80	1, 89	.02
e. Markedness	Phonetic Properties (monosyllables)	.07	3.63	1, 44	.07
f. Markedness	Phonetic Properties (disyllables)	.057	6.49	1, 92	.02

also considered the possibility that performance might be sensitive to the homorganicity of the onset consonants (i.e., whether they share the same place of articulation—a factor known to affect the performance of both children (Pertz & Bever 1975; Kirk 2008) and adults (e.g., Hallé et al. 1998). We next evaluated the contribution of these factors by means of a step-wise linear regression. We first forced into the model the homorganicity and markedness predictors, whereas statistical properties were entered together as the third and last predictor. To evaluate whether statistical properties can subsume the effect of markedness, we reversed the order of the last two predictors and forced markedness in the last step. The results (see Table 3, a vs. d) showed no evidence that statistical properties affect misidentification. Moreover, markedness accounted for a unique 5% of the variance even when the contribution of statistical properties and homorganicity was controlled.

We next examined the possibility that children misidentify marked onsets because the phonetic properties of such monosyllables resemble the acoustic properties of typical disyllables. Past research has suggested that adult speakers sometimes misinterpret the release burst associated with stop consonants as a cue for a schwa (Kang 2003; Iverson & Lee 2006). This factor could potentially confound the evaluation of markedness with our stop-initial onsets—for sonority rises and plateaus. If marked onsets of level sonority have a more prominent burst release than less marked clusters with sonority rises, then the burst might lead children to more frequently misidentify sonority plateaus as disyllabic. Identification accuracy in our experiment was indeed negatively and reliably correlated with both the duration of the release burst ($r = -.35$, $p < .003$) and its intensity ($r = -.45$, $p < .001$). Closer scrutiny, however, revealed that these correlations were largely due to a small number of items with homorganic onset consonants (e.g., *bwif*, *dlif*). When these items were removed, the correlation was greatly attenuated ($r = -.155$; $r = -.265$; for burst duration and intensity, respectively).[5] Moreover, step-wise linear regression analyses demonstrated that phonetic properties did not reliably account for any unique variance in identification accuracy, whereas the unique effect

[5]The duration of the burst for sonority rise items was $M = 10.57$ ms (range: 5.22–17.05 ms); for sonority plateaus, it was $M = 10.32$ ms (range: 3.86–27.58 ms). In the non-homorganic items, burst duration for items of rising and level sonority, respectively, were $M = 13.69$ ms (range: 8–17.5 ms); $M = 10.32$ ms (range: 3.86–27.58 ms).

of markedness was marginally significant even when phonetic properties were statistically controlled (see Table 3, b vs. c).

Another possibility is that the misidentification of marked onsets with their disyllabic counterparts is caused by the phonetic properties of the disyllables. For example, if the disyllabic counterparts of highly marked onsets had a shorter pre-tonic schwa, then such items might be more readily confusable with their respective monosyllables. However, an inspection of the materials suggests that the disyllabic counterparts of marked onsets did not invariably manifest longer schwas—sonority plateaus, for instance, had, on average, a shorter schwa than the better-formed rises (the means for sonority rises, plateaus, and falls were $M = 76$ ms, $M = 66$ ms, $M = 86$ ms, respectively), and the duration of the schwa did not correlate with overall response accuracy ($r = -.109$, $p < .15$, one-tailed). Indeed, step-wise linear regression analyses demonstrated that schwa duration did not reliably account for any unique variance in identification accuracy, whereas the effect of markedness remained reliable as the last predictor, after controlling for schwa duration and homorganicity, in the previous step (see Table 3, c vs. f).

Taken as a whole, our results suggest that marked onsets tend to be misidentified, and that misidentifications are inexplicable by numerous phonetic and statistical factors. Our analyses obviously do not exhaust the full range of non-grammatical explanations for the findings—statistical or phonetic. Moreover, the linguistic knowledge of 4-year-old children cannot address the initial state of the language system. Such caveats notwithstanding, the results obtained from our present perceptual task nonetheless agree with many previous studies (e.g., Pater 1997; Ohala 1999; Pater & Barlow 2003; Gnanadesikan 2004; Barlow 2005; Yavas et al. 2008), demonstrating that the production of onsets in early stages of acquisition mirrors sonority restrictions. The detection of sonority effects across modalities, in both production and perception, is consistent with an abstract grammatical source that bans onsets with small sonority distances. Crucially, such constraints generalize to onsets that are unattested in the child's language. These findings suggest that grammatical constraints on sonority are active in early childhood, and the scope of such knowledge is quite broad.

ACKNOWLEDGMENTS

This research was supported by NIDCD grant DC003277 to Iris Berent.

REFERENCES

Barlow, Jessica A. 2001. The structure of /s/-sequences: Evidence from a disordered system. *Journal of Child Language* 28. 291–324.

Barlow, Jessica A. 2003. Asymmetries in the acquisition of consonant clusters in Spanish. *The Canadian Journal of Linguistics* 48. 179–210.

Barlow, Jessica A. 2005. Sonority effects in the production of consonant clusters by Spanish-speaking children. In David Eddington (ed.), *Selected proceedings of the 6th Conference on the Acquisition of Spanish and Portuguese as First and Second Languages*, 1–14. Somerville, MA: Cascadilla Proceedings Project.

Berent, Iris & Tracy Lennertz. 2010. Universal constraints on the sound structure of language: Phonological or acoustic? *Journal of Experimental Psychology: Human Perception & Performance* 36. 212–223.

Berent, Iris, Tracy Lennertz, Jongho Jun, Miguel A. Moreno & Paul Smolensky. 2008. Language universals in human brains. *Proceedings of the National Academy of Sciences* 105. 5321–5325.

Berent, Iris, Tracy Lennertz, Paul Smolensky & Vered Vaknin-Nusbaum. 2009. Listeners' knowledge of phonological universals: Evidence from nasal clusters. *Phonology* 26. 75–108.

Berent, Iris, Donca Steriade, Tracy Lennertz & Vered Vaknin. 2007. What we know about what we have never heard: Evidence from perceptual illusions. *Cognition* 104. 591–630.

Bergelson, Elika & William Idsardi. 2009. Structural biases in phonology: Infant and adult evidence in artificial language learning. In Jane Chandlee, Michelle Franchini, Sandy Lord & Gudrun-Marion Rheinerx (eds.), *Proceedings of the 33rd annual Boston University Conference on Language Development [BUCLD 33]*, 85–96. Somerville, MA: Cascadilla Press.

Blevins, Juliette. 2004. *Evolutionary phonology*. Cambridge: Cambridge University Press.

Bybee, Joan & James L. McClelland. 2005. Alternatives to the combinatorial paradigm of linguistic theory based on domain general principles of human cognition. *Linguistic Review* 22. 381–410.

Clements, George N. 1990. The role of the sonority cycle in core syllabification. In John Kingston & Mary Beckman (eds.) *Papers in laboratory phonology I: Between the grammar and physics of speech*, 282–333. Cambridge: Cambridge University Press.

Davidson, Lisa. 2006. Phonotactics and articulatory coordination interact in phonology: Evidence from nonnative production. *Cognitive Science* 30. 837–862.

de Lacy, Paul. 2006a. *Markedness: Reduction and preservation in phonology*. Cambridge: Cambridge University Press.

de Lacy, Paul. 2006b. Transmissibility and the role of the phonological component. *Theoretical Linguistics* 32. 185–196.

Demuth, Katherine & Elizabeth McCullough. 2009. The longitudinal development of clusters in French. *Journal of Child Language* 36. 425–448.

Friederici, Angela D. & Jeanine M. Wessels. 1993. Phonotactic knowledge of word boundaries and its use in infant speech perception. *Perception and Psychophysics* 54. 287–295.

Gnanadesikan, Amalia. 2004. Markedness and faithfulness constraints in child phonology. In René Kager, Joe Pater & Wim Zonneveld (eds.), *Constraints in phonological acquisition*, 73–108. Cambridge: Cambridge University Press.

Goad, Heather & Yvan Rose. 2004. Input elaboration, head faithfulness, and evidence for representation in the acquisition of left-edge clusters in West Germanic. In René Kager, Joe Pater & Wim Zonneveld (eds.), *Constraints in phonological acquisition*, 109–157. Cambridge: Cambridge University Press.

Greenberg, Joseph H. 1978. Some generalizations concerning initial and final consonant clusters. In Joseph H. Greenberg, Charles A. Ferguson & Edith A. Moravcsik (eds.), *Universals of human language. Vol. 2: Phonology*, 243–279. Stanford, CA: Stanford University Press.

Hallé, Pierre A., Juan Segui, Uli Frauenfelder & Christine Meunier. 1998. The processing of illegal consonant clusters: A case of perceptual assimilation? *Journal of Experimental Psychology: Human Perception and Performance* 24. 592–608.

Hayes, Bruce & Donca Steriade. 2004. A review of perceptual cues and cue robustness. In Bruce Hayes, Robert Martin Kirchner & Donca Steriade (eds.), *Phonetically based phonology*, 1–33. Cambridge: Cambridge University Press.

Iverson, Gregory K. & Ahrong Lee. 2006. Perception of contrast in Korean loanword adaptation. *Korean Linguistics* 13. 49–87.

Jakobson, Roman. 1968. *Child language aphasia and phonological universals*. The Hague: Mouton.

Jusczyk, Peter W., Paul Smolensky & Theresa Allocco. 2002. How English-learning infants respond to markedness and faithfulness constraints. *Language Acquisition* 10. 31–73.

Kang, Yoonjung. 2003. Perceptual similarity in loanword adaptation: English postvocalic word-final stops in Korean. *Phonology* 20. 219–273.

Kenstowicz, Michael. In press. The phonetics and phonology of Korean loanword adaptation. In Sang-Jik Rhee (ed.), *Proceedings of First European Conference on Korean Linguistics*. Leiden, Germany.

Kirk, Cecilia. 2008. Substitution errors in the production of word-initial and word-final consonant clusters. *Journal of Speech, Language & Hearing Research* 51. 35–48.

Levelt, Clara C., Niels O. Schiller & Willem J. Levelt. 1999. The acquisition of syllable types. *Language Acquisition* 8. 237–264.

MacNeilage, Peter F. 2008. *The origin of speech*. Oxford: Oxford University Press.

Moreton, Elliott. 2002. Structural constraints in the perception of English stop-sonorant clusters. *Cognition* 84. 55–71.

Moreton, Elliott. 2008. Analytic bias and phonological typology. *Phonology* 25. 83–127.

Ohala, Diane K. 1999. The influence of sonority on children's cluster reductions. *Journal of Communication Disorders* 32. 397–421.
Parker, Steve. 2008. Sound level protrusions as phsycial correlates of sonority. *Journal of Phonetics* 36. 55–90.
Pater, Joe. 1997. Minimal violation and phonological development. *Language Acquisition* 6. 201–253.
Pater, Joe & Jessica A. Barlow. 2003. Constraint conflict in cluster reduction. *Journal of Child Language* 30. 487–526.
Pertz, D. L. & T. G. Bever. 1975. Sensitivity to phonological universals in children and adolescents. *Language* 51. 149–162.
Prince, Alan & Paul Smolensky. 1993/2004. *Optimality theory: Constraint interaction in generative grammar*. Malden, MA: Blackwell.
Smolensky, Paul. 1996. On the comprehension/production dilemma in child language. *Linguistic Inquiry* 27. 720–731.
Smolensky, Paul. 2006. Optimality in phonology II: Markedness, feature domains, and local constraint conjunction. In Paul Smolensky & Géraldine Legendre (eds.), *The harmonic mind: From neural computation to optimality-theoretic grammar. Vol. 2: Linguistic and philosophical implications*, 27–160. Cambridge, MA: MIT Press.
Stone, Gregory O. & Guy C. Van Orden. 1993. Strategic control of processing in word recognition. *Journal of Experimental Psychology: Human Perception and Performance* 19. 744–774.
Wilson, Colin. 2006. Learning phonology with substantive bias: An experimental and computational study of velar palatalization. *Cognitive Science* 30. 945–982.
Yavas, Mehmet, Avivit Ben-David, Ellen Gerrits, Kristian E. Kristoffersen & Hanne G. Simonsen. 2008. Sonority and cross-linguistic acquisition of initial s-clusters. *Clinical Linguistics & Phonetics* 22. 421–441.

Submitted 21 May 2010
Final version accepted 11 February 2011

APPENDIX A

TABLE A1
THE MONOSYLLABIC ITEMS USED
IN THE EXPERIMENT

Trio Number	*Rise*	*Plateau*	*Fall*
1	bwif	bdif	lbif
2	dlɑf	dgɑf	rdɑf
3	dmʊp	dgʊp	mdʊp
4	dnʊp	dbʊp	rdʊp
5	gmɛf	gbɛf	rgɛf
6	gmit	gbit	mgit
7	kmæf	kpæf	rgæf
8	dlif	dbif	rdif
9	kmʊp	ktɑp	ltɑp
10	tlʊf	tkʊf	rtʊf
11	tlɛp	tkɛp	mtɛp
12	tnɑk	tkɑk	rtɑk
13	tmæf	tpæf	mtæf
14	tnɛf	tpif	rtɛf
15	tnʊk	tgʊk	mgʊk
16	tmæp	tpæp	rpæp

APPENDIX B

TABLE B1
THE STRUCTURE OF THREE OF THE SIX SUBLISTS USED IN THE EXPERIMENT

			Sublist 1		*Sublist 2*		*Sublist 3*	
		Trio	*Rise*	*Fall*	*Rise*	*Plateau*	*Plateau*	*Fall*
Identity	CCVC	1	bwif-bwif	lbif-lbif	bwif-bwif	bdif-bdif	bdif-bdif	lbif-lbif
		3	dmʊp-dmʊp	mdʊp-mdʊp	dmʊp-dmʊp	dgʊp-dgʊp	dgʊp-dgʊp	mdʊp-mdʊp
		5	gmɛf-gmɛf	rgɛf-rgɛf	gmɛf-gmɛf	gbɛf-gbɛf	gbɛf-gbɛf	rgɛf-rgɛf
		7	kmæf-kmæf	rgæf-rgæf	kmæf-kmæf	kpæf-kpæf	kpæf-kpæf	rgæf-rgæf
		9	kmʊp-kmʊp	ltɑp-ltɑp	kmʊp-kmʊp	ktɑp-ktɑp	ktɑp-ktɑp	ltɑp-ltɑp
		11	tlɛp-tlɛp	mtɛp-mtɛp	tlɛp-tlɛp	tkɛp-tkɛp	tkɛp-tkɛp	mtɛp-mtɛp
		13	tmæf-tmæf	mtæf-mtæf	tmæf-tmæf	tpæf-tpæf	tpæf-tpæf	mtæf-mtæf
		15	tnʊk-tnʊk	mgʊk-mgʊk	tnʊk-tnʊk	tgʊk-tgʊk	tgʊk-tgʊk	mgʊk-mgʊk
	CəCVC	1	bəwif-bəwif	ləbif-ləbif	bəwif-bəwif	bədif-bədif	bədif-bədif	ləbif-ləbif
		3	dəmʊp-dəmʊp	mədʊp-mədʊp	dəmʊp-dəmʊp	dəgʊp-dəgʊp	dəgʊp-dəgʊp	mədʊp-mədʊp
		5	gəmɛf-gəmɛf	rəgɛf-rəgɛf	gəmɛf-gəmɛf	gəbɛf-gəbɛf	gəbɛf-gəbɛf	rəgɛf-rəgɛf
		7	kəmæf-kəmæf	rəgæf-rəgæf	kəmæf-kəmæf	kəpæf-kəpæf	kəpæf-kəpæf	rəgæf-rəgæf
		9	kəmʊp-kəmʊp	lətɑp-lətɑp	kəmʊp-kəmʊp	kətɑp-kətɑp	kətɑp-kətɑp	lətɑp-lətɑp
		11	təlɛp-təlɛp	mətɛp-mətɛp	təlɛp-təlɛp	təkɛp-təkɛp	təkɛp-təkɛp	mətɛp-mətɛp
		13	təmæf-təmæf	mətæf-mətæf	təmæf-təmæf	təpæf-təpæf	təpæf-təpæf	mətæf-mətæf
		15	tənʊk-tənʊk	məgʊk-məgʊk	tənʊk-tənʊk	təgʊk-təgʊk	təgʊk-təgʊk	məgʊk-məgʊk
Nonidentity	CCVC-CəCVC	2	dlɑf-dəlɑf	rdɑf-rədɑf	dlɑf-dəlɑf	dgɑf-dəgɑf	dgɑf-dəgɑf	rdɑf-rədɑf
		4	dnʊp-dənʊp	rdʊp-rədʊp	dnʊp-dənʊp	dbʊp-dəbʊp	dbʊp-dəbʊp	rdʊp-rədʊp
		6	gmit-gəmit	mgit-məgit	gmit-gəmit	gbit-gəbit	gbit-gəbit	mgit-məgit
		8	dlif-dəlif	rdif-rədif	dlif-dəlif	dbif-dəbif	dbif-dəbif	rdif-rədif
		10	tlʊf-təlʊf	rtʊf-rətʊf	tlʊf-təlʊf	tkʊf-təkʊf	tkʊf-təkʊf	rtʊf-rətʊf
		12	tnɑk-tənɑk	rtɑk-rətɑk	tnɑk-tənɑk	tkɑk-təkɑk	tkɑk-təkɑk	rtɑk-rətɑk
		14	tnɛf-tənɛf	rtɛf-rətɛf	tnɛf-tənɛf	tpif-təpif	tpif-təpif	rtɛf-rətɛf
		16	tmæp-təmæp	rpæp-rəpæp	tmæp-təmæp	tpæp-təpæp	tpæp-təpæp	rpæp-rəpæp
	CəCVC-CCVC	2	dəlɑf-dlɑf	rədɑf-rdɑf	dəlɑf-dlɑf	dəgɑf-dgɑf	dəgɑf-dgɑf	rədɑf-rdɑf
		4	dənʊp-dnʊp	rədʊp-rdʊp	dənʊp-dnʊp	dəbʊp-dbʊp	dəbʊp-dbʊp	rədʊp-rdʊp
		6	gəmit-gmit	məgit-mgit	gəmit-gmit	gəbit-gbit	gəbit-gbit	məgit-mgit
		8	dəlif-dlif	rədif-rdif	dəlif-dlif	dəbif-dbif	dəbif-dbif	rədif-rdif
		10	təlʊf-tlʊf	rətʊf-rtʊf	təlʊf-tlʊf	təkʊf-tkʊf	təkʊf-tkʊf	rətʊf-rtʊf
		12	tənɑk-tnɑk	rətɑk-rtɑk	tənɑk-tnɑk	təkɑk-tkɑk	təkɑk-tkɑk	rətɑk-rtɑk
		14	tənɛf-tnɛf	rətɛf-rtɛf	tənɛf-tnɛf	təpif-tpif	təpif-tpif	rətɛf-rtɛf
		16	təmæp-tmæp	rəpæp-rpæp	təmæp-tmæp	təpæp-tpæp	təpæp-tpæp	rəpæp-rpæp