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Universal linguistic pressures and their solutions

Evidence from Spanish

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Do speakers possess universal linguistic restrictions on the sound structure of their language? We examine this question by investigating the restrictions on onset clusters (e.g., *bl* in *block*). Cross-linguistic comparisons suggest that certain onset clusters are universally preferred: Onsets like *bn* are preferred to *bd*, which, in turn, are preferred to *lb*. In four experiments, we demonstrate that such preferences constrain onset identification by Spanish speakers: the worst formed the onset, the more likely its misidentification. Onset structure, however, determines not only the rate of disyllabic recoding but also its type. While better-formed onsets of rising sonority are repaired epenthetically (e.g., *bnif*→*benif*), worse-formed onsets are recoded prothetically (e.g., *lbif*→*elbif*), and the choice of repair (epenthesis vs. prothesis) is modulated by linguistic experience. These findings suggest that speakers possess broad linguistic restrictions that extend to structures unattested in their language, but the response to such putatively universal pressures is experience-dependent.

Keywords: phonology, Spanish, universal grammar, sonority, optimality theory, syllable, onset, repair

It is well known that human languages manifest systematic structural regularities (e.g., Chomsky, 2002; Greenberg, 1966; Jakobson, 1968). Across languages, CV syllables (where C and V denote a consonant and vowel, respectively, e.g., *ba*), for example, are preferred to CCV syllables (e.g., *bla*). Not only are CV syllables more frequent across languages but languages that tolerate the less frequent CCV syllables tend to also allow CV syllables, whereas languages with CV syllables do not necessarily tolerate CCV ones (Greenberg, 1966; Prince & Smolensky, 1993/2004).

Such regularities might reflect universal constraints on language structure — either phonological or phonetic. Phonological constraints (Prince & Smolensky, 1993/2004; Smolensky & Legendre, 2006) might render certain structures ill formed,

and consequently, those structures might be systematically avoided across languages. CCV syllables, for instance, might be underrepresented across languages because they violate a putatively universal grammatical constraint against complex onsets (Prince & Smolensky, 1993/2004). In addition, cross-linguistic regularities could result from phonetic pressures. Indeed, the preferred CV syllable, for example, optimizes speech perception and production by allowing for greater coarticulation of consonants and vowels compared to less preferred syllables (e.g., CCVC, Mattingly, 1981; Ohala, 1990; Wright, 2004). Regardless of whether the relevant linguistic pressures are phonological or phonetic, both accounts assume that people possess universal systematic restrictions concerning the sound structure of language. Our interest here is in whether such restrictions are, in fact, operative in all speakers.

As a case study, we examine the restrictions on onset clusters — the sequence of consonants occurring at the beginning of syllables (e.g., *dr* in *drop*). As mentioned earlier, syllables that begin with an onset cluster are generally dispreferred to those with a single consonant. Nonetheless, not all onset clusters are equally disliked. Sequences as in *blif* are preferred to those in *bnif*, which, in turn are preferred to those in *bdif*. At the bottom of the hierarchy are sequences as in *lbif*. Such preferences have been attributed to the sonority of consonants (indicated as *s*) — a phonological property that correlates with their intensity (e.g., Clements, 1990; Parker, 2002). Most sonorous (i.e., loudest) are glides (e.g., *w,y*), with a sonority level of 4 ($s=4$), followed by liquids (e.g., *l,r*, $s=3$), nasals (e.g., *m,n*, $s=2$), and obstruents (e.g., *p,t,k,b,d,g,v,f,s,z*, $s=1$). Thus, onsets such as *bl* manifest a large rise in sonority (a sonority distance of 2, $\Delta s=2$), *bn* onsets manifest a smaller rise ($\Delta s=1$), *bd*-onsets exhibit a sonority plateau ($\Delta s=0$), whereas in *lba*, the onset falls in sonority ($\Delta s=-2$).

The preference (denoted \succ) for $bl \succ bn \succ bd \succ lb$ favors onsets with large sonority distances (i.e., Large rises \succ Small rises \succ Plateaus \succ Falls) — the larger the sonority distance, the more preferred is the onset (Clements, 1990; Hooper, 1976; Smolensky, 2006). Typological data (Greenberg, 1978, reanalyzed in Berent, Steriade, Lennertz, & Vaknin, 2007) indeed show that small sonority distances (including negative distances, as in *lba*, $\Delta s=-2$) are systematically underrepresented across languages. Not only do onsets with small sonority distances tend to be infrequent across languages, but languages that tolerate them typically manifest larger distances as well. For example, Russian, a language that tolerates a fall in sonority, also allows plateaus and rises, whereas English allows only large rises — it does not systematically tolerate plateaus or falls. While these facts do not determine the origins of those preferences — whether they reflect phonological restrictions on sonority, or the phonetic properties of those clusters — these observations imply that certain onset structures are systematically dispreferred across languages. Our interest here is whether such preferences are active among individual speakers.

To address this question, our past research examined whether speakers favor onsets with large sonority distances even when these onsets are unattested in their language. For example, do English speakers favor *bnif* to *bdif* despite the fact that neither syllable is possible in English? We infer such preferences from the phenomenon of perceptual repair. A large body of research shows that people tend to perceptually misidentify ill-formed consonant sequences (e.g., Davidson, 2011; Dupoux, Kakehi, Hirose, Pallier, & Mehler, 1999; Fleischhacker, 2005; Hallé, Segui, Frauenfelder, & Meunier, 1998; Massaro & Cohen, 1983; Moreton, 2002; Zuraw, 2007). For example, English speakers misidentify *tla* as *tela* (Buchwald, Rapp, & Stone, 2007; Pitt, 1998). Such misidentifications indicate that people repair the illicit onset *tla* by inserting a schwa between the onset consonants (e.g., *tla*→*tela*), namely, epenthesis. Building on these findings, we have exploited the phenomenon of perceptual repair as a gauge for linguistic preferences (e.g., Berent et al., 2007; Berent, Lennertz, Smolensky, & Vaknin-Nusbaum, 2009; Berent, Lennertz, & Balaban, 2012). We reasoned that, if small sonority distances are dispreferred, then such structures should be less likely to be encoded faithfully. Instead, ill-formed onsets will be recoded as some better-formed structures, and consequently, they will be systematically misidentified. Our findings are consistent with this prediction. We found that worst formed onsets of falling sonority (e.g., *lba*) are most likely to undergo repair (e.g., as *leba*), repair is less likely for onsets of level sonority (e.g., *bdif*), and least likely it is to affect onsets with sonority rises (e.g., *bnif*). While the misidentification of ill-formed onsets could, in principle, result from either phonological or phonetic constraints, subsequent analyses of the results have provided various reasons to favor a phonological explanation. And indeed, similar results obtained even when the challenges of acoustic processing are entirely eliminated due to the use of printed stimuli (Berent, 2008; Berent & Lennertz, 2010). Regardless of origin, these results demonstrate that English speakers possess preferences for onsets that are unattested in their language.

Although these findings are consistent with the hypothesis of universal linguistic preferences (phonological and/or phonetic), several limitations of this research are noteworthy. First, most of the existing data come from English — a language that is itself rich with onset clusters. Not only does English allow a large range of onsets with a sonority rise (e.g., *twin*, $\Delta s = 3$; *blow*, *break*, *true* $\Delta s = 2$), but it also tolerates a handful of exceptional *s*-initial onsets with smaller distances — both small sonority rises (e.g., *smell*, *snow*, $\Delta s = 1$) and plateaus (e.g., *sport*, $\Delta s = 0$). In addition, English speakers routinely reduce schwas in fast speech, and this phenomenon gives rise to acoustic sequences that resemble onset clusters (e.g., *believe* → *b'lieve*), including, potentially, even onsets that are not lexically attested (e.g., *potato* → *p'tato*). The ample experience of English speakers with a variety of clusters opens up the possibility that their sonority preferences might reflect inductive

learning from their linguistic (phonological and phonetic) experience, rather than universal linguistic preferences (Daland et al., 2011). While subsequent research has replicated the English results with speakers of Korean — a language that arguably has no onset clusters nor does it eliminate vowels in fast speech (Berent, Lennertz, Jun, Moreno, & Smolensky, 2008) — further tests of the universality of the sonority restriction are called for.

A second limitation of the existing results concerns their assessment of structural pressures. Our past research has inferred speakers' linguistic preference from their tendency to systematically misidentify ill-formed onsets with their epenthetic disyllabic counterparts. Such repairs, we reasoned, indicate biases (phonological or phonetic) against such onsets — the more likely the repair, the stronger the putative bias. Since the likelihood of repair is monotonically related to sonority distance, those results suggest that speakers disfavor onsets with small sonority distances. The linguistic literature, however, has demonstrated that repair can acquire multiple forms (e.g., Davidson, 2011; Davidson & Shaw, 2012; Fleischhacker, 2005; Gouskova, 2004; Shaw & Davidson, 2012; Steriade, 1982; Zuraw, 2007), and that the precise form of repair could be further modulated by linguistic experience (Dupoux, Parlato, Frota, Hirose, & Peperkamp, 2011). In particular, monosyllables with ill-formed onsets are also repaired by adding a vowel before the consonant (e.g., *lbif* → *elbif*) namely, prothesis. Our past research did not systematically assess such repairs. Consequently, we cannot rule out the possibility that, when all disyllabic repairs are considered together, misidentification — the hallmark of structural pressures — might no longer be monotonically related to sonority distance (Peperkamp, 2007). Such a scenario would challenge our conclusion that people are sensitive to the onset hierarchy.

The following experiments address these concerns by extending our research program to Spanish. Spanish is informative for two reasons. First, Spanish is a language that is poor in onset clusters (compared to English). Spanish restricts onset clusters to obstruent-liquid (e.g., *playa*, 'beach') and obstruent-glides (*bueno*, 'good') — it allows no *s*-initial clusters (e.g., Alba, 1998; Harris, 1983; Harris, 1989; Hooper, 1976), and it is also far less likely to reduce its vowels compared to English (Dauer, 1983; Nespor, 1990). Accordingly, the experience of Spanish speakers with onset clusters — either in lexical forms, or in reduced speech — is relatively limited. Of interest is whether Spanish speakers are nonetheless sensitive to the structure of unattested onsets.

A second interesting property of Spanish concerns its repair mechanisms. Spanish is known to productively rely on two forms of repair. While epenthetic repairs are common (e.g., *reloj* "clock" → *relojes*, "clocks"; Harris, 1987), Spanish speakers also employ prothesis (e.g., *stress* → *estrés*), and such repairs are frequently seen in loanword adaptation (Altenberg, 2005; Harris, 1983; Hooper, 1976) and they have been documented in psychological experiments (Halle, Dominguez,

Cuetos, & Segui, 2008; Theodore & Schmidt, 2003). Accordingly, Spanish allows us to compare these two forms of repair of ill-formed onsets.

The following experiments thus examine the identification of unattested onsets by Spanish speakers. Unlike our past research, here, we do not seek to identify the precise linguistic pressures affecting the identification of ill-formed onsets — whether they are phonological or phonetic, as both sources might converge to modulate the identification of unattested onsets. Rather, we focus on two general questions. First, are Spanish speakers sensitive to the (phonological or phonetic) structure of onsets that are unattested in their language? Second, how do Spanish speakers repair ill-formed onsets? Experiment 1 investigates whether Spanish speakers misidentify monosyllables with ill-formed onsets (e.g., *lbif*) as disyllabic. Experiments 2–4 move to investigate whether such disyllabic repairs specifically concern epenthesis (e.g., *lbif* = *lebif*), or prothesis (e.g., *lbif* → *elbif*). In view of the existing literature, we expect Spanish speakers to employ both forms of repair, and their repair of choice could be possibly modulated by linguistic experience. But if their linguistic knowledge is sensitive to the onset hierarchy, then, as sonority distance decreases, repair should be more likely, and consequently, monosyllables with small sonority distances should be more likely misidentified as disyllabic.

Experiment 1

Experiment 1 compared the preferences of Spanish speakers with respect to three types of onset clusters that are unattested in their language: a small rise in sonority (e.g., *bn*), a sonority plateau (e.g., *bd*), and a fall in sonority (e.g., *lb*). The onsets were presented in matched monosyllabic words (e.g., *bnif*, *bdif*, *lbif*). We also presented participants with the disyllabic counterparts of these monosyllables — items in which the onset consonants were separated by a schwa (e.g., *benif*, *bedif*, *lebif*). In each trial, participants were presented with a single auditory item and asked to determine whether it includes one syllable or two. If onsets with small sonority distances are repaired as disyllabic (by either epenthesis or prothesis, e.g., *lbif* → *lebif* or *lbif* → *elbif*), then as sonority distance decreases, people should be more likely to misperceive the monosyllabic items as disyllabic, and consequently, their response accuracy should decrease monotonically.

The structure of the monosyllabic form might also affect the processing of its disyllabic counterpart. To determine that a target (e.g., *lebif*) is disyllabic, participants must make a forced choice between the (correct) disyllabic form and the monosyllabic competitor. Their ability to reject the monosyllabic competitor might depend on its structure: As the sonority distance of the monosyllabic counterpart increases, the bias against this unattested structure will decrease, and

consequently, participants might be tempted to incorrectly identify the disyllabic target as monosyllabic. Accordingly, sonority distance might constrain not only responses to ill-formed monosyllables but also to disyllables.

Method

Participants. Seventeen native Spanish speakers participated in the experiment at Florida Atlantic University. To minimize the possibility that the performance of our Spanish-speaking participants (recruited in the United States) might reflect their experience with English, we restricted the selection of participants, such that most participants acquired English as a second language late in life. Accordingly, we recruited most participants from English as Second Language courses, offered at Florida Atlantic University and at Palm Beach Community College. Most participants (16/17) were born in a Spanish-speaking country. They moved to the US between the ages of 4–56 (mean: 22 years, 11 months), they mostly acquired English later in life (Mean = 11 years 6 months; range 6–36 years) and most (13/17) reported to speak Spanish at home.¹ In this and subsequent experiments, participants received either course credit or a \$5 gift-card for their participation.

Materials. The experimental materials consisted of the 90 monosyllabic non-words and their disyllabic counterparts used in previous research with English (Berent et al., 2007) and Korean (Berent et al., 2008) speakers. The monosyllabic items were $C_1C_2VC_3$ non-words arranged in 30 triplets (see Appendix for a list of experimental stimuli). Most (25/30) triplet members shared their rhyme and differed only on the sonority structure of their onset. One member of a triplet manifested a small rise in sonority (mostly obstruent-nasal combinations, e.g., *bnif*), a second had a sonority plateau (obstruent-obstruent sequences, e.g., *bdif*), and a third member had a fall in sonority (sonorant-obstruent sequences, e.g., *lbif*). All three members of the triplet were unattested in Spanish. Disyllabic items differed from their monosyllabic counterparts only on the presence of an epenthetic schwa between the onset consonants (e.g., *benif*, *bedif*, *lebif*).

As in our previous research (Berent et al., 2007), the experiment also included a set of 30 monosyllabic filler items and their disyllabic counterparts. These monosyllabic items had onsets with a large sonority rise (either obstruent-liquid or obstruent-glide sequences, e.g., *blif*), onsets that are attested in Spanish. These items were included in order to increase the overall similarity of the items to Spanish words. Responses to these items were removed from all analyses.

The materials were presented aurally. They were recorded by a Russian speaker who produced all items naturally (Russian allows all four types of onset clusters, for further information, see Berent et al., 2007).

Procedure. Participants were seated in front of a computer wearing headphones. The trial began with a fixation point (*) and a message indicating the trial number. Participants initiated the trial by pressing the space-bar key, triggering the presentation of a single auditory item. They were instructed to indicate as quickly and accurately as possible whether the item included one syllable or two by pressing one of two keys (1 = one syllable, 2 = two syllables). Response time was measured from the onset of the auditory stimulus. Prior to the experiment, participants were familiarized to the procedure with a brief practice session including real Spanish words (e.g., *flan* — *filón*). The order of trials was randomized. In this and all subsequent experiments, the instructions to the participants were presented in Spanish. Participants were tested in groups of up to three participants at a time.

Results

In this and all subsequent experiments, we excluded outliers (correct responses falling 2.5SD beyond the grand mean, less than 4% of the total correct responses) from the analyses of response time. Mean response accuracy and response time as a function of onset type and the number of syllables is provided in Figure 1.

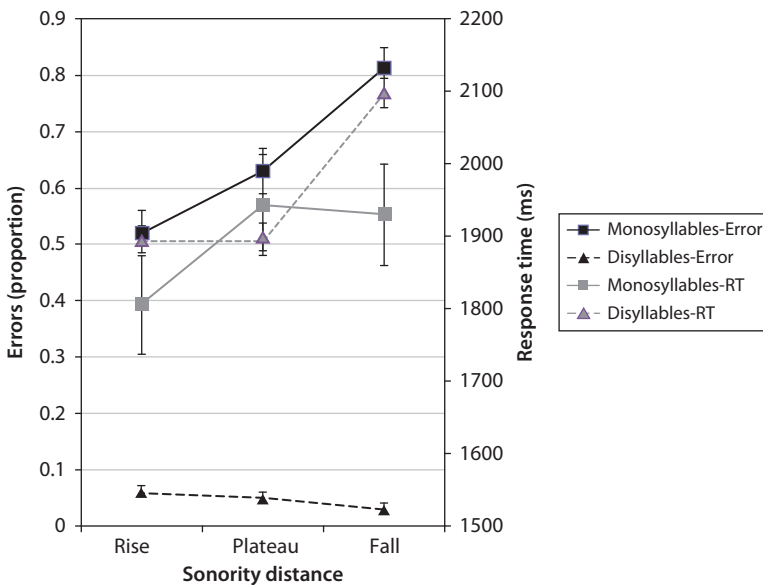


Figure 1. Mean error rate and response time in the syllable count task as a function of the number of syllables (one vs. two) and onset type (Experiment 1). Error bars are confidence intervals constructed for the difference between the means.

We first assessed the effect of onset type on response accuracy and response time to monosyllabic and disyllabic items using a 3 Type x 2 Syllable ANOVAs using both participants (F_1) and items (F_2) as random variables. The interaction was significant in the analysis of response accuracy ($F_1(2, 32) = 24.49$, $MSE = 0.009$, $p < 0.0001$, $\eta^2 = .61$; $F_2(2, 58) = 12.17$, $MSE = 0.0321$, $p < 0.0001$, $\eta^2 = .29$) and marginally significant in the analyses of response time ($F_1(2, 30) = 1.15$, $MSE = 24,122$, $p < 0.34$, $\eta^2 = .07$; $F_2(2, 46) = 3.54$, $MSE = 45,078$, $p < .04$, $\eta^2 = .13$). We thus proceeded to test the effect of onset type separately, for monosyllabic and disyllabic items.

An inspection of the means suggests that participants were sensitive to the structure of monosyllabic items. As sonority distance decreased, response accuracy to monosyllabic items decreased. A one way ANOVA indeed yielded a significant effect of onset type in the analysis of response accuracy ($F_1(2, 32) = 23.19$, $MSE = .016$, $p < .0002$, $\eta^2 = .59$; $F_2(2, 58) = 10.93$, $MSE = .06$, $p < .0002$, $\eta^2 = .27$); in response time: ($F_1(2, 30) = 2.12$, $MSE = 42,273$, $p < .14$, $\eta^2 = .12$; $F_2(2, 46) = 4.12$, $MSE = 79,393$, $p < .03$, $\eta^2 = .15$).² Planned contrasts comparing responses to monosyllabic items showed that sonority rises produced more accurate responses than plateaus, an effect significant by participants and marginally significant by items ($t_1(32) = 2.61$, $p < .02$; $t_2(58) = 1.78$, $p < .09$). Sonority plateaus, in turn, yielded reliably more accurate responses than sonority falls ($t_1(32) = 4.14$, $p < .003$; $t_2(58) = 2.85$, $p < .007$). Likewise, sonority rises produced reliably more accurate responses than falls ($t_1(32) = 6.75$, $p < .0001$; $t_2(58) = 4.63$, $p < .001$).

Turning to the disyllabic forms, an inspection of the means suggested that response accuracy was inversely related to the sonority distance of the monosyllabic counterpart. A one way ANOVA yielded a marginally significant effect of onset type in the analysis of response accuracy ($F_1(2, 32) = 2.97$, $MSE = .001$, $p < .07$, $\eta^2 = .16$; $F_2(2, 58) = 1.52$, $MSE = .004$, $p < .23$, $\eta^2 = .05$); In response time: $F_1(2, 32) = 1.3$, $MSE = 3,354$, $p < .29$, $\eta^2 = .07$; $F_2(2, 58) < 1$, $MSE = 10,187$, $\eta^2 = .03$). Planned comparisons showed that responses to the disyllabic counterparts of sonority falls were more accurate relative to the counterparts of rises, an effect significant by participants ($t_1(32) = 2.43$, $p < .03$; $t_2(58) = 1.74$, $p < .09$). No other contrast was significant (all $p > .22$).

Discussion

The results of Experiment 1 show that Spanish speakers are sensitive to the structure of onsets that are unattested in their language. As sonority distance decreased, participants were more likely to misperceive monosyllabic items as disyllabic. In fact, Spanish speakers were reliably more likely to categorize these ill-formed monosyllabic items as disyllabic compared to chance level ($M = .50$, for sonority

plateaus $t1(16) = 2.19, p < .05$; $t2(29) = 4.18, p < .003$; for sonority falls $t1(16) = 9.77, p < .0002$; $t2(29) = 8.44, p < .0002$). It is unlikely that the misperception of monosyllabic items is due to stimuli artifacts. Previous research (Berent et al., 2007) has shown that Russian speakers, whose language allows all these sonority profiles, did perceive these items as monosyllabic on over 90% of the trials. The tendency of Spanish speakers to misperceive ill-formed monosyllables as disyllabic must therefore reflect linguistic biases — either phonological or phonetic — against onsets with small sonority distances.

The structure of the monosyllabic form also affected the processing of their disyllabic counterparts. Disyllabic forms whose counterparts had sonority falls (e.g., *lebif*, counterpart of *lbif*) produced higher accuracy than those whose counterparts were rising in sonority (e.g., *benif*, counterpart of *bnif*). Although this trend was significant only across participants, it agrees with previous results with English, Russian (Berent et al., 2007) and Korean (Berent et al., 2008) participants. Such difficulty likely reflects competition from the monosyllabic counterpart. Indeed, the forced-choice syllable count requires that participants discriminate the disyllabic input from the monosyllabic alternative. In this situation, people's certainty about their percept might depend on the structure of the monosyllabic alternative. If well-formed onsets of rising sonority are linguistically preferred, they might present a stronger contender, and consequently, participants might occasionally opt for the incorrect monosyllabic form. Taken together, then, the responses to monosyllables and disyllables suggest that Spanish speakers are sensitive to the onset hierarchy: onsets that are dispreferred across languages tend to be misidentified by individual speakers.

Experiment 2

Experiment 1 shows that, like English speakers, Spanish participants perceptually repair monosyllabic forms with illicit onsets as disyllabic. However, these results do not determine the precise nature of such repair. Previous research suggests that English speakers misperceive marked onsets epenthetically (e.g., *lbif* → *lebif*; Berent et al., 2007). Although epenthetic repair is also attested in Spanish (e.g., Harris, 1987), prothesis is frequently used, especially in the borrowing of *s*-initial onset clusters into Spanish (Altenberg, 2005; Harris, 1983; Hooper, 1976).

Experiment 2 reexamines the sensitivity of Spanish speakers to sonority distance and evaluates the role of epenthesis in their repair. To this end, this experiment employs an AX task. Participants are presented with a pair of auditory stimuli, either identical (e.g., *bnif*-*bnif*; *benif*-*benif*) or epenthetically-related (e.g., *bnif*-*benif*), and they are asked to indicate whether the two items are identical.

Our main interest is in responses to non-identical items. If Spanish speakers repair onsets with small sonority distances by epenthesis, then, as sonority distance decreases, people should be more likely to misperceive monosyllabic forms as identical to their epenthetic counterparts. If, however, Spanish speakers rely on prothesis, then, these repaired forms (e.g., *lbif*, represented as *elbif*) should be quite distinct from the epenthetic inputs (e.g., from *lebif*). Accordingly, despite their disyllabic misperception (in Experiment 1), ill-formed monosyllables may not be misperceived as identical to their epenthetic counterparts.

Method

Participants. Twenty native Spanish speakers participated in the experiment. Participants were students at Florida Atlantic University, Davie. All participants reported Spanish to be their native language. Most (12/20) participants were born in a Spanish-speaking country and moved to the US between the ages of 2–39 (Mean: 9 years 10 months); most have not been unexposed to English before the age 5 (26/20, mean age of English acquisition = 9 years 7 months); most participants (13/20) reported to speak Spanish at home, and five of which were lived in Spanish-English bilingual households.

Materials. The materials consisted of the same set of items used in Experiment 1. The materials were arranged in pairs; half comprised of identical tokens (either monosyllabic or disyllabic, e.g., *bnif-bnif*, *benif-benif*), half were epenthetically-related (e.g., *bnif-benif* in either order). The materials were arranged in two lists, matched for the number of stimuli per condition (onset type x identity x order) and counterbalanced, such that, within a list, each item appeared in either the identity or the non-identity condition but not both. Each participant was assigned to one list. The order of the trials within a list was random.

Procedure. Participants were seated in a front of computer wearing headphones. Each trial began with a fixation point (*) and a message indicating the trial number. Participants initiated the trial by pressing the space bar, triggering the presentation of two consecutive auditory items (an onset asynchrony of 1500 ms). Participants determined whether the two items were identical by pressing the numeric keypad (1 = identical, 2 = not identical). Slow responses (response time > 2500 ms) triggered a computerized warning (e.g., “TOO SLOW”). Response time was measured from the onset of the second auditory stimulus. Prior to the experiment, participants were familiarized to the procedure with a brief practice session including real Spanish words (e.g., *flan-flan*; *flan-filón*).

Results and discussion

An inspection of the responses to identity trials suggests that responses were generally fast ($M=939$ ms, $SD=139$) and accurate ($M=.96$, $SD=.051$). Our main interest is in responses to non-identity trials. Response time and response accuracy to such trials are presented in Figure 2.

A one way ANOVA yielded a significant effect of onset type in the analysis of response accuracy ($F(2, 38)=19.88$, $MSE=.014$, $p<.0001$, $\eta^2=.50$, 1; $F(2, 58)=6.63$, $MSE=.06$, $p<.003$, $\eta^2=.19$) and response time ($F(2, 38)=7.39$, $MSE=9413$, $p<.002$, $\eta^2=.28$; $F(2, 52)=7.54$, $MSE=15630$, $p<.002$, $\eta^2=.22$).³ Planned comparisons showed that responses to sonority rises were significantly more accurate ($t(38)=5.54$, $p<.001$; $t(58)=3.26$, $p<.002$) and faster ($t(38)=3.84$, $p<.0005$ $t(52)=3.91$, $p<.0002$) relative to plateaus. Responses to sonority rises were likewise more accurate compared to sonority falls ($t(38)=5.16$, $p<.0001$; $t(58)=3.04$, $p<.004$; in response time: ($t(38)=1.94$, $p<.06$; $t(52)=1.09$, $p<.29$, n.s.). Remarkably, the most ill-formed onsets of falling sonority were in fact easier to identify than sonority plateaus, a trend that approached significance in response time, $t(38)=1.91$, $p<.07$; $t(52)=2.87$, $p<.006$ (in response accuracy both $t<1$).

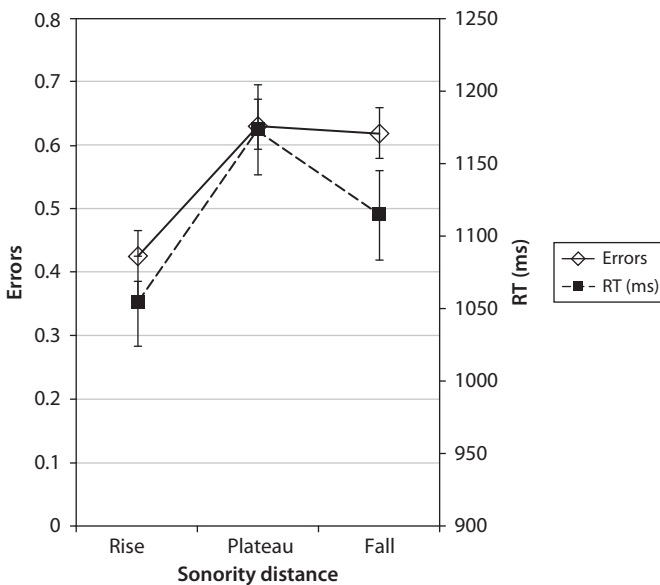


Figure 2. Mean error rate and response time in the identity judgment task as a function of onset type (Experiment 2). Error bars are confidence intervals constructed for the difference between the means.

This nonlinear effect of onset structure is puzzling. Why do Spanish speakers misidentify sonority falls as disyllabic (in Experiment 1), but they do not consider them identical to their disyllabic counterparts (in Experiment 2)?

The answer, we suggest, is that Spanish speakers repair these monosyllables by means of prothesis (e.g., *lbif*→*elbif*), rather than epenthesis (e.g., *lbif*→*lebif*). Because these repairs are still disyllabic, participants in Experiment 1 did identify these inputs as disyllabic. But since these recoded forms (e.g., *elbif*) differ substantially from the epenthetic inputs in Experiment 2 (e.g., *lebif*), participants in the AX task did not confuse those recoded forms with the epenthetic input. The possibility that Spanish speakers rely on prothetic repair is indeed consistent with the documentation of such repairs in loanword adaptation and in experimental studies (Harris, 1987; Altenberg, 2005; Halle et al., 2008; Harris, 1983; Hooper, 1976). Moreover, the prothetic repair of sonority falls, specifically, has clear linguistic motivation, to be reviewed in the General Discussion. Before considering why sonority falls might be recoded prothetically, however, we must first provide direct evidence that Spanish speakers do, in fact, rely on such repairs. Experiments 3–4 evaluate this hypothesis.

Experiment 3

Experiment 3 examines the role of prothetic repair in the representation of marked onsets. To this end, we repeat the AX procedure of Experiment 2 with one significant modification. Rather than comparing the monosyllables to epenthetic disyllables (e.g., *lbif*-*lebif*), we now pair them with their prothetic counterparts (e.g., *lbif*-*elbif*). If ill-formed onsets are repaired by prothesis, then these monosyllable should be highly confusable with their prothetic counterparts. Consequently, as sonority distance decreases, non-identity trials in Experiment 3 should elicit more errors and slower correct responses.

Method

Participants. Twenty-four native Spanish speakers, students at Florida Atlantic University, participated in the experiment. All participants reported that Spanish was their first language, most participants (18/24) were born in a Spanish-speaking country and moved to the US between the ages of 1–41 (Mean = 12 years 6 months), and they acquired English between the ages of 3–28 years (Mean = 10 years). Thirteen participants reported to speak only Spanish at home; seven had bilingual (English-Spanish) households, three spoke only English at home, and one participant did not disclose this information.

Materials. The materials corresponded to the same monosyllabic non-words used in Experiments 1–2 along with their prosthetic counterparts. All items were newly recorded by the same Russian talker employed in previous experiments. The structure of the materials and experimental lists was the same as in Experiment 2, except that disyllables and monosyllables were now prosthetically related. Procedure was as in Experiment 2.

Results

As in Experiment 2, responses to identity trials in the present experiment were overall fast ($M=928$ ms, $SD=143$ ms) and accurate ($M=.93$, $SD=.10$). Our main interest concerns responses to non-identity trials — trials in which the monosyllable is paired with its prosthetic counterpart. Those means are provided in Figure 3.

One-way ANOVAs yielded a reliable main effect of onset type in both response accuracy ($F(2, 38)=130.61$, $MSE=.013$, $p<.0001$, $\eta^2=.70$; $F(2, 58)=226.73$, $MSE=.011$, $p<.0001$, $\eta^2=.87$) and response time ($F(2, 38)=14.96$, $MSE=7854$, $p<.0002$, $\eta^2=.31$; $F(2, 54)=12.4$, $MSE=15397$, $p<.0004$, $\eta^2=.31$).⁴ An inspection of the means suggests that, this time, responses were monotonically linked

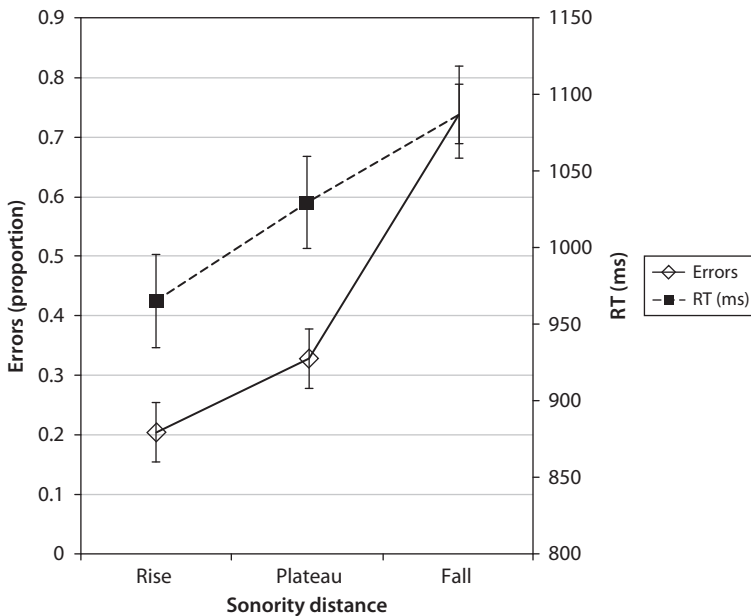


Figure 3. Mean error rate and response time in the identity judgment task as a function of onset type (Experiment 3). Error bars are confidence intervals constructed for the difference between the means.

to sonority distance: As sonority distance decreased, the rate of errors increased, and correct responses became slower. Planned contrasts confirmed that onsets of rising sonority indeed yielded significantly more accurate responses compared to plateaus ($t1(38)=5.12, p<.0001$; $t2(58)=6.75, p<.0001$); In response time: $t1(38)=1.49, p<.15$; $t2(58)=1.68, p<.10, n.s.$). Sonority rises likewise yielded reliably faster ($t1(38)=5.32, p<.0001$; $t2(58)=5.06, p<.0001$) and more accurate ($t1(38)=16.22, p<.0001$; $t2(58)=20.87, p<.0001$) responses compared to sonority falls. Crucially, responses to onsets of level sonority were now faster ($t1(38)=3.82, p<.0005$; $t2(58)=3.38, p<.002$) and more accurate ($t1(38)=11.10, p<.0001$; $t2(58)=14.11, p<.00001$) compared to sonority falls.

Discussion

Experiment 3 demonstrates that the ability of Spanish speakers to distinguish monosyllables from their prothetic counterparts depends on their sonority distance: As sonority distance decreases, errors and response time increase. The contrast between the monotonic effect of onset structure, in the present experiment, and the nonlinear pattern, observed in Experiment 2 suggests that the choice of repair might be modulated by the structure of the onset: Better-formed onsets of rising and level sonority might be repaired by either epenthesis or prothesis, and for this reason, the moderately ill-formed onsets of level sonority are harder to identify than sonority rises, regardless of the choice of disyllabic counterpart — epenthesis (in Experiment 2) or prothesis (in Experiment 2). In contrast, highly ill-formed onsets of falling sonority might favor a prothetic repair, and consequently, monosyllables of falling sonority are perceptually confused with disyllabic inputs only when those disyllables are paired with prothetic-related, but not with epenthetic ones. This nonlinear effect of onset type on the discrimination of monosyllables from their epenthetic counterparts also differs from previous results with English and Korean speakers (Berent et al., 2007; Berent et al., 2008), for whom the effect of onset was monotonically related to sonority distance. This contrast suggests that the preferred form of repair might be modulated by linguistic experience. In what follows, we evaluate these two possibilities.

a. The role of epenthetic vs. prothetic repair in Spanish

We first examined whether the reliance of Spanish speakers on epenthetic vs. prothetic repair depends on the structure of the onset. To this end, we examined the sensitivity of Spanish speakers (d') to onset structure across Experiments 2–3. We reasoned that the choice of repair should affect the discrimination of monosyllables from the disyllabic counterparts. Disyllables that match the preferred

form of repair should result in an attenuated sensitivity. For example, if *lbif* is repaired as *elbif*, then this monosyllable should be harder to discriminate from a prothetic counterpart (in Experiment 3) compared to an epenthetic disyllable (in Experiment 2). In contrast, if onsets of rising sonority favor epenthesis (e.g., *bnif*→*benif*), then those onsets should exhibit the opposite pattern (i.e., attenuated sensitivity with epenthetic compared to prothetic disyllables).

A 2 disyllable type x 3 onset type ANOVA yielded a reliable main effect of onset type ($F(2, 84)=45.13$, $MSE=0.288$, $p<.0001$, $\eta^2=.52$; $F(2, 56)=45.02$, $MSE=0.392$, $p<.0001$, $\eta^2=.75$), as well as a significant disyllable x onset type interaction ($F(2, 84)=21.19$, $MSE=0.288$, $p<.0001$, $\eta^2=.33$; $F(2, 56)=8.25$, $MSE=0.530$, $p<.0008$, $\eta^2=.23$). The means are provided in Figure 4.

Tests of the simple main effect of disyllable type demonstrated that prothetic disyllables yielded greater sensitivity than epenthesis for onsets of both rising ($F(1, 42)=7.47$, $MSE=.796$, $p<.01$, $\eta^2=.15$; $F(1, 28)=6.45$, $MSE=0.357$, $p<.02$, $\eta^2=.19$) and level sonority ($F(1, 42)=6.58$, $MSE=0.5799$, $p<.02$, $\eta^2=.14$; $F(1, 28)=9.22$, $MSE=0.454$, $p<.005$, $\eta^2=.25$). In contrast, the worst-formed onsets of falling sonority produced greater sensitivity with epenthesis than prothesis ($F(1, 42)=10.91$, $MSE=0.390$, $p<.002$, $\eta^2=.21$; $F(1, 28)=5.72$, $MSE=0.570$, $p<.002$, $\eta^2=.17$). Assuming that discrimination reflects the degree of similarity with the repaired form, the results thus imply that Spanish speakers repair better-formed onsets epenthetically, whereas the worst formed onsets of falling sonority are re-coded prothetically.

Each of these repair reflexes, however, is sensitive to the structure of the onset. To further support this conclusion, we next evaluated the effect of onset type on sensitivity of discrimination with epenthetic and prothetic onsets, separately. The main effect of onset type was significant for both the epenthetic ($F(2, 38)=11.34$, $MSE=0.148$, $p<.0002$, $\eta^2=.38$; $F(2, 56)=6.99$, $MSE=0.639$, $p<.002$, $\eta^2=.20$) and prothetic conditions ($F(2, 46)=47.09$, $MSE=.403$, $p<.0001$, $\eta^2=.67$; $F(2, 56)=62.08$, $MSE=0.287$, $p<.0001$, $\eta^2=.69$). Planned contrasts showed that onsets of rising sonority yielded reliably higher sensitivity regardless of the disyllabic counterparts. Specifically, when compared to epenthetic disyllables, sonority rises produced higher sensitivity than either plateaus ($t(38)=4.62$, $p<.0001$; $t(56)=3.31$, $p<.002$) or falls ($t(46)=3.32$, $p<.002$; $t(56)=3.16$, $p<.003$). Similarly, sonority rises produced higher sensitivity than plateaus ($t(46)=3.87$, $p<.0004$; $t(56)=3.97$, $p<.0003$) and falls ($t(46)=9.64$, $p<.0001$; $t(56)=11.00$, $p<.0001$) when compared to prothetic disyllables. Moreover, the prothetic condition further yielded higher sensitivity to onsets of level sonority compared to falls ($t(46)=5.77$, $p<.0001$; $t(56)=7.03$, $p<.0001$; for the epenthetic condition: $t(38)=1.29$, $p<.21$; $t(56)<1$, n.s.). These results confirm that ill-formed onsets acquire multiple forms of disyllabic repairs, but, taken as a whole, the repair of

such onsets is systematically linked to their sonority profile: as sonority distance decreases, disyllabic repair is more likely.

b. The effect of linguistic experience on repair

The previous analyses make it clear that Spanish speakers are more likely to rely on prothesis in the repair of sonority falls, and for this reason, they are faster to distinguish onsets of falling sonority counterparts (in Experiment 2). These results contrast with findings from English participants (Berent et al., 2007). Unlike their Spanish counterparts, English speakers took longer to distinguish monosyllables of falling sonority from their epenthetic counterparts compared to sonority plateaus. These divergent patterns suggest that the preferred form of repair might be modulated by linguistic experience. We evaluated this possibility in two ways. First, we compared the performance of our Spanish participants as a group to English speakers. We next moved to a more fine-grained analysis of the group of Spanish participants by gauging whether their experience with English as a second language affected their repair preferences.

i. Spanish- vs. English-speaking participants. To evaluate the role of linguistic experience on the mode of repair, we compared the sensitivity (d') of Spanish participants with each form of repair to that of English participants. For the analysis of epenthesis, we compared the Spanish results (from Experiment 2) to our previous published data with English participants (Berent et al., 2007; Experiment 3). For prothesis, we compared the Spanish results (from Experiment 3) to a new group of 24 native English speakers, students at Florida Atlantic University, who were tested using the same materials and procedure employed with Spanish participants.

We next assessed the role of language experience by means of 2 language \times 3 onset type ANOVAs, performed separately for epenthesis and prothesis. Our interest here specifically concerns the effects involving the language factor. The analysis of epenthetic repairs yielded a reliable interaction ($F(2, 96) = 7.51$, $MSE = .145$, $p < .001$, $\eta^2 = .14$; $F(2, 56) = 5.63$, $MSE = .18$, $p < .006$, $\eta^2 = .17$). An inspection of the means (see Figure 4) suggested that English speakers were more sensitive than their Spanish counterparts to the epenthetic repair of onsets of rising sonority. Tests of the simple main effects of language suggested that the sensitivity of English participants was reliably higher than Spanish speakers for onsets of rising sonority ($F(1, 48) = 7.60$, $MSE = .234$, $p < .009$, $\eta^2 = .14$; $F(1, 28) = 10.86$, $MSE = .21$, $p < .003$, $\eta^2 = .28$), but the two groups did not reliably differ for sonority plateaus and falls (all $F < 1$). Similar ANOVAs conducted on prothetic repair did not yield a reliable main effect ($F(1, 48) < 1$; $F(1, 28) = 4.82$, $MSE = .416$, $p < .04$, $\eta^2 = .15$) or interaction (both $F < 1$) involving the language factor. While language does not seem to systematically

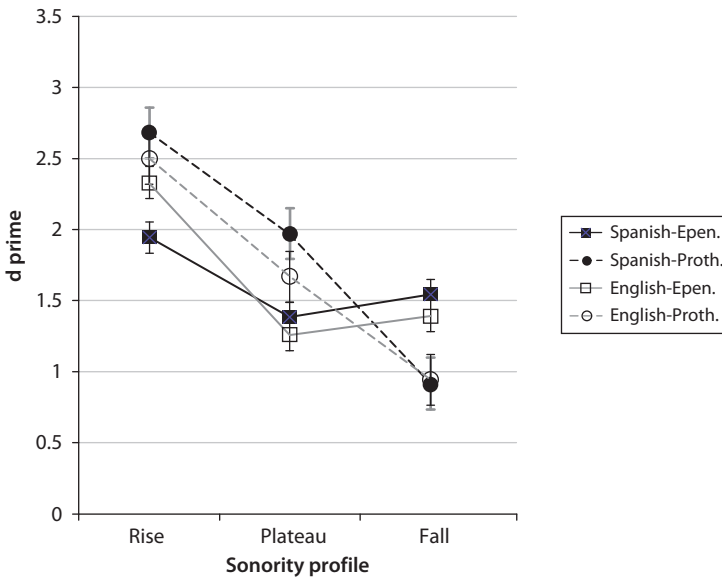


Figure 4. The sensitivity (d') of Spanish and English speakers as a function of onset type and the type of the disyllabic counterpart (epenthetic vs. prothetic). Error bars are confidence intervals constructed for the difference between the means. Note: Epen = epenthesis; Proth = prothesis

modulate the reliance on prothetic repair, it does affect the use of epenthesis. Spanish speakers are selectively more likely to employ epenthesis in the repair of onsets of rising sonority, but for smaller sonority distances, both groups favor prothetic repair. If this explanation is correct, then it is conceivable that the reliance of Spanish participants on epenthesis as a repair mechanism could be also modulated by their exposure to English as a second language. The next set of analysis addresses this possibility.

- ii. *The role of L2 English experience on the mode of repair by Spanish speaking participants.* To determine whether experience with English as a second language modulates the reliance on epenthesis, we next performed a median split of participants in Experiments 2–3 according to their age of their arrival at the US — a proxy of their experience with English as a second language. The mean age of arrival at the US for late vs. early English learners was 19.6 ($SD=7.42$) and 0.2 ($SD=0.63$) years in Experiment 2, and 21.09 ($SD=9.29$) vs. 2.86 ($SD=4.21$) in Experiment 3.⁵ We next examined whether experience with English as a second language modulated the effect of onset structure in the two experiments.

Table 1. The sensitivity (d') of late- vs. early Spanish learners to onset structure when compared to epenthetic vs. prothetic disyllables.

		Mean			SD		
		Rise	Plateau	Fall	Rise	Plateau	Fall
Epenthesis (Experiment 2)	Late English learners	1.96	1.30	1.63	0.33	0.32	0.62
	Early English learners	1.92	1.45	1.45	0.64	0.55	0.48
Prothesis (Experiment 3)	Late English learners	2.96	2.46	1.03	1.00	0.68	0.63
	Early English learners	2.56	1.66	0.79	1.26	0.99	0.68

A 2 group x 3 onset type ANOVAs examining the sensitivity (d') to monosyllables as compared with their prothetic counterparts (in Experiment 3, see Table 1) found no significant effect of group ($F(1, 20) = 2.29$, $MSE = 1.64$, $p > .15$, $\eta^2 = .10$) and no evidence of an interaction ($F(2, 40) = 1.17$, $MSE = .401$, $p > .32$, $\eta^2 = .055$). There were also no such effects in response time to either identical (for effect of group: $F(1, 20) < 1$, $\eta^2 = .0006$; for the interaction: $F(2, 40) = 1.43$, $MSE = 3267$, $p > .25$, $\eta^2 = .07$) or nonidentical trials (for the effect of group: $F(1, 20) < 1$, $\eta^2 = .01$; for the interaction: $F(2, 40) < 1$, $\eta^2 = .04$), suggesting that reliance on prothesis was unaffected by experience with English as a second language. This conclusion is in line with the omnibus group comparison of English and Spanish participants, where both groups did not differ on their reliance on prothetic repair. In contrast, linguistic experience with English reliably modulated the ability of Spanish speakers to discriminate monosyllables from their epenthetic repairs in Experiment 2. The group x onset type interaction was significant in for the analysis of response time to nonidentical trials ($F(2, 36) = 3.42$, $MSE = 8350$, $p < .05$, $\eta^2 = .16$; for identity trials: $F(2, 36) < 1$, $\eta^2 = .05$) and similar effects were also found in response accuracy ($F(2, 36) = 3.59$, $MSE = .012$, $p < .04$, $\eta^2 = .17$; for sensitivity: $F(2, 36) < 1$, $\eta^2 = .05$).

An inspection of the means (see Figure 5) suggested that Spanish speakers with early vs. late exposure to English displayed similar patterns in response to onsets of rising and level sonority, but the two groups differed with respect to sonority falls. Planned comparisons demonstrated that late English learners were faster ($t(36) = 2.40$, $p < .03$) and more accurate ($t(36) = 2.80$, $p < .009$) to distinguish monosyllables of falling sonority from their epenthetic counterparts. The two groups did not differ reliably in their responses to the better formed onsets — both sonority rises ($t(36) = 1.05$, $p > .30$; $t(36) < 1$, for response time and accuracy, respectively) and plateaus ($t(36) < 1$; for both response time and accuracy). An easier

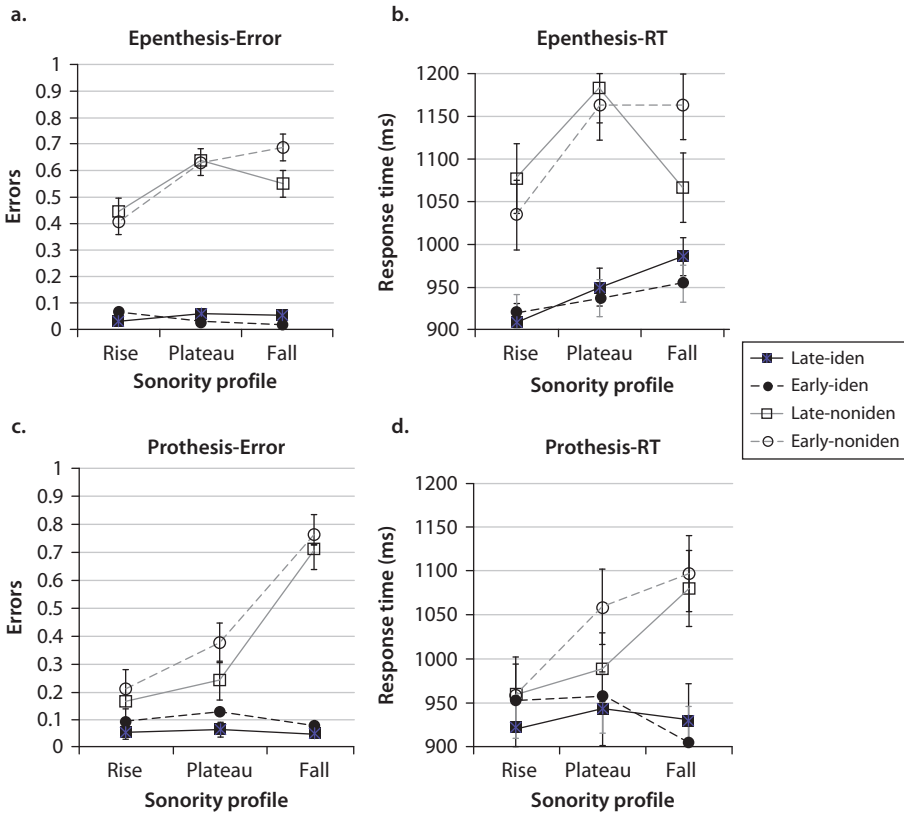


Figure 5. The effect of sonority distance and experience with English as a second language on the ability of Spanish speakers to discriminate monosyllables from their epenthetic and prothetic counterparts. Error bars are confidence intervals constructed for the difference between the means. Note: Late vs. Early indicates the age of arrival of participants in the US; iden = identity; noniden = nonidentity.

discrimination of onsets of falling sonority from their epenthetic counterparts indicates that such onsets are not repaired using epenthesis. These results thus converge with the overall group comparisons to suggest that linguistic experience modulates the repair of onsets of falling sonority — by prothesis or epenthesis. While all participants employed prothetic repair, irrespective of their linguistic experience, reliance on epenthesis in the repair of onsets of falling sonority is only found in participants with early exposure to English — either native English speakers, or Spanish speakers with an early experience with English as a second language. Absent early experience with English, however, Spanish speakers easily discriminated onsets of falling sonority from their epenthetic counterparts, suggesting that the preferred repair of such onsets is prothesis, rather than epenthesis.

Experiment 4

The results of the AX identity task in Experiments 2–3 suggest that, although the method of repair employed by Spanish speakers is modulated by linguistic experience, its rate is related to the structure of the onset. While this task presents a strong on-line demonstration that ill-formed monosyllables are misidentified, it provides only a partial assessment of the range of repairs used by any given participant — it does not assess the role of monosyllabic repairs nor does it directly compare the rate of various types of disyllabic repair (prothesis and epenthesis). To obtain a broader evaluation of speakers' repair strategies, Experiment 4 examines the representation of these onsets using an open-ended spelling task. In each trial, Spanish participants are presented with a single auditory item and are asked to spell it using conventional Spanish orthography. Two questions are of interest: (a) Are ill-formed onsets with small sonority distances less likely to be perceived faithfully than better-formed onsets? (b) When an onset is misperceived, how is it repaired in perception?

The spelling task allows us to assess both issues. The first issue — the effect of onset structure on faithful encoding can be addressed by examining correct spelling responses. If onsets with small sonority distances are misperceived, then as sonority distance decreases, the rate of correct (faithful) responses should decrease. The nature of the errors can directly illuminate the repairs of such onsets. In accord with the findings of Experiments 1–3, we expect onsets with small sonority distances to elicit disyllabic responses. Moreover, the preferred method of disyllabic repair should depend on sonority distance: moderately ill-formed onsets of rising and level sonority should favor an epenthetic response, whereas highly ill-formed onsets of falling sonority should elicit prothesis.

Method

Participants. Twenty native Spanish speakers participated in the experiment. Most participants (15/20) were born in a Spanish-speaking country and moved to the US between the ages of 1–18 (Mean = 7 years 4 months) and they acquired English between the ages of 3–18 years (Mean = 7 years 10 months). All participants reported to speak Spanish at home (one lived in a bilingual household).

Materials. The materials corresponded to the 90 monosyllabic non-words used in Experiments 1–2. The items were arranged in two randomized lists, presented in a fixed order. Each participant was assigned to one list.

Data scoring. Correct responses were responses that correctly preserved the onset (changes to the rhyme were not scored as errors). Errors in the report of the onsets were next coded as Monosyllabic responses (either CCVC or CVC

responses), Epenthesis (e.g., *lbif*→*lebif*) Prothesis (e.g., *lbif*→*elbif*) and others (mostly lexicalization, as well as no responses and radical changes to the input). The data were scored by both a native Spanish and a native English speaker, and all disagreements were resolved by discussion.

Procedure. Participants were seated in front of a computer wearing headphones. Each trial began with a message indicating the trial number. Participants initiated the trial by pressing the spacebar, triggering the presentation of a single auditory stimulus. They were instructed to transcribe the stimulus using conventional Spanish orthography. Prior to the experiment, participants were familiarized to the procedure with a brief practice session in which they were asked to spell real Spanish words (e.g., *tren*, *flan*).

Results

To assess the sensitivity of Spanish speakers to the structure of unattested onsets, we examined the effect of onset type on both correct responses and errors. The means are provided in Figure 6.

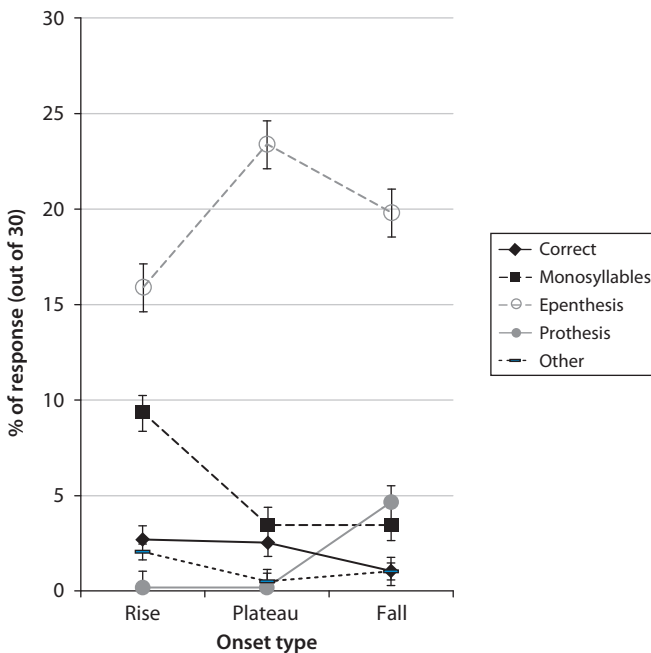


Figure 6. The number of correct responses and error types in the spelling task as a function of onset type (Experiment 4). Error bars are confidence intervals constructed for the difference between the means.

The rate of correct responses was highly sensitive to onset type ($F(2, 38) = 3.26$, $MSE = 4.97$, $p < .05$, $\eta^2 = .15$; $F(2, 58) = 5.74$, $MSE = 1.65$, $p < .006$, $\eta^2 = .17$). As the sonority distance of the onset decreased, response accuracy decreased. Planned comparisons showed that participants responded more accurately to onsets of rising sonority compared to falls ($t(38) = 2.34$, $p < .03$; $t(58) = 3.11$, $p < .003$). Likewise, onsets of level sonority produced significantly more accurate responses compared to falls ($t(38) = 2.06$, $p < .05$; $t(58) = 2.71$, $p < .009$). Although the accuracy to onsets of rising sonority was numerically higher than to plateaus, the difference was not statistically significant (both $t < 1$).

We next turned to evaluate several categories of erroneous responses.

Monosyllabic responses were highly sensitive to onset type: As the sonority distance decreased, participants were less likely to produce a monosyllabic form ($F(2, 38) = 26.04$, $MSE = 8.61$, $p < .0002$, $\eta^2 = .58$; $F(2, 58) = 6.78$, $MSE = 21.87$, $p < .003$, $\eta^2 = .29$). Specifically, sonority rises were more likely to produce monosyllabic responses than plateaus ($t(38) = 6.30$, $p < .0001$; $t(58) = 3.22$, $p < .003$) and falls ($t(38) = 6.19$, $p < .0001$; $t(58) = 3.14$, $p < .003$), which, in turn, did not differ on the rate of monosyllabic responses (both $t < 1$).

The structure of the onset also affected the rate of "other responses" ($F(2, 38) = 6.46$, $MSE = 1.94$, $p < .004$, $\eta^2 = .25$; $F(2, 58) = 2.81$, $MSE = 2.96$, $p < .07$, $\eta^2 = .09$). Because this category consisted primarily of lexicalizations, one would expect such responses mostly with targets of rising sonority. Indeed, sonority rises were significantly more likely to produce such errors relative to plateaus ($t(38) = 3.52$, $p < .002$; $t(58) = 2.32$, $p < .03$) and marginally so relative to falls ($t(38) = 2.38$, $p < .03$; $t(58) = 1.57$, $p < .13$), which, in turn, did not differ (all $p > .27$).

Our main interest concerns the rate of disyllabic responses, specifically, epenthesis vs. prothesis. As expected, epenthesis was the most frequent form of repair. Indeed, epenthesis was virtually the only form of disyllabic repair for both rises and plateaus. Sonority falls, however, triggered a sudden increase in prothesis at the expense of epenthesis. To assess the tradeoff in the reliance on epenthesis vs. prothesis, we compared the effect of onset type on these two types of responses by means of a 2 way ANOVA (3 onset type x 2 repair (epenthesis vs. prothesis)). The interaction was highly significant ($F(2, 38) = 12.16$, $MSE = 16.21$, $p < .0001$, $\eta^2 = .31$; $F(2, 58) = 6.91$, $MSE = 19.17$, $p < .003$, $\eta^2 = .19$), and so were the simple main effects of onset type on both epenthesis ($F(2, 38) = 17.32$, $MSE = 16.25$, $p < .0001$, $\eta^2 = .95$; $F(2, 58) = 7.04$, $MSE = 26.64$, $p < .002$, $\eta^2 = .88$) and prothesis ($F(2, 38) = 15.24$, $MSE = 8.66$, $p < .0002$, $\eta^2 = .94$; $F(2, 58) = 19.51$, $MSE = 4.41$, $p < .0002$, $\eta^2 = .95$). Planned comparisons confirmed that people were more likely to engage in the epenthesis of plateaus relative to either rises ($t(38) = 5.88$, $p < .0001$; $t(58) = 3.75$, $p < .0005$) or falls ($t(38) = 2.75$, $p < .0009$; $t(58) = 1.83$, $p < .08$). In contrast, sonority falls triggered an increase in prothesis compared to both plateaus ($t(38) = 4.73$,

$p < .0001$; $t2(58) = 5.35$, $p < .0001$) and rises ($t1(38) = 4.84$, $p < .0001$; $t2(58) = 5.47$, $p < .0001$), which, in turn, did not differ (both $t < 1$).

The spelling results thus offer converging evidence for the sensitivity of Spanish speakers to the structure of unattested onsets: As sonority distance decreases, people were less likely to correctly report the onset cluster, and instead, they tended to misidentify the monosyllable as a disyllable. However, the precise disyllabic repair — epenthesis vs. prothesis — was affected by onset structure: onsets of falling sonority triggered prothesis, whereas better formed onsets of level sonority triggered epenthesis.⁶

General discussion

This research examines whether speakers of different languages manifest systematic, shared preferences concerning the structure of onset clusters that are unattested in their language. Typological research suggests that onsets with small sonority distances are dispreferred across languages. Specifically, small sonority rises, as in *bn* are preferred to plateaus, as in *bd*, which, in turn, are preferred to sonority falls, as in *lb* (Greenberg, 1978; Berent et al., 2007). Previous research has demonstrated that such preferences are available to English speakers despite the absence of all three onset types in their language (Berent et al., 2007; Berent et al., 2008). Here, we extend this investigation to speakers of Spanish — a language whose lexical inventory of onset clusters is smaller, and is less likely than English to yield unattested onsets due to vowel reduction in fast speech.

Despite their relatively limited experience with onset clusters, Spanish speakers in our experiments extended knowledge of the sonority hierarchy to onsets that are unattested in their language. Onsets with small sonority distances were more likely to be misperceived as disyllabic (in Experiment 1), less likely to be discriminated from their disyllabic counterparts (in Experiment 2–3) and to be represented faithfully (in Experiment 4). Spanish speakers, however, relied on distinct strategies in responding to such clusters. Onsets of rising and level sonority were typically repaired by epenthesis, but sonority falls were more likely to be repaired by prothesis. Moreover, the repair method of choice was modulated by linguistic experience. While Spanish and English participants both relied on prothesis, the use of epenthesis in repairing the worst-formed onsets of falling sonority was experience dependent. Participants who had early exposure to English (as either a first or early-acquired second language) employed epenthesis, whereas, absent such experience, Spanish speakers were resorted to prothesis. Thus, the choice of repair strategies is modulated by linguistic experience, but the pressures that elicit such repairs are common to those languages.

Why do Spanish speakers misperceive onsets with small sonority distances? One possibility is misperception reflects phonetic pressures. In this view, the phonetic form of onsets with small sonority distances is more similar to those of their disyllabic counterparts. Specifically, monosyllables with onsets of rising and level sonority might be phonetically similar to their epenthetic counterparts, whereas onsets with sonority falls might more readily resemble prothetically-related disyllables. Misidentification, in this view, reflects the confusion between these phonetic forms. An alternative explanation attributes misidentification to the phonological grammar. In this view, the grammar includes abstract algebraic constraints that ban small sonority distances. Misidentification, then, reflects the grammatical recording of ill-formed onsets as better-formed structures — a direct consequence of these grammatical pressures.

There is ample evidence that phonetic and phonological biases are both active in the identification of unattested onsets. A large body of phonetic literature shows that the repair of unattested onsets is affected by a host of phonetic cues, including the intensity and duration of the release burst associated with stop consonants and their prevoicing (Davidson, 2006; Kang, 2003; Wilson & Davidson, in press). While the role of such phonetic cues is undeniable, it is also clear that misidentification can emerge for purely phonological reasons. First, English speakers are demonstrably able to correctly encode the acoustic form of highly ill-formed onsets when attention to phonetic detail is encouraged. In fact, their encoding of ill-formed clusters is as accurate as better-formed ones (Berent et al., 2007, Experiments 5–6; Berent et al., 2012). Second, the dispreference of onsets with small sonority distances even affected the processing of their disyllabic counterparts: People are more accurate determining that *lebif* (counterpart of the highly ill-formed *lbif*) is disyllabic compared to *benif* (counterpart of the better-formed *bnif*), suggesting that the aversion to *lbif* affects processing even when it is not physically present (Berent et al., 2007; Berent et al., 2008). Finally similar errors are observed when the inputs are printed (Berent, 2008; Berent & Lennertz, 2010).

The phonological explanation can account not only for the rate of repair but also for its kind (see Table 2). Because each of these constraints violates structural restrictions on onset structure (i.e., sonority distance), these inputs cannot be represented faithfully, and consequently, the output must be repaired as some better-formed structure. The choice of the repair — epenthesis or prothesis — can be attributed to two distinct forces. One force — Contiguity — demands that elements that are contiguous in the input remain contiguous in the repaired formed (e.g., see McCarthy & Prince, 1993). Prothesis satisfies this demand because it alters syllable structure in a manner that maintains the consonant clusters adjacent in the output (e.g., *lbif* → *elbif*). The insertion of the prothetic vowel, however, yields a consonant cluster between syllables, and as such, this cluster is subject to a second

constraint on the co-occurrence of consonants across syllable boundaries. This constraint, Contact, favors a large fall in sonority between these consonants — the larger the fall, the better-formed is the onset (Gouskova, 2004). Table 2 shows how these constraints conspire to produce the observed pattern of repair. The three constraints are arrayed according to their ranking (highly ranked constraints are indicated on the left). The effect of those constraints is evaluated by comparing the optimality of various output candidates (i.e., representations) for a given input (listed in the top left corner). Constraint violation is indicated an asterisk — the higher ranked the constraint, the worse-formed is that output.

In the case of an input of falling sonority (e.g., *lbif*), the prothetic output will satisfy both the Contact low and Contiguity, and consequently, prothesis repair will be preferred to epenthesis, which violates contiguity (the preferred output is indicated by the pointed hand). But for larger sonority distances (e.g., sonority rises, *bnif*), the maintenance of consonant contiguity will violate the Contact constraint. Accordingly, all other things being equal, large sonority distance will favor epenthesis over prothesis, a prediction that is borne out by our results as well as typological evidence concerning loanword adaptation, reduplication, poetic alterations and puns (Fleischhacker, 2005). Nonetheless, these epenthetic repairs of large sonority distance come at the cost of violating Contiguity. The reliance on epenthesis vs. prothesis in repairing large sonority distances thus depends on the ranking of Contact relative to Contiguity, and this ranking could vary across languages. The finding that Spanish speakers show greater reliance on epenthetic repair than English participants could suggest that Contact is more highly ranked in their grammar.

Our present results, however, do not allow us to determine whether the misidentification we documented among Spanish participants is due to these

Table 2. The role of various phonological constraints in choosing the repair (epenthesis vs. prothesis) of onsets of falling vs. rising sonority.

Input = <i>lbif</i>	Onset structure	Contact	Contiguity
☞ <i>el.bif</i>			
<i>le.bif</i>			*
<i>lbif</i>	*		

Input = <i>bnif</i>	Onset structure	Contact	Contiguity
<i>eb.nif</i>		*	
☞ <i>be.nif</i>			*
<i>bnif</i>	*		

particular phonological constraints nor can it determine whether it generally originates from phonological or phonetic pressures. Another important question that is not addressed by the present results concerns the scope of the restrictions on onset structure. Because our experiments address the role of sonority distance with a single set of stimuli, we cannot presently determine whether the dislike of onsets such as *lba*, for instance, stems from properties of sonority falls, generally, or liquid-initial onsets, specifically (but see Berent et al., 2009, for comparable findings with sonority rises and falls that are al nasal-initial onsets). Finally, our findings leave open questions regarding the generality of these preferences across languages. Despite their limited experience with onset clusters, Spanish speakers clearly have ample familiarity with onset clusters. Accordingly, we are presently unable to rule out the possibility that the preferences documented here might be partly due to inductive learning from their linguistic experience (but see Berent et al., 2008 and Hayes, in press, for some empirical and computational challenges to an inductive approaches).

These limitations notwithstanding, the findings imply that Spanish speakers possess linguistic knowledge concerning onsets that are unattested in their languages, and this knowledge mirrors the distribution of the same onset across languages. These conclusions carry general implications to theories of both first- and second-language knowledge and acquisition. Much of the research on bilingualism, in general, and the acquisition of second languages by Spanish speakers, in particular, examines the role of speakers' first language in shaping the acquisition of the second (for review, see Eckman & Iverson, 1993; Sebastian-Galles & Bosch, 2005). Although the effect of linguistic experience is undeniable, our findings underscore the role of broad, possibly universal linguistic constraints on language acquisition, including second language acquisition (e.g., Broselow & Finer, 1991; Broselow, Chen, & Wang, 1998; Eckman, 2004; Pater, 1997). The challenge for future research is to define the relevant knowledge (phonological or phonetic) more precisely and explain how speakers of different languages converge on similar knowledge.

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Notes

1. The demographic information is not available for three participants in Experiment 1.

2. To assure that these results are not due to artifacts associated with binary data (Jaeger, 2008), we also submitted response accuracy data to a mixed effect logit model, conducted separately for monosyllables and disyllables. Each such analysis compared among subsequent sonority levels using helmert contrasts. Specifically, responses to sonority rises were compared to plateaus, and plateau and rises (averaged) were compared to falls. The analyses of the monosyllables confirmed that sonority rises produced reliably more accurate responses compared to onsets of level sonority, responses to onsets of falling sonority were reliably different than the better-formed onsets of rising and level sonority ($\beta = -0.31$, $SE = 0.07$, $z = -4.66$, $p = .0001$), and sonority rises and plateaus produced more accurate responses than sonority falls ($\beta = -0.47$, $SE = 0.046$, $z = -10.21$, $p = .0001$). Similar analyses conducted on responses to disyllables found that the counterparts of sonority falls produced reliably more accurate responses compared to the counterparts of rises and plateaus (combined) ($\beta = 0.21$, $SE = 0.095$, $z = 2.24$, $p = .03$), whereas these latter two types did not differ reliably ($\beta = 0.14$, $SE = 0.13$, $z = 1.06$, $p = .29$, n.s.).
3. A linear mixed effect analysis confirmed that sonority rises produced reliably more accurate responses compared to sonority plateaus ($\beta = -0.36$, $SE = 0.067$, $z = -5.35$, $p = 0.0001$), and sonority rises and plateaus (combined), in turn, produced reliably more accurate responses compared to sonority falls ($\beta = 0.82$, $SE = 0.04$, $z = -20.16$, $p = 0.00001$).
4. A linear mixed effect analysis confirmed that sonority rises produced reliably more accurate responses compared to sonority plateaus ($\beta = -0.50$, $SE = 0.063$, $z = -7.98$, $p = 0.0001$), and sonority rises and plateaus (combined), in turn, produced reliably more accurate responses compared to sonority falls ($\beta = -0.157$, $SE = 0.036$, $z = -4.31$, $p = 0.00001$).
5. Two participants were excluded from the analyses of Experiment because their age of arrival into the US was unknown.
6. Because most participants in this experiment arrived at the US in early childhood, and several (5/20) were born in the US, we were unable to effectively examine the effect of English exposure in this sample.

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Appendix

Small rise	Plateau	Fall
bwif	Bdif	lbif
bnap	bdap	rgap
knim	kpim	lpim
knek	kteg	rtek
dlif	dbif	rdif
dlaf	dgaf	rdaf
dmip	dgip	mdip
dmop	dgop	mdop
dnop	dbop	rdop
dnif	dgif	rbif
gmep	gdap	lgap
gman	gban	lfan
gmef	gbef	rgap

Small rise	Plateau	Fall
gmit	gbit	mgit
kmɛf	ktef	lkef
kmæf	kpæf	rgæf
knik	ktig	rkik
knok	kpak	mkok
kmop	ktap	ltap
kmɛp	ktep	rkep
pnik	pkik	ltik
pnæf	ptæf	rpæf
tlɔf	tkɔf	rtɔf
tlɛp	tkep	mtɛp
tnak	tkak	rtak
tmæf	tpæf	mtæf
tnɛf	tpif	rtɛf
tnok	tgok	mgok
tmæp	tpæp	rpæp
tmak	tpak	mtak

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