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Title: The role of prosodic structure in the L2 acquisition of Spanish stop lenition

Introduction

The study of Spanish spirantization (i.e., the weakening of an underlying stop consonant to an approximant (/b d g/ → [β̞ ð̞ ɣ̞])) is one of the most studied phenomena in L2 Spanish phonology (see e.g., Alvord and Christensen, 2012; Face and Menke, 2009; Rogers and Alvord, 2014; Shea and Curtin, 2011; Zampini, 1997, 1998, *inter alia*). Spirantization has been found to be challenging for native English speakers (e.g., Díaz Campos, 2004, 2006; Shively, 2008) since approximants are not allophones of /b d g/ in English, although it has been shown that advanced learners produce continuants upwards of 80% of the time in postvocalic position (Face and Menke, 2009). However, we do not fully understand how certain variables moderate the path of the adult acquisition of spirantization, including proficiency and the operation of prosodic structure. The purpose of this study will be to contribute to our understanding of how the interaction of these two variables moderates acquisition.

Earlier studies of L2 spirantization examined learner productions at low levels of proficiency, and therefore it was not possible to have a full view into the acquisition process. More recent studies have observed cross sections of learners across proficiency levels and have provided acoustic evidence for the roles of variables such as stress, place of articulation (POA), and word position in the acquisition process (e.g., Face and Menke, 2009; Rogers and Alvord, 2014; Shea and Curtin, 2011). Our primary interest in this study is in the variable of word position. While Face and Menke (2009), Rogers and Alvord (2014), and Shea and Curtin (2011) report differences in learner productions in word-initial versus word-medial position, little is known about the specific role of prosodic structure in the acquisition of spirantization.
As a point of departure, we consider the analysis of impressionistic data from beginner and intermediate L2 Spanish learners in Zampini (1997, 1998), which yielded an acquisition pattern whereby learners acquired spirantization according to the prosodic hierarchy. The operation of phonological hierarchies has been documented in both L1 acquisition (e.g., Branigan, 1976) and L2 acquisition (e.g., Cardoso, 2007). Specific to structural position, L1 phonological acquisition research indicates a relationship between word position and consonant acquisition (e.g., Branigan, 1976; Kiparsky and Menn, 1977). While there are no L1 studies to our knowledge that specifically examine word position and spirantization, it has been shown, for example, that English-speaking children acquire fricatives first in word-medial position (Edwards, 1979). As Vokic (2008) notes, structural position may also correlate with ease of acquisition in L2 learning. For example, Major (1986) indicates that perception of rhotics can vary according to structural position, and reports that the few learners in his study that produced a native-like trill, did so only in word-medial position. These acquisition patterns can be explained by the Subset Principle (e.g., Wexler and Manzini, 1987), which states that acquisition occurs first at the most restrictive domain of the grammar (in this case, word-medial position). With positive evidence, learners can then expand the domain to the superset of the subset (e.g., Young-Scholten, 1994, Zampini, 1997, 1998). The L1 and L2 findings mentioned here, taken together with the aforementioned studies of L2 Spanish spirantization and word position, warrant further investigation to better understand the relationship between prosodic structure and L2 acquisition.

Herein, we provide acoustic evidence to inform the governance of prosodic structure over the path of both categorical and gradient acquisition. A cross-sectional comparison of beginner, intermediate, and advanced learners indicates that learners first produce underlying stops as postvocalic approximants at the onset of the syllable (i.e., word-medial position), followed by the onset of the prosodic word (i.e., word-initial position). Our findings only partially align with those of Zampini, whose data suggest that acquisition of
word-initial spirantization occurs first at the onset of the minimal projection of the prosodic word (i.e., across the boundary of a lexical word and its clitic) and then at the onset of the maximal projection of the prosodic word (i.e., across the boundary of two lexical words). As a potential explanation of the mechanisms that drive acquisition, we model the categorical pattern found in our data within the framework of Optimality Theory (Prince and Smolensky, 1993[2004]), following the assumption that the L2 learning task consists of the gradual demotion of a set of prosodic positional faithfulness constraints below a markedness constraint that prohibits voiced stops in postvocalic position.

The second contribution we aim to make regards ultimate attainment. In particular, we are interested in a) how learners’ productions compare to those of native speakers in terms of degree of lenition and b) residual variation. Our results show that advanced learners produce continuants in postvocalic position at all of the applicable prosodic levels, which we take to indicate that this group has acquired the target constraint ranking. However, the question remains as to whether learners’ productions, while not frequently stops, are truly native-like. That is, do learners lenite segments to the same degree as the native speaker control group, and does degree of lenition change across development? We will show that, for the learners that produce continuants, there is gradual development of the acoustic target. Specifically, the difference in degree of lenition between native speakers and learners lessens at the higher levels of the prosodic hierarchy as acquisition progresses, and several advanced learners produce target-like segments across the three prosodic levels. However, even these learners who consistently produce native-like continuants occasionally produce stops. Does that mean that their constraint ranking is not native-like? Herein, we consider the possibility that non-target-like variability and the acquisition of a native-like mental representation (i.e., constraint ranking)

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1 We consider spirantization to be a type of lenition.
are not mutually exclusive. While there is general agreement in the field that virtually nothing in adult language acquisition is categorical, the treatment of L2 ultimate attainment is often presented as a can/cannot dichotomy: A learner either acquires a native-like L2 representation, or she does not (see e.g., Rothman, 2008, for discussion). As a departure from this view, we demonstrate via the modeling of L2 phonological acquisition in a stochastic (i.e., probabilistic) framework that adult L2 learners can converge on a target-like constraint ranking and still occasionally produce outputs that are not target-like when crucial constraints partially overlap. This study thus goes beyond the valuable first step that other studies have taken in describing learner productions according to word position, by offering an explanation for patterns of categorical and gradient acquisition as well as residual variation.

The remainder of this article is organized as follows: We begin with a description of postvocalic underlying stops in Spanish followed by the constraint interaction that we adopt to explain how and in which contexts these underlying stops are weakened. We then present an OT analysis of postvocalic stops in English. Based on the Spanish and English analyses, we posit the L2 learning task and present our research questions and predictions. In the sections that follow, we present the methodology for the study, followed by a presentation of the results of our acoustic analysis. Finally, we discuss the implications of the data for acquisition and phonological theory more generally and outline future directions for this line of inquiry.

**Spanish postvocalic voiced stops**

In Spanish, there is a stop/continuant alternation in which voiced stops [b d g] surface after nasal stops, pauses, and, in the case of /d/, after /l/. On the other hand, continuants [β ð ɣ] (typically voiced approximants) surface in other contexts. While there are a number of reports of dialectal variation informed by acoustic data (e.g., Carrasco et al., 2012 for Costa Rican and Iberian Spanish; Colantoni and Marescu, 2010, for Argentine Spanish; Radu, 2014, for Colombian Spanish), continuants are thought to surface categorically in postvocalic
syllable-onset position across dialects, both within and across word boundaries. In the present study, we focus on lenition in postvocalic syllable-onset position.

Following the hierarchy proposed by Nespor and Vogel (1986) that delimits the levels at which a phonological phenomenon applies, Zampini (1997, 1998) determined that the prosodic domain within which the process occurs is the intonational phrase (IP). That is, she showed that continuants surface in all instances of post-vocalic stops within the IP and that stops surface at the left edge of the IP. As seen in examples 1a-d, the same pattern occurs within the prosodic domains below it, including the phonological word (the terminal element of a syntactic tree) and the clitic group (within the boundaries of a phonological word and its clitics).²

(1) Spanish stop/continuant alternation according to Nespor and Vogel’s (1986) prosodic hierarchy

a. At the left edge of the intonational phrase

\[ [g] \sim [g] \]

\[ \text{gané la lotería} \quad [\text{ga.’ne la lo.te.’ri.a}] \quad \text{‘I won the lottery’} \]

b. Within the intonational phrase (across the boundary of lexical words)

\[ [\gamma] \sim [g] \]

\[ \text{buena gafa} \quad [\text{bu.e.na ‘\gamma.a.fà}] \quad \text{‘good hook’} \]

\[ \text{buen gato} \quad [\text{’bu.\gamma.e ‘gà.to}] \quad \text{‘good cat’} \]

c. Clitic group (across the boundary of a functional and lexical word)

\[ [\gamma] \sim [g] \]

\[ \text{la gafa} \quad [là ‘\gamma.a.fà}] \quad \text{‘the hook’} \]

\[ \text{un gato} \quad [\text{\'u.\gamma.\gamma.a.to}] \quad \text{‘a cat’} \]

² For support of the inclusion of a clitic group level in the prosodic hierarchy, see Hayes (1989) and Nespor and Vogel (1986).
d.  Phonological word (word-medial)

[ɣ] ~ [g]

 agua  [a.ɣa]  ‘water’
 manga  [maŋ.ga]  ‘sleeve’

Traditional generative analyses treat the stop/continuant alternation as categorical (see ‘Theoretical analysis’ for an OT account of this alternation). While context-dependent degree of lenition should not affect the phonological representation as long as the segment is not produced with complete occlusion, there is ample evidence that the degree of lenition in postvocalic position is variable. Acoustic studies (e.g., Carrasco et al., 2012; Cole et al., 1999) have measured the intensity difference (in dB) of CV sequences, whereby a larger intensity difference indicates a greater degree of occlusion of the consonant and a smaller intensity difference indicates a greater degree of openness (i.e., lenition). The gradience of lenition is thought to be conditioned by several factors, including POA of the segment, flanking vowels, lexical stress, and position within the word or prosodic phrase (see e.g., Simonet et al., 2012, for a review). The last variable is of primary interest to the current study. It has been found that segments are weaker in word-medial positions than in word-onset position (Carrasco et al., 2012, for Costa Rican Spanish; Eddington, 2011 for /b/ and /d/), although Simonet et al. (2012) did not find a difference in word position for Madrid Spanish and Rogers and Alvord (2014) did not find a difference among speakers from three varieties of Latin American Spanish. To our knowledge, there are no studies that address the role of segment position beyond a word-medial versus word-initial distinction. Specifically, in word-initial position, we do not have acoustic evidence of whether the prosodic domain that governs the word in question (i.e., the prosodic word or intonational phrase) conditions the degree of lenition.
This question is relevant to the present study since one of the central questions is whether learners acquire spirantization according to the prosodic hierarchy. If learners’ degree of lenition correlates with the prosodic hierarchy, it is possible that there are prosodic constraints at play that are part of the grammar. We now turn to the presentation of the Optimality Theoretic analyses we use to make predictions for L2 development.
Theoretical analysis

As seen in the examples in (1), voiced continuants surface in postvocalic position in Spanish within the intonational phrase. While several generative accounts of spirantization are based on assimilation (e.g., Goldsmith, 1981; Harris, 1969, 1984; Holt, 2002; Mascaró, 1984, 1991) or effort reduction (e.g., Kaplan, 2010; Kirchner, 1998, 2004; Piñeros, 2002; Recasens, 2002), we assume that the basis for stop lenition is perceptual enhancement via sonority promotion (Kingston, 2007). Kingston puts forth the notion that lenition of voiced stops, while not due to effort reduction, might be a result of undershoot of an articulatory target. That is, a speaker shortens the closure duration to sustain vibration of the vocal folds. Maintenance of voicing comes at the expense of closure of the oral cavity, resulting in an approximant. Kingston posits that whether a stop lenites depends on prosodic structure, whereby lenition occurs more frequently inside a prosodic constituent than at its edge. The weakening of a stop (which is less sonorous than an approximant and thus is thought to interrupt the acoustic signal more) within the word or at the beginning of a word communicates to the hearer that the word is within a prosodic constituent (p. 17). Since the domain of the stop/continuant alternation in Spanish is the intonational phrase (IP; Zampini, 1997, 1998), we follow here that voiced stops will surface only at the left edge of an IP.

Herein, we adopt a modified version of Kingston’s (2007) constraint-based analysis. This analysis consists of a (prosodic) positional faithfulness constraint (Beckman, 1997) that outranks a more general

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3 See Harris (2003) for a similar analysis.

4 The modification comes in the form of the markedness constraints. In his analysis, Kingston addresses an instance of lenition in which the input is [-cont] and the output is [+cont]. While this is adequate for Spanish spirantization, since we are working with L1 English/L2 Spanish speakers, it is ideal to adopt an analysis that also accounts for English lenition of voiced stops (i.e., flapping of /d/), a case in which both the input and output are [-cont].
faithfulness constraint and contextual markedness constraints. The general faithfulness constraint is IDENT-IO (CONT) and the positional faithfulness constraint IDENT-IO (CONT) ONSET IP dictates preservation of identity at the left edge of an IP.

**IDENT-IO (CONT)**

The specification for the feature [continuant] of an input segment must be preserved in its output correspondent.

**IDENT-IO (CONT) ONSET IP**

The specification for the feature [continuant] of an input segment at the onset of an intonational phrase must be preserved in its output correspondent.

The markedness constraints prohibit a group of segments from surfacing in a particular context. This set of constraints forms a hierarchy which aligns with the sonority scale such that the highest-ranked constraints refer to groups of segments that are the lowest in sonority (i.e., voiceless stop >> ... glide). The two markedness constraints that play an important role in our analysis of Spanish spirantization refer to a) voiced stops and b) approximants, with the former outranking the latter.

**\*VOICED STOP/V_**

There are no postvocalic voiced stops in the output.

**\*APPROXIMANT/V_**

There are no postvocalic approximants in the output.

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5 These markedness constraints typically indicate the context as X_Y, with X and Y specifying minimal sonority of the flanking segments. Since the relevant context for spirantization is postvocalic, we use the shorthand notation ‘V_’ throughout.
In Spanish, the high ranking of *VOICED STOP/V_ in relation to the IDENT-IO (CONTINUANT) forces continuants to surface in postvocalic position. If the positional faithfulness constraint IDENT-IO (CONTINUANT)_IP dominates the markedness constraint *VOICED STOP/V_ (2), postvocalic approximants will surface within the IP (Table 1) and stops will surface at the onset of the IP (Table 2).

(2) Spanish ranking:

IDENT-IO (CONT) ONSET IP >> *VOICED STOP/V_ >> IDENT-IO (CONT) >> *APPROXIMANT/V_

Table 1. Postvocalic continuant output in Spanish within the IP.

<table>
<thead>
<tr>
<th>/agua/6</th>
<th>IDENT-IO (CONT) ONSET IP</th>
<th>*VOICED STOP/V_</th>
<th>IDENT-IO (CONT)</th>
<th>*APPROXIMANT/V_</th>
</tr>
</thead>
<tbody>
<tr>
<td>[a.ɣua]</td>
<td></td>
<td></td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>[a.gua]</td>
<td></td>
<td></td>
<td>*</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Postvocalic continuant output in Spanish at the left edge of the IP.

<table>
<thead>
<tr>
<th>/buena/6</th>
<th>IDENT-IO (CONT) ONSET IP</th>
<th>*VOICED STOP/V_</th>
<th>IDENT-IO (CONT)</th>
<th>*APPROXIMANT/V_</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ˈβye.na]</td>
<td></td>
<td></td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>[ˈbye.na]</td>
<td></td>
<td></td>
<td>*</td>
<td></td>
</tr>
</tbody>
</table>

While several constraint accounts propose that the input is a [+continuant] segment (e.g., Barlow, 2003; de Lacy, 2001; Maddieson, 2011; Smith, 2005), we assume a [-continuant] input based on Piñeros (2003). His analysis is based on the assumption that IDENT (FEATURE) (input and output correspondents must agree in their specifications for all features) constraints outrank the constraint *VOICED STOP (voiced obstruent stops are prohibited). This assumption has recent empirical support in the form of developmental data (Fabiano-Smith et al., 2015), for which children show higher accuracy on voiced stops than continuants even at age 8;2.
L2 acquisition of Spanish spirantization

Having established an L2 target, we can proceed with a discussion of the L2 learning task and predictions for the current study. We start with an analysis of English postvocalic stops to establish the constraint reranking task, followed by a description of an algorithm used to model phonological acquisition. We then conclude with a brief review of the L2 literature that informs our study.

English postvocalic stops

The phonemic inventory of American English contains voiced stops /b d g/ in simple and complex onset and coda position, as well as intervocally (Celce-Murcia et al., 1996). In intervocalic position, the output of /b/ and /g/ is faithful to the input. However, /d/ surfaces as an alveolar flap ([ɾ]), a voiced consonant without a release burst, violating IDENT-IO (FLAP) (e.g., Piñeros, 2003).

**IDENT-IO (FLAP)**

The specification for the feature [flap] of an input segment must be preserved in its output correspondent.

(3) American English postvocalic voiced stops

| [b] | ‘baby’ | [ˈbeɪ.bi] |
| [d] ~ [ɾ] | ‘daddy’ | [ˈdeɪ.ɾi] |
| [ɡ] | ‘muggy’ | [ˈmʌ.ɡi] |

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7 Bouavichith and Davidson (2013), Warner and Tucker (2011), *inter alia*, show that English speakers lenite stops in fast speech, particularly in unstressed syllables (Bouavichith & Davidson, 2013). However, Bouavichith and Davidson conclude that this phonetic weakening is not phonological in nature, as evidenced by the prioritization of maintenance of acoustic cues to stress by English speakers. Even in the environment most susceptible to weakening (unstressed position), 49% of underlying intervocalic voiced stops still surface as stops. Moreover, the data that point to weakening come from tasks that are less formal than the recitation task that we use in the present study. As a result, we assume that intervocalic /b g/ lenition is not a phonological process in English and therefore do not presume that lenition in Spanish production is transferred from English.
Flapping is a type of stop lenition in which the period of closure is shortened (e.g., Herd, Jongman, and Sereno, 2010). Flaps are higher in sonority than their stop counterpart, and have been shown to have higher root mean square (RMS) amplitude than stops (Herd et al., 2010; Lavoie, 2000). Bonet and Mascaró (1997) propose that a flap has sonority akin to that of glides. Therefore, it does not violate *VOICED STOP/V since the markedness constraints employed in this analysis are sonority-based. Rather than conflating a flap and a glide (which differ in terms of [continuant]) and assuming that a flap violates *GLIDE/V_, we propose that a flap in the output violates *FLAP/V_ (C. Wiltshire, personal communication, November 19, 2015).

*GLIDE/V_

There are no postvocalic glides in the output.

*FLAP/V_

There are no postvocalic flaps in the output.

Just as the feature constraint IDENT-IO (CONT) dominated by *VOICED STOP/V_ yields a continuant output, the domination of IDENT-IO (FLAP) by *VOICED STOP/V_ yields a postvocalic flap. The feature [continuant] is not relevant here, since both stops and flaps are [-continuant]. Because there are no stop/continuant input/output relationships in English, IDENT-IO (CONT) is undominated (Table 3). Note that IDENT-IO (CONTINUANT) ONSET IP is not part of the English ranking since there is no evidence that it is undominated in English.

(4) English ranking:

IDENT-IO (CONT) >> VOICED STOP/V_ >> IDENT (FLAP), *FLAP/V_  

We assume that IDENT(FLAP) and *FLAP/V_ do not have a strict ranking relationship since the same candidate wins regardless of the constraints’ relative order.
Table 3. English postvocalic /d/ in the word ‘daddy’.

<table>
<thead>
<tr>
<th>/dædi/</th>
<th>IDENT (CONT)</th>
<th>*VOICED STOP/V_</th>
<th>IDENT (FLAP)</th>
<th>*FLAP/V_</th>
</tr>
</thead>
<tbody>
<tr>
<td>[dæ.di]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[dæ.ɾi]</td>
<td></td>
<td></td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>[dæ.ði]</td>
<td>*!</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Now that we have established the Spanish and English constraint interactions that yield the surface outputs attested in each language, we can define the L2 Spanish initial state and outline the L2 learning task.

**Gradual acquisition and the L2 learning task**

Due to the lack of a stop-continuant alternation in English, learners first have to acquire the Spanish surface distribution of stops and continuants. While the degree of lenition will vary across dialects and speech styles, learners will minimally have to determine that underlying stops are produced as continuants in postvocalic position. In the following sections, we describe the mechanism that we assume to underlie phonological acquisition, followed by the learning task and the potential role of the prosodic hierarchy in the learning task.

**The Gradual Learning Algorithm.** In our analysis, we assume that there is a learning mechanism that drives allophonic acquisition. We follow Boersma (1997) and Boersma and Hayes (2001), who posit that acquisition of the distribution occurs via an error-driven learnability algorithm called the Gradual Learning Algorithm (GLA). The GLA is based on stochastic (i.e., probabilistic) OT and simulates both L1 and L2 phonological acquisition. Boersma and Hayes claim that each constraint has an absolute ranking value and occupies a range on a continuous scale, which they interpret as a probability distribution. The amount of space between constraints indicates the strictness of the relative ranking. During production, selection points (i.e., actual) ranking values from within the range that a constraint occupies) are picked and the constraints are ranked according to these points. If this constraint ranking is a mismatch with that of the surface form, the algorithm
goes to work to alter the constraint ranking values so that the grammar will be more likely to generate the optimal candidate the next time. Since constraints’ probability distributions can continuously be adjusted, the GLA predicts L2 convergence upon a native-like ranking, although it is of course possible that variable outputs can persist in the case of two constraints with ranking values that are close together (just as they do, to a lesser extent, in native grammars). While the assignment of actual ranking values to the constraints in our analysis is outside the scope of this paper, we will demonstrate in the results and discussion that the tenets of the GLA presented here are attestable.

In the only study that we know of that has formally modeled L2 acquisition of Spanish postvocalic continuants based on acoustic data, Shea and Curtin (2011) set out to identify acquisition as categorical or gradient. In their investigation of low intermediate and high intermediate learners, they hypothesized that uniform acquisition across places of articulation (POA) would support a categorical generative account (either rule-based or constraint-based). On the other hand, if learners were to acquire the alternation at different rates according to POA, the authors proposed that such gradient acquisition would favor a gradual input-based system. A difference in high intermediate productions according to POA led Shea and Curtin to claim support for an exemplar-based model in which frequency of input drives acquisition under the assumption that gradient acquisition and a generative approach are incompatible. However, frequency is a key component in the GLA and a mismatch between aural input and a current constraint ranking drives

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9 An anonymous reviewer brings up the question of how the GLA accounts for fossilization (i.e., lack of ultimate convergence on the L2 target). Although Boersma and Hayes do not explicitly address the question, we assume that fossilization occurs as a result of a lack of parsing failures. That is, learners continue to use L1 parsing routines and “map interpretations onto the stimuli and ignore unanalyzable parts of speech” (Carroll, 2001, p. 305).
acquisition. Gradient acquisition is not only compatible with OT, but is in fact predicted under the GLA. Depending on the constraints at play, rate and path of acquisition could indeed vary according to the frequency according to POA in the input. We therefore posit that the GLA can also explain Shea and Curtin’s (2011) data.

The constraint reranking task. Assuming that learners’ L2 initial state is a copy of the L1 phonological grammar, L1 English/L2 Spanish learners come to the task with a ranking in which the faithfulness constraint IDENT-IO (CONT) is undominated. Thus, to produce Spanish postvocalic underlying stops as continuants, the faithfulness constraint IDENT-IO (CONT) will have to be demoted below *VOICED STOP/V_ so that the markedness constraint can block a postvocalic voiced stop from surfacing. Initially, learners will evaluate Spanish surface candidates against their L1 rankings. It is predicted that since the L2 input will violate undominated IDENT-IO (CONT), EVAL (evaluator, the mechanism that determines the relationship between the candidates and the universal constraint set) will initially rule out the Spanish candidates with fatal violations. As input increases, however, the GLA will successively alter the probability distributions until the target ranking of *VOICED STOP/V_ >> IDENT-IO (CONT) is reached.

The role of the prosodic hierarchy in the L2 learning task. As we have noted, recent L2 research has considered effects of position on the production of postvocalic underlying stops, finding segments to be more approximant-like in word-medial versus word-initial context even at lower levels of proficiency (Rogers and Alvord, 2014; Shea and Curtin, 2011). These authors show that although position distinctions are maintained across proficiency levels, there is an overall reduction in intensity difference, which indicates progression towards convergence on the native-like target. Zampini (1997, 1998) also observed a pattern with regard to the position of the segment, finding that production by beginner and intermediate learners differed according to position in the prosodic hierarchy as a function of proficiency. In light of Zampini’s impressionistic
evidence that learners acquire postvocalic spirantization according to different domains of the prosodic hierarchy, we hypothesize that there could be additional constraint interactions that go beyond those already described. Herein, we present these constraints, working from Itô and Mester’s (2007) more recent instantiation of the prosodic hierarchy for reasons of economy, and an ONSET-driven analysis that is compatible with the positional faithfulness approach to spirantization.

Itô and Mester (2007) address several proposals of the levels to be included in the prosodic hierarchy, including that of Nespor and Vogel (1986). They posit that a more minimal framework with fewer categories is necessary, in which prosodic adjunction is central in the parsing of phonological strings (Figure 1).

In the spirit of syntactic constituent structure, each prosodic category has a maximal and minimal projection and has the option of recursivity. To illustrate, Figure 2 demonstrates that for a prosodic category (in this case, that of the prosodic word), the larger structure is the maximal projection. The structure consists of the innermost subconstituent (the lexical word) and the functional words that adjoin to it, and the innermost subconstituent is the minimal projection.
In this analysis, function words occupy positions within the maximal prosodic words. Itô and Mester (2007) provide support for this analysis via a discussion of onset requirements for the levels of the prosodic hierarchy and their faithfulness properties, and argue that this economical approach yields flexibility for whatever distinctions are necessary without the noise of additional categories such as the clitic group (Nespor and Vogel, 1986) and intermediate and accentual phrases (Pierrehumbert and Beckman, 1988). Taking this idea of onset markedness and faithfulness at the different prosodic levels as a point of departure, we can illustrate Spanish spirantization across prosodic levels in terms of the location of the onset that surfaces unfaithfully in postvocalic onset position. Word-medially, a lenited postvocalic onset is dominated by the syllable, demonstrated in Figure 3 with the word *agua* ‘water’.

![Figure 3](image3.png)

**Figure 3.** Prosodic level of the syllable; dominates word-medial syllable onset.

Across the boundary of a lexical word and the function word(s) adjoined to it, the onset of the minimal projection of a prosodic word is lenited. This is seen in Figure 4 with *la gafa* ‘the hook’.

![Figure 4](image4.png)

**Figure 2.** Minimal and maximal projections of the prosodic word (Itô and Mester, 2007).
Finally, across the boundary of two lexical words, the onset of the maximal projection of a prosodic word is lenited, as in Figure 5 with *buena gafa* ‘good hook’.

Based on Zampini’s (1997, 1998) findings, it is predicted that the learners will start with the most restrictive setting for the alternation on the prosodic hierarchy (in this case, syllable onset). As introduced in ‘Introduction’, this prediction follows from the Subset Principle (Dell, 1981; Wexler and Manzini, 1987), which assumes that the learning mechanism maps input to the most restrictive (subset) grammar. The Subset Principle was developed to account for L1 acquisition patterns and has been found to be operative in L2 acquisition as well, particularly when the L2 learning task consists of acquiring a superset grammar and not a subset grammar (see Kilpatrick, 2009, for discussion). In the case of L2 Spanish spirantization, the most
restrictive grammar is the lowest level of the prosodic hierarchy at which spirantization occurs, which is the onset of the syllable. With positive evidence, learners will incrementally extend the domain of spirantization to less restrictive (superset) grammars, first in word-initial position across the boundary of a word and its clitic and then across the boundary of two lexical words. If we find that L2 Spanish learners acquire postvocalic spirantization according to prosodic level, we can posit that there are separate stricture faithfulness constraints for the onset of each prosodic level and that learners gradually demote onset stricture faithfulness constraints. With evidence, they will extend the domain of spirantization until they reach a native-like ranking in which \( *\text{VOICED STOP/V} _{\text{onset}} \) outranks all onset stricture faithfulness constraints. If our data support Zampini’s findings, the following onset stricture faithfulness constraints are thus predicted to be part of the ranking:

**IDENT-IO (CONT) ONSET SYLL**

The specification for the feature [continuant] of an input segment at the level of the syllable must be preserved in its output correspondent.

**IDENT-IO (CONT) ONSET PW-MIN**

The specification for the feature [continuant] of an input segment at the level of the minimal projection of the prosodic word must be preserved in its output correspondent.

**IDENT-IO (CONT) ONSET PW-MAX**

The specification for the feature [continuant] of an input segment at the level of the maximal projection of the prosodic word must be preserved in its output correspondent.

Under this analysis, IDENT-IO (CONT) will be the first constraint to be demoted because it is violated every time a continuant appears in the evidence, independent of the phonological domain. Given that each level of the prosodic hierarchy subsumes the levels below, a violation at a higher level will mean a violation at each of the levels below. As such, the constraints will be demoted at different rates according to the number of violations incurred and are demoted in order from the lowest level to the highest level of the hierarchy at which continuants are evidenced. As the learner is exposed to surface forms that the learner’s current ranking
would not yield, IDENT-IO (CONT) ONSET SYLL will demote, followed by IDENT-IO (CONT) ONSET PW-MIN, and finally by IDENT-IO (CONT) ONSET PW-MAX. By demoting the stricture faithfulness constraints below *VOICED STOP/V_, learners are predicted to converge on the target grammar. Assuming the GLA, reranking is gradual and constraints are expected to overlap throughout the acquisition process even in the grammars of near-native speakers that have acquired the target ranking. As discussed, overlap of crucially ranked constraints can lead to variable outputs, and multiple constraints can overlap one another. As a result, upon convergence it is highly probable that an underlying postvocalic stop surface as a continuant regardless of the prosodic level in which the stop occurs.

Convergence on the L2 acoustic target. While we posit that constraint reranking is a critical component of L2 acquisition of Spanish spirantization, there is another component involved. As mentioned, if a learner’s constraint ranking reflects the target Spanish ranking, it can be expected that a learner will reliably produce postvocalic continuants. However, that does not mean that a learner’s productions will reflect native-like degree of lenition. Therefore, the other aspect of the learning task is to develop the acoustic target such that occlusion is reduced to the same extent as a native speaker’s productions.

Research questions. Recall from the introduction that the goals of this study are twofold. First, we aim to account for the acoustic patterns observed at different levels of proficiency across domains of the prosodic hierarchy. Our second goal is to determine whether late L2 learners can revise an L1 ranking in their L2, and to illustrate that a native-like ranking/acoustic target and non-target-like productions are not mutually exclusive. To meet these objectives, we put forth the following questions:

1a. Can learners acquire spirantization in L2 Spanish across all of the relevant levels of the prosodic hierarchy?
1b. Does the acquisition of spirantization in L2 Spanish occur in stages according to the prosodic hierarchy? That is, do learners first produce postvocalic underlying stops as continuants at the onset of the syllable, followed by the onset of the minimal and maximal projections of the prosodic word, respectively?

Face and Menke (2009) present categorical data from 13 PhD students that show development towards a native-like representation of postvocalic underlying stops in word-medial (85%) and word-initial (73%) positions, although learners still produced significantly more stops in word-initial position than in word-medial position. Comparing the PhD students to fourth semester Spanish undergraduate students and Spanish majors, there was an overall reduction of stops produced across proficiency levels while all groups maintained a significant distinction between word positions. Therefore, additional data are warranted to determine whether and how the prosodic hierarchy moderates the learners’ acquisition path, and whether learners can reliably produce continuants even at the onset of the PW-max.

2a. For the learner groups that produce approximants at each prosodic level, is the degree of lenition similar to that of the native controls' approximants?

2b. Is there evidence of an increase in degree of lenition as proficiency increases?

To answer this question, an analysis of intensity ratio or difference is necessary. Two L2 acquisition studies have used this method: Shea and Curtin (2011) and Rogers and Alvord (2014). Shea and Curtin report a significant difference in lenition in word-medial position when comparing low intermediate learners, high intermediate learners, and native speakers. This finding indicates an increase in degree of lenition as proficiency increases, at least in word-medial position, although degree of lenition is not native-like. The authors do not report between-group pairwise comparisons for word-initial position; however, descriptively we see an increase in degree of lenition in word-medial and word-initial position when comparing the two groups. Based on their word-medial pairwise comparison, we assume word-initial lenition is not native-like.
Rogers and Alvord (2014) found that a group of advanced learners’ (n=4) that had spent two years abroad produced postvocalic segments with a degree of lenition that was descriptively similar to that of three native speakers in word-medial and word-initial positions. They also compared the degree of lenition between word positions for the advanced learners and learners that had completed two years of university Spanish (n=4), and indicate an overall reduction of occlusion in both positions. We anticipate that the examination of a larger sample size and the use of inferential statistics will further inform our understanding of the development of learners’ acoustic targets.

**Methodology**

As stated in the introduction, spirantization is one of the most studied phenomena in L1 English/L2 Spanish phonology research, although a review of the literature shows a need for further empirical inquiry to better understand acquisition from the initial state to L2 target convergence. Specifically, there is a lack of 1) data from advanced/near-native learners and control participants, 2) proficiency assessment, and 3) acoustic analysis from both gradient and binary accounts of stricture. We address these issues throughout the section.

**Participants**

The cross-sectional study consisted of three learner groups with a mean age of acquisition of Spanish of 13 years (SD = 1.98) at the beginner (n = 11), intermediate (n = 13), and advanced (n = 20) proficiencies, and a control group of native speakers (n = 5).
Table 4. Participant age, gender, and proficiency scores.

<table>
<thead>
<tr>
<th>Group</th>
<th>age (M (SD))</th>
<th>Gender</th>
<th>M (SD) proficiency score (out of 50)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beginner</td>
<td>21 (.69)</td>
<td>0</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11</td>
<td>25.09 (2.87)</td>
</tr>
<tr>
<td>Intermediate</td>
<td>21 (.74)</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9</td>
<td>33.15 (2.51)</td>
</tr>
<tr>
<td>Advanced</td>
<td>23 (3.99)</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>44.2 (3.03)</td>
</tr>
<tr>
<td>Control</td>
<td>21 (1.78)</td>
<td>3</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

The inclusion of advanced learners and a control group addresses a gap in the literature. While a considerable body of research reports persistent difficulty in target-like productions (e.g., Diaz-Campos, 2004, 2006; Elliot, 1997; Shively, 2008) with only González Bueno (1995) and Lord (2005) evidencing target production by intermediate learners surpassing the 50% mark, few studies (Alvord and Christensen, 2012; Face and Menke, 2009; Rogers and Alvord, 2014) test advanced speakers and ultimate attainment to determine if and when postvocalic underlying stops surface as continuants. However, in the Face and Menke (2009) study, the most advanced group of participants was categorized based solely on their standing as students in a Spanish PhD program, and the authors recognize overlap in the learner profiles from the three groups tested (fourth semester students, graduating Spanish majors, and PhD students). While the PhD students produced approximants 82% of the time, significantly more than the other groups, there is no control data with which to make a statistical comparison. Similarly, Alvord and Christensen (2012) reported an 81% accuracy rate in intervocalic approximant production by returning missionaries that had spent two years abroad, but there was no control group as a comparison (although the authors claim that spirantization is categorical, p. 22). To our knowledge, only Rogers and Alvord (2014) have tested near-native speakers (n = 4) and compared them with
native controls (n = 3) using a continuous measurement. However, the authors were unable to statistically compare the learners and controls due to small sample sizes.

The control group (n = 5) was composed of native speakers of Cuban Spanish that had moved to the US and acquired English after late childhood, rather than monolingual Spanish speakers. The speakers had lived in the US for an average of 5.3 years (SD = 2.74), and had demonstrated sufficient English proficiency to study in American universities at the undergraduate level. The use of a mirror image of the experimental group follows Hopp and Schmid (2013), who posit that a monolingual native norm is not an appropriate measurement of L2 ultimate attainment. It has been established that a bilingual speaker is not equivalent to two monolinguals, even in the case of ‘balanced’ bilinguals (see e.g., Grosjean, 1998). Therefore, “the choice [to use monolingual productions]…serves to move the yardstick of nativelikeness to a point which may, by definition, be out of reach for most bilinguals” (Hopp and Schmid, p. 354). To this end, Hopp and Schmid suggest that a more appropriate control group is a mirror image of the experimental group. That is, if the population under investigation is composed of L1 English/L2 Spanish speakers, the control group should consist of L1 Spanish speakers that have acquired L2 English after a certain age and are living in an immersion context.

Proficiency measurement

All participants completed a background questionnaire to assess age of acquisition, length of residence in Spanish immersion environments, formal education in Spanish, and self-reported use (context/frequency) of Spanish. Participants did not report fluency in any languages other than English and Spanish. Most studies do not apply an objective proficiency assessment, instead classifying learners according to course or program enrollment (e.g., Face and Menke, 2009; González Bueno, 1995; Rogers and Alvord, 2014; Shea and Curtin, 2011; Zampini, 1997, 1998). This practice can be problematic considering the variation that can be found
even when proficiency is carefully controlled for via independent assessment. To address this issue, proficiency was assessed via a 50-item test composed of portions of the Diploma of Spanish as a Foreign Language (DELE) and Modern Language Association (MLA) Spanish proficiency exams. This test has been used extensively in generative L2 Spanish research (see, e.g., Montrul, 2008), and consists of a passage-based cloze section (30 items) and sentence-based cloze section (20 items). As in other studies (e.g. Giancaspro, 2013, Slabakova and Montrul, 2003, inter alia), learners with a score of 40-50 were classified as advanced, learners with a score of 30-39 were classified as intermediate, and learners with a score below 30 were classified as beginner.

Task and stimuli

Participants completed a sentence recitation task which consisted of 54 tokens in the carrier phrase Diga _____, por favor ‘Say _____, please’ (Appendix 1). The task was selected to control for task effects (see e.g., Radu, 2014; Zampini, 1994) and speech rate. Following Shea and Curtin (2011), items differed in terms of POA of the underlying stop (/b d g/), following vowel (/a i u/), and stress (stressed/unstressed). While Shea and Curtin also investigated word position (word-initial/word-medial), our items were designed to be equally distributed across the three onset positions introduced in ‘The role of the prosodic hierarchy in the L2 learning task’ (syllable (word medial), minimal prosodic word (across the boundary of a word and its clitic), maximal prosodic word (across lexical word boundaries), see (5) for example stimuli).\(^{10,11}\) All tokens from the

\(^{10}\) In our discussion of the acquisition of spirantization in this paper, we focus on postvocalic productions and do not report on data from contexts that favor stop productions. However, data from a study in preparation by Authors show that advanced learners that pattern with native controls in postvocalic position, also pattern with controls in that they produce stops in post-pausal and post-nasal positions.

\(^{11}\) Although our primary interest is in how the position of an underlying stop conditions lenition across L2 development, we incorporated POA, following vowel, and stress into our design to add meaningful variability
syl\allowbreak lable onset condition (word-medial position) were trisyllabic or quadrisyllabic, and the critical segment was never in the final syllable (Shea and Curtin, 2011). To summarize, the stimuli comprised a 3 (POA) x vowel (3) x stress (2) x prosodic level (3) design. However, due to researcher error, three conditions at the onset of the syllable (stressed /ba/, stressed /bi/, stressed /da/), and three at the onset of the maximal prosodic word (unstressed /gu/, stressed /du/, stressed /gi/) were excluded from analysis. Since contextual vowels were not considered a factor in our analysis, our error does not necessarily impact the results negatively.

(5) Example stimuli by prosodic level (critical segment in bold)

a. Onset of the syllable (word medial)
   
   \textit{duda} /duda/ \text{‘doubt’}

b. Onset of the minimal projection of the prosodic word (across the boundary of two lexical words)
   
   \textit{la duda} /la duda/ \text{‘the doubt’}

c. Onset of the maximal projection of the prosodic word (across the boundary of two lexical words)
   
   es una vida \textit{digna} /es una bida digna/ \text{‘(it) is a dignified life’}

Frequency was controlled for, using only stimuli from the 5000 most frequent Spanish words (taken from Davies, 2006). Past participle forms were excluded, as they have been found to be more lenited due to frequency effects (e.g., Díaz-Campos and Gradoville, 2011; Eddington, 2011). We also excluded items with orthographic ‘v’, as its inclusion has been found to yield fricative production in L2 studies (Face and Menke, 2009; Zampini, 1994) and studies of heritage speaker Spanish (Fabiano Smith et al., 2014; Ronquest, 2014).

Procedure

to the dataset in terms of contextual factors found to influence native speech. Given the focus of the current study, however, we limit our discussion to the variable of prosodic level.
All communication with the researchers was conducted in Spanish to avoid language mode effects. Participants were asked to read the list of sentences at a normal rate of speech and to pause for two seconds between each sentence. They completed the list of words twice to control for a novelty effect, and the second reading was used for analysis. All recordings were made in a quiet room using a Marantz PMD660 recorder and a head-mounted Shure SM10A microphone at a sampling rate of 44.1 kHz.

**Analysis**

Most existing L2 work has been based on an impressionistic binary analysis of stop versus approximant production, with few exceptions. While Face and Menke (2009) and Alvord and Christensen (2012) analyzed acoustic data, they coded their data only for manner of articulation. Our analysis methodology aligns with that of Shea and Curtin (2011) and Rogers and Alvord (2014), who are the only L2 researchers to investigate the phenomenon via acoustic analysis of the intensity curve, in line with evidence from monolingual data as described earlier.

Measurements of intensity (an acoustic index of lenition, Parker, 2002, 2008) were used to determine the degree of constriction of each segment. Specifically, the minimum intensity (measured in decibels, dB) of the consonant in a CV syllable was subtracted from the maximum intensity of the following vowel (e.g., Hualde et al., 2011; Soler and Romero, 1999). Intensity difference was measured to control for variation across speakers and recordings. The lower the intensity difference, the more open the constriction (i.e., the higher the degree of lenition).

To measure intensity difference, each underlying stop and following vowel was segmented in Praat (Boersma and Weenink, 2014). We followed Lavoie (2001) and Shea and Curtin (2011), marking the onset of the consonant as the offset of the previous vowel’s second formant (F2) and the offset as the onset of the following vowel’s F2. F2 onset and offset was used to segment the following vowel segment. In the case that
F2 was not a clear enough indicator, we followed Hualde et al. (2011), marking the onset of the underlying stop at the location of a dip in Praat’s intensity curve. The offset of the consonant was then marked at the location of an increase in the waveform’s amplitude. Once all segments were marked, we ran a script in Praat that calculated the difference (in dB) between the maximum intensity of the vowel and the minimum intensity of the consonant. A total of 2307 items were analyzed. Figure 6 shows a continuant production from a control, and Figure 7 shows a stop production from a beginner.

Figure 6. Continuant production of /b/ in hábito ‘habit’ by a native control participant (intensity difference = 2.85 dB). Note: Transcription is phonemic.
Figure 7. Stop production of /b/ in hábito ‘habit’ by a beginner participant (intensity difference = 21.16 dB).

Results

To examine the relationship between proficiency and prosodic level that conditions the production of postvocalic underlying stops in L2 Spanish, we report descriptive and inferential statistics. Our descriptive statistics include means, 95% confidence intervals, and effect sizes (Hedges’ g). We also computed a Linear Mixed Model in SPSS using the MIXED procedure. The dependent variable was Intensity Difference, measured in decibels (dB). The between-subjects effect was Group (control, beginner, intermediate, advanced). Because existing experimental data shows that native Spanish speakers categorically produce continuant in postvocalic position (see section on Spanish postvocalic voiced stops), the native speaker group data provide an appropriate baseline for comparison with the learner data for determining whether learner productions are lenited to the same degree as the native control. The within-subject fixed effect was Prosodic
Level (onset of syllable, onset of PW-min, onset of PW-max). We included the Prosodic Level*Group interaction in the model and planned pairwise comparisons for the interaction (Bonferroni adjustments to observe differences in means and TOSTs to observe similarity in means). A random intercept and a random slope for prosodic level were included at the participant level. We also included a random intercept at the item level in order to capture variance in the dependent variable across items. Alpha was set at \( p = .05 \). Significant main effects were found for Group \( (F (3, 45.05) = 10.67; p = .000) \) and Prosodic Level \( (F (2, 91.07) = 17.59; p = .000) \). Considering the questions that drive the study, the significant interaction of Prosodic Level*Group \( (F (6, 87.363) = 3.348; p = .005) \) is of primary interest (see Figure 8 for a visual presentation of the interaction). Looking at the figure, there are two observable patterns. First, the intensity difference increases across prosodic levels for all groups except for the advanced group. Second, the intensity difference of the spirants for each group varied as a function of proficiency group; the control group has the lowest intensity difference values and the beginners have the highest ones.

We will explore this interaction of proficiency and prosodic level descriptively and inferentially throughout the rest of the section as we address the relevant results for each research question.

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To our knowledge, equivalence tests as a method of similarity testing have not been used in SLA research before (see Juzek and Kizach, submitted), and therefore a brief explanation is warranted. The equivalence test we have implemented consists of two one-sided t-tests (TOST) and is attributed to Westlake (1976) and Schuirmann (1981). The null hypothesis assumes a difference in means and a rejection of the null hypothesis allows a conclusion that the means are equivalent. The first test evaluates the difference in means plus delta (absolute difference) and the second test evaluates the difference in means minus delta. If both t-tests yield positive results, the means are concluded to be similar. The reason TOSTs have not been used in linguistic research before now is the difficulty in setting \( \delta \), which is the critical parameter that controls the TOST. Juzek and Kizach (submitted) outline how to objectively set \( \delta \) “to achieve the narrowest similarity range that meets common error rates of \( 1 - \beta = 80\% \) and \( 1 - \alpha = 95\% \) (where \( \beta \) is the rate of false negatives and \( \alpha \) the rate of false positives)” (p. 2). We have used Juzek’s (2016) web-based TOST calculator, which sets \( \delta \) and returns a result of positive \( (p < .05) \) or negative \( (p > .05) \).
Figure 8. Intensity difference (in dB) according to group and prosodic level. Error bars represent standard error.

Research question 1

To determine a) whether learners acquire spirantization in L2 Spanish across all of the relevant levels of the prosodic hierarchy and b) if the hierarchy moderates the path of acquisition, it was first necessary to see whether the learner groups produced stops or continuants segments at each level. While our dependent variable (intensity difference) is continuous, it is possible to categorize each mean as a stop or continuant
using one-sided 97.5% confidence intervals. A plausible lower limit of intensity difference for a stop was calculated by measuring intensity difference in a pseudorandom sample distributed among the variables crossed in the stimuli set of 150 stops from the learner data. Tokens came from 38 learners, although there was naturally a higher ratio of beginner and intermediate tokens since they produced a larger number of stops. A segment was classified as a stop based on the presence of a release burst in the spectrogram. Upon noting the differences in mean intensity difference across prosodic levels, we treated the data points at each prosodic level separately (n = 50 each). Items with an intensity difference value larger than 2 SDs above the mean for the relevant prosodic level were removed from the data set, leaving 47 items at the syllable and PW-min levels and 48 at the PW-max (n = 142). T-tests comparing the stop data at each prosodic level revealed a significant difference between the syllable and PW-min (p = .003) and PW-max (p = .000), and between the PW-min and PW-max (p = .001). In light of these results, we constructed separate CIs for the syllable (M = 13.48, SD = 3.94), PW-min (M = 16.07, SD = 4.42), and PW-max (M = 20.08, SD = 7.28). Table 5 details a) the CI of the segments with release bursts for each prosodic level and b) the mean intensity difference and CI for each learner group and the control group. Cells with group means that fall above the one-sided CI are shaded.

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13 This method was implemented subsequent to our initial gradient analysis to address the question of categorical stop/continuant production. Future analysis will entail categorization of the full data set as stops or continuants according to presence/absence of burst separate analyses of tokens with and without bursts.

14 We assume independence of the 142 responses, as a check of the interclass correlation indicated a correlation of .104 among responses from the same individual.
Table 5. Intensity difference in dB (estimated marginal means and 95% two-sided CIs) according to group and prosodic level. The 97.5% one-sided CI for the lower limit of the sample of segments with a release burst is included as a reference.

<table>
<thead>
<tr>
<th>CI</th>
<th>Beginner</th>
<th>Intermediate</th>
<th>Advanced</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Syllable</td>
<td>[12.35]</td>
<td>12.26</td>
<td>11.74</td>
<td>10.35</td>
</tr>
<tr>
<td></td>
<td>[10.04-15.16]</td>
<td>[9.35-14.11]</td>
<td>[8.37-12.34]</td>
<td>[2.16-9.44]</td>
</tr>
<tr>
<td></td>
<td>[13.82-18.83]</td>
<td>[12.09-16.76]</td>
<td>[9.88-13.78]</td>
<td>[2.84-10.02]</td>
</tr>
<tr>
<td>PW-max</td>
<td>[18.02]</td>
<td>18.86</td>
<td>16.22</td>
<td>11.38</td>
</tr>
</tbody>
</table>

Based on the categorization of means as stops or continuants, the beginner group produces continuants at the level of the syllable and stops at the PW-min and PW-max. Within-group pairwise comparisons (Table 6) indicate that the degree of occlusion increases significantly with each prosodic level, although effect sizes are very small. The intermediate group produces continuants at all three levels. Segments are significantly less occluded at the level of the syllable than at the level of the PW-min and PW-max, again with very small effect sizes. There is no significant difference between the PW-min and PW-max, although a TOST did not yield a positive (similar) result. The advanced group also produces continuants at all

---

15 When evaluating effect sizes, we follow Plonsky and Oswald (2014), who propose based on meta-analysis that small, medium, and large effects in second language acquisition research correspond respectively to absolute values of .40, .70, and 1.00 for between-groups analyses and .60, 1.00, and 1.40 for within-groups analyses.
three prosodic levels. Like the control group, none of the within-group pairwise comparisons across prosodic levels are statistically significant. While only the PW-min/PW-max comparison returns a positive TOST for the advanced group and control group, all within-group effect sizes for the two groups fall well below .70 and the CIs overlap substantially in each case. That said, it remains to be seen whether the advanced group’s productions are statistically different than those of the control group and how the other groups compare with the control group as well.

**Table 6.** Within-groups pairwise comparison *p* values from Bonferroni post hoc tests and effect sizes (Hedges’ g, in parentheses) according to prosodic level. TOST results are included when Bonferroni test yields *p* > .05.

<table>
<thead>
<tr>
<th></th>
<th>Beginner</th>
<th>Intermediate</th>
<th>Advanced</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Syllable</td>
<td>.001* (.49)</td>
<td>.017* (.43)</td>
<td>.166 (.28)</td>
<td><em>p &gt; .05</em></td>
</tr>
<tr>
<td>PW-min</td>
<td>.045* (.73)</td>
<td>&lt;.001* (.63)</td>
<td>.573 (.22)</td>
<td><em>p &gt; .05</em></td>
</tr>
<tr>
<td>Syllable</td>
<td>&lt;.001* (.25)</td>
<td>.179 (.22)</td>
<td><em>p &gt; .05</em></td>
<td>1.000 (.04)</td>
</tr>
</tbody>
</table>

* *p < .05

Research question 2

To answer our question of whether learners’ degree of lenition is similar to that of the native controls’ approximants, we evaluate between-groups pairwise comparisons and effect sizes at each prosodic level. Specifically, we are interested in the comparisons between the control group and the learner groups (Table 7).
Table 7. Between-groups pairwise comparison p values and effect size values according to prosodic level. TOST results are included when Bonferroni results are p > .05.

<table>
<thead>
<tr>
<th></th>
<th>Beginner</th>
<th>Intermediate</th>
<th>Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>p</td>
<td>g</td>
<td>p</td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Syllable</td>
<td>.013*</td>
<td>1.05</td>
<td>.035*</td>
</tr>
<tr>
<td>PW-min</td>
<td>.000*</td>
<td>1.12</td>
<td>.001*</td>
</tr>
<tr>
<td>PW-max</td>
<td>.000*</td>
<td>1.05</td>
<td>.000*</td>
</tr>
</tbody>
</table>

*p < .05

Recall that the beginners produce continuants only at the onset of the syllable. Their mean intensity difference is significantly larger than that of the control group at all levels, and the effect sizes are all around 1, indicative of a large effect size according to Plonsky and Oswald (2014). The outcome of the comparison between the control group and intermediate group is similar; again, there are significant differences between groups at each of the three levels with large effect sizes. Therefore, although the intermediate group produces continuants at the three levels, the degree of lenition is significantly less than in the control group’s productions. The advanced learners do not differ significantly from the control group at the syllable onset, and a positive TOST result indicates that the degree of lenition at this prosodic level is similar. The Bonferroni tests used to compare the advanced and control groups at the PW-min and PW-max yield a null result. Although the TOSTs are negative and therefore indicate an inconclusive outcome, the effect size values suggest very low practical significance in both cases. Although the beginner and intermediate learners’ intensity difference values are not native-like at the prosodic levels in which they produce continuants (i.e., the syllable onset for both beginners and intermediates; the PW-min and PW-max onset for intermediates), we were interested in whether learners’ intensity difference values decrease as proficiency increases. At the onset
of the syllable, a pairwise comparison of the beginner and intermediate learners yields a non-significant result ($p = 1.000$) and a positive TOST ($p < .05$) with an effect size of .13. Comparing the intermediate and advanced learners at the onset of the PW-min, there was not a significant difference ($p = .396$) and the effect size was .35. However, the TOST was negative ($p > .05$) and the intermediate mean (14.45 dB) falls above the upper limit of the advanced group’s CI ([9.88-13.78]). At the onset of the PW-max, there was a significant difference ($p = .006$) between the intermediate and advanced means.

**Discussion**

In this section, we begin with a summary of the results, and then address these results in light of our research questions, followed by a consideration of future research.

**Summary**

Our analysis reveals that all of the groups produce continuants at the prosodic level of the syllable onset (word-medial position). The beginner and intermediate groups’ intensity difference values are similar to each other (TOST $p < .05$) and lower than that of the control group, while the advanced group and control group produce continuants with similar intensity difference values (TOST $p < .05$). At the onset of PW-min (at the boundary of a lexical word and its clitic), the beginners produce stops while the other learner groups and controls produce continuants. The intermediate and advanced groups produce continuant segments with a lower degree of lenition than the control group, and there is an increase in lenition between intermediate and advanced proficiencies. At the onset of PW-max (at the boundary of two lexical words), the intermediate, advanced, and control groups produce continuants, and the advanced and control groups produce segments with a higher degree of lenition than the intermediate group. While the results of the statistical comparison between the advanced and control groups were inconclusive at this prosodic level (i.e., neither different nor similar), practical significance was very low.
Discussion of research question 1

We used cross-sectional data to determine a) whether late learners of L2 Spanish can acquire spirantization at all relevant levels of the hierarchy and b) whether acquisition occurs in stages according to the prosodic hierarchy. Recall that the intermediate and advanced learners’ intensity difference values at the prosodic level of the PW-max (and the levels below it) fall below the one-sided confidence interval established for a stop, which leads us to posit that these learners have acquired spirantization at the highest relevant level of the prosodic hierarchy. This finding patterns in part with what is reported in Face and Menke (2009) since the learners produce approximants in word-initial position. However, unlike in Face and Menke (2009), the advanced learners do not produce more continuants in word-medial position than across word boundaries and therefore pattern with the control group. Since there is no evidence that neither the advanced nor the control group differentiate among prosodic levels, data from these two groups do not warrant further consideration of the acquisition of postvocalic spirantization as a developmental process that spans multiple stages.

The beginner and intermediate data contain evidence of gradual categorical acquisition moderated by prosodic structure. Our results partially support Zampini’s (1997, 1998) original hypothesis that postvocalic stop lenition is acquired according to the prosodic hierarchy; spirantization is acquired first at the most restrictive domain (i.e., the onset of the syllable), as predicted by the Subset Principle. However, there is no evidence that continuants are produced first at the onset of the PW-min and subsequently at the onset of the PW-max. Instead, the data from the intermediate and advanced learners only allow us to conclude that the prosodic levels that moderate the acquisition of spirantization include a) the syllable and b) the prosodic word (without the distinction of minimal and maximal projections). While our data is limited to evidence of two domains that are operative in this process of acquisition, these data add to the evidence for the operation of phonological hierarchies in L2 acquisition that we reference in ‘Introduction’. We now propose a revised
constraint ranking that captures the stages of acquisition of this phenomenon and accounts for residual variation.

Assuming that learners start with an L1 English ranking in which the stricture faithfulness constraint IDENT-IO (CONT) outranks *VD STOP/V_, evidence from the beginner and intermediate learners indicates that L2 Spanish learners gradually acquire spirantization according to prosodic level. The data support our hypothesis that there are separate stricture faithfulness constraints, specifically for the onset of the syllable and prosodic word. While it is possible that there are separate PW-min and PW-max constraints that are simultaneously demoted, there is no evidence for this and we therefore assume here that there is a single PW constraint. Therefore, the two stricture faithfulness constraints in our analysis are IDENT-IO ONSET (CONT) SYLL and IDENT-IO ONSET (CONT) PW. As learners extend the domain of spirantization, they gradually demote IDENT-IO (CONT) ONSET SYLL, followed by IDENT-IO (CONT) ONSET PW. Once they demote IDENT-IO (CONT) ONSET PW, *VOICED STOP/V_ dominates all of the identity constraints and the target ranking is acquired:

(4) *VOICED STOP/V_ >> IDENT-IO (CONT) ONSET PW >> IDENT-IO (CONT) ONSET SYLL >> IDENT-IO (CONT) >> *APPROXIMANT/V_

The tableaux in Table 7 illustrate the beginners’ ranking. Recall that IDENT-IO (CONT) is the first constraint to be demoted because it is violated every time a continuant appears in the evidence, independent of prosodic domain. Since the beginners reliably produce continuants in word-medial position, we propose that IDENT-IO (CONT) ONSET SYLL has been demoted below *VOICED STOP/V_ (Table 7). However, since IDENT-IO (CONT) ONSET PW still dominates *VOICED STOP/V_, a stop is predicted to surface at the onset of the PW whether it shares a boundary with a function word or lexical word.
Table 7. Spanish postvocalic underlying stops – Beginners.

<table>
<thead>
<tr>
<th>prosodic level and input</th>
<th>output candidates</th>
<th>IDENT-IO (CONT) ONSET PW</th>
<th>*VOICED STOP/ V_</th>
<th>IDENT-IO (CONT) ONSET SYLL</th>
<th>IDENT (CONT)</th>
<th>*APPROXIMANT/V_</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. syllable /agua/</td>
<td>[ˈa.ɣuɑ]</td>
<td></td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
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<tr>
<td></td>
<td>[ˈa.ɣuɑ]</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>b. PW /buena gafa/</td>
<td>[ˈbɥe.na.ɣu.fa]</td>
<td>*!</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>[ˈbɥe.na.ɣa.fa]</td>
<td></td>
<td>*</td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td>[ˈbɥe.na.ɣa.fa]</td>
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</tr>
</tbody>
</table>

As an anonymous reviewer points out, the existence of approximants in English in word-medial position (see footnote 7) may facilitate the task of the beginners, i.e., their continuant production could be a result of transfer and not acquisition. This would align with findings from studies such as Major’s (1986) investigation of L2 Spanish rhotics. He found that learners produced Spanish [ɾ] in word-medial position with a higher rate of accuracy than in word-final position, and posited that this difference was due to the presence of [ɾ] in word-medial position in English. This is an empirical question which could be answered by comparing these beginners’ productions with those of learners at the very initial stages of L2 Spanish acquisition.

By examining the intermediate and advanced learners’ productions, we can address the other part of this first research question, which is whether learners can acquire a native-like categorical representation. Since the intermediate and advanced groups produce continuants across the prosodic levels we tested, we posit that a native-like representation has been acquired in which *VOICED STOP /V_ dominates the prosodically conditioned identity constraints. This means that a continuant will likely surface in postvocalic position at the onset of the syllable and PW (Table 8).
Anonymous reviewers bring up the question of whether acquisition is mediated by prosodic structure or by the frequency with which /b d g/ appear in a leniting context as a consequence of prosodic structure. They note that a postvocalic underlying stop in word-medial position will always surface as a continuant, and therefore continuants will be most frequent in the input in this context. At the PW-min, /b d g/ is likely to frequently be in a lenition context since a word will be preceded by a clitic, whereby there will be more variability in terms of the preceding segment at the PW-max. If segments at the onset of the PW-min appear more frequently in a leniting context than those at the onset of the PW-max (and less frequently than those at the onset of the syllable), then we would expect to find a difference in the learner data when comparing the two higher prosodic levels, which we did not. However, we agree that if the difference in frequency of segments in a leniting context is that much greater in word-medial position than in word-initial position, it is possible that the observed reranking occurs independently of the inherent ranking of the positional identity constraints. With that said, we cannot ignore the independent evidence of L1 and L2 acquisition according to prosodic structure that has been reported for other types of segments that may not have a similar confound of

<table>
<thead>
<tr>
<th>prosodic level and input</th>
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<th>*VOICED STOP/ V_</th>
<th>IDENT-IO ONSET PW</th>
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</tr>
<tr>
<td>b. PW /buena gafa/</td>
<td>ˈbye.na.ɣa.fa]</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ˈbye.na.ˈga.fa]</td>
<td>*</td>
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</table>

Table 8. Spanish postvocalic underlying stops – Intermediate/Advanced/Control.
frequency and structure (see ‘Introduction’). This is an empirical question that could be pursued going forward by determining the frequency of leniting contexts in each position and running a simulation of the GLA with this frequency information.

Discussion of research question 2

We have presented evidence that the L1 English/L2 Spanish learners in the present study acquire postvocalic spirantization in stages according to prosodic structure, and that a native-like constraint ranking can be acquired. That said, a target-like constraint ranking does not guarantee that the continuants that learners produce will be native-like in their degree of lenition. Within this study, we consider two pieces of the acquisition puzzle, the first being the acquisition of categorical representation and the second being the development of the acoustic representation of the target approximant category.

To address native-like acoustic target development, we compared the learners with the control group. While the beginners produce continuants at the onset of the syllable, the control group’s segments are significantly more lenited than the beginners’, which indicates that the group has not fully developed the acoustic representation of the target. Comparing the control group with the intermediate learners, who produce continuants at the three levels\textsuperscript{16} tested, there are significant differences at all three levels. Thus, we can conclude that these learners’ continuant productions are not target-like. While the advanced and control groups produce continuants with a similar degree of lenition at the onset of the syllable, their comparison at the two higher levels is not as clear, although individual data inform the question of whether at least a subset of the learners lenite postvocalic stops to the same degree as the native control group. At the PW-min, there is

\textsuperscript{16} While the categorical data do not show evidence of separate stages of acquisition at the PW-min and PW-max, we did not collapse the PW-min and PW-max data in order to determine whether there were gradient differences at these two prosodic levels.
a significant difference in the degree of lenition at the PW-min with a medium effect size. However, seven out of 20 advanced learners fall below the upper limit of the control group’s 95% CI (10.02 dB), that is, they produce segments that are lenited to the same degree as the controls. At the PW-max, 10 learners fall below the upper limit of the control group CI (11.00 dB) and 10 fall above. A total of six of the learners produce target-like segments across the three levels. Thus, it would appear that several individuals have converged on the acoustic target as well as the target constraint ranking across the prosodic levels.

The variability in native-like attainment among the advanced learners leads us to a consideration of the source of difficulty in producing a native-like continuant. One possibility is that some have not been accurately been categorized as advanced learners. We recognize that the proficiency measurement used to categorize the participants might not adequately reflect proficiency as it relates to phonological production, and that the oral proficiency of some of the learners might be more advanced than the others. Since carrying out this project, we have begun implementing foreign accent ratings as a global oral proficiency measurement (e.g., Authors, 2016), the use of which could result in placement of some of these advanced participants in a lower proficiency group. Another possibility is that acquisition has fossilized as a result of one or more factors that have been reported to impede native-like L2 production (see e.g., Broselow and Kang, 2013 for a review of these factors). While additional factors may be at play, we posit that speech rate might be a locus of the difference in degree of lenition between these advanced learners and controls. Degree of lenition increases as a function of speech rate; given that L2 speech is typically slower than native speech (e.g., Derwing and Munro, 1997), it is possible that higher rates of intensity difference could be due in to slower speech rate. Learner speech rate might also be reduced in this case because of the task type; spontaneous speech samples could potentially yield lower intensity difference.
In addition to ultimate attainment, we were interested in whether there was evidence of target development according to word position. There are several indications of this type of development: First, the beginner and intermediate learners produce segments that are less lenited than the controls’ segments while the advanced group produces segments that are equally lenited, suggesting development at the most restrictive setting for postvocalic stop lenition. Second, the intermediate learners produce more lenited segments at the level of the syllable than at the PW-min and PW-max, which again points to differential development of the target at the lowest prosodic level. Third, the intermediate learners produce less lenited segments than the advanced group at the PW-min and PW-max. This last finding highlights the benefit of approaching the acquisition of L2 spirantization from both categorical and gradient perspectives. If we were to limit our investigation to categorical acquisition, we might conclude that the intermediate learners had fully acquired L2 spirantization. However, the difference in degree of lenition between the intermediate and advanced/control groups suggest that there are two parts to this acquisition story.

Comparing these results with those of the two previous studies that have examined degree of lenition in L2 Spanish spirantization, there are commonalities in terms of both acquisition and ultimate attainment. Data from Shea and Curtin (2011) indicate that the high intermediate learners they tested produced segments that were (descriptively) more lenited than the segments that low intermediate learners produced in both word-medial and word-initial positions, although not native-like. Our data show that there is further reduction in intensity difference between intermediate and advanced proficiencies, and that it is possible for learners to eventually develop a native-like acoustic target. These findings mirror the smaller-scale findings in Rogers and Alvord (2014) in terms of a) development of the acoustic target across proficiency levels and b) ultimate attainment, and do so with a larger sample size (n=20) and with inferential statistical support.
Residual variation

A frequent question that comes up in the study of second language acquisition is why an adult L2 learner can so often be identified as a nonnative speaker even at a very advanced level of proficiency, and we believe it is possible to use L2 spirantization as a case study to consider this question. As reported, there are several advanced learners that have acquired the categorical representation but not developed the relevant acoustic target. However, what about the advanced learners that have successfully developed the target? Let’s take advanced participant 1003, for example, whose lenition is native-like across the three prosodic levels. In Authors (2016), a 15-second speech sample from this participant was submitted to a foreign accent rating whereby native Spanish speakers assigned a score between 1 (very strong foreign accent) and 7 (without a doubt is a native speaker). The score given to the participant was 5.50 out of 7, which indicates that his global oral proficiency falls short of that of a native speaker. There are undoubtedly numerous variables that raters attend to when making their judgments (e.g., intonational patterns, other segmental phenomena, verbal fluency, etc.), but we would like to propose that one of the variables that might be responsible for a non-native accent is residual optionality, which can be explained by overlapping constraints. If we examine the individual data points of the learners who appear to have converged on the target ranking as well as the acoustic target, five of the learners produce at least one stop at each prosodic level. Even participant 1053, who exclusively produces continuants at the two lower levels, produces two stops at the PW-max. These findings align with those of Face and Menke (2009), who found that the PhD students they tested continued to produce stops upwards of 20% of the time. Recall that within a stochastic model of OT, variable outputs can persist when two constraints’ ranking values are close to one another. It is therefore possible that although the probability distributions have been adjusted such that these learners have acquired the native-like ranking shown in in Table 9, the ranges that *VOICED STOP /V_ and the relevant IDENT constraint(s) occupy are
overlapping. As long as the selection points do not occur where there is overlap (Figure 9), a continuant will be produced. However, if the selection points for the relevant constraints occur in the space in which the constraints overlap (Figure 10), a stop will be produced.

Figure 9. Selection points for two constraints that are made outside of the range in which there is overlap.

Figure 10. Selection points for two constraints that are made in the range in which there is overlap.

Considering that there are 18 tokens for each prosodic level, if a learner produces one stop, we can assume that the constraint overlap is minimal since the probability that a continuant will surface is very high. On the other hand, consider advanced participant 1014, who produces 10/18 stops across the boundary of two lexical words; the constraint overlap is such that there is a higher probability that the selection points will result in an \textsc{ident-IO (cont) onset PW} >> *\textsc{voiced stop /V_} ranking than a *\textsc{voiced stop /V_} >> \textsc{ident-IO (cont) onset PW} ranking.
Future directions

The findings in this study lead us the considerations for future investigations related to L2 acquisition and L1 acquisition, respectively.

Although our data do not support Zampini’s (1997, 1998) finding of a separate stage of acquisition at the onset of the PW-min, it is possible that our cross-sectional investigation does not capture the full path of acquisition. After all, this is the only study to use acoustic data to address segment position beyond a word-medial/word-initial distinction and thus additional research would be welcome. In particular, a longitudinal examination of L2 spirantization would afford observation of the acquisition process across the same individuals without the obstacle of classifying learners according to proficiency. Such a study would allow us to a) determine at the initial stages whether learners transfer spirantization in word-medial position from English and b) identify any intermediate stages of acquisition.

Our second consideration is that of L1 acquisition of postvocalic stop lenition. Adult L2 data can inform phonological theory in a way in which adult monolingual data cannot, because we are able to observe development, including the effects of the prosodically conditioned constraints that we have proposed here. Indeed, we provide further experimental evidence in support of the Subset Principle (e.g., Wexler and Manzini, 1987), showing that adult L2 learners start with the most restrictive grammar and expand their grammar according to positive evidence in the input. That is, postvocalic lenition is first evident in word-medial position (at the onset of the syllable), and as proficiency increases, learners lenite across word boundaries at the onset of the prosodic word. However, we can only make claims for L2 learners, as we cannot be sure that the L2 developmental path is the same as the L1 developmental path. As noted in Schuttenhelm (2013), although the acquisition process has led to a native-like target (at least for some), the underlying representation (in this case, the constraint ranking) for an L2 learner might be different from that
of a native speaker of Spanish. The only way to verify this is of course via investigation of children’s productions. While several studies have investigated children’s acquisition of spirantization (e.g., Barlow, 2003; Fabiano-Smith et al., 2014; Murillo, 1978), their studies have not explicitly addressed position of the segment.

**Conclusion**

The primary aim of this study has been to test the hypothesis that adult L2 acquisition of postvocalic continuants is moderated by the prosodic hierarchy. Within a stochastic Optimality Theoretic framework, we proposed an analysis of gradual frequency-driven acquisition according to prosodic structure and provide acoustic data that supports that L2 Spanish learners acquire postvocalic spirantization according to prosodic structure. We also determined that while learners can acquire a native-like representation (i.e., constraint ranking), the development of native-like acoustic representations is harder to come by. Importantly, the analysis accounts for data which support advanced learners’ attainment of a native-like target, while also explaining why we observe non-native outputs even at near-native proficiency.
Appendix 1. Recitation task items according to prosodic level

**Syllable**
- arriba
- hábito
- ubica
- dibujo
- abusar
- duda
- rodilla
- adivinar
- maduro
- madurez
- regar
- hígado
- seguir
- águila
- aguja
- agujero

**PW-min**
- mi barrio
- la ballena
- la biblia
- mi bigote
- lo busqué
- su burro
- su dado
- lo dañaba
- la dicha
- su dinero
- la duda
- de dureza
- mi gato
- su ganancia
- una guía
- la guitarra
- su gusto
- tu gusano

**PW-max**
- es un curso básico
- me quiero bajar
- es algo bíblico
es mi primera bicicleta
es un estilo buque
quiere buscar a ella
necesito darme cuenta
no puedo dañarme
es una vida digna
da ella quiere disfrazarse
es una chica dudosa
no tengo ganas
le puede garantizar
odio guiar a ellos
tiene gusto de fútbol
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