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Perceptual discrimination and categorization of vowels in different levels of foreign language instruction

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ABSTRACT: This paper reports on the development of L2 English vowel pair perception by adult L1 Spanish/Basque speakers of differing levels of English instruction. This study focuses on vowel pairs /i-ɪ/, /u-ʊ/ and /ʌ-ɔ/, with differing levels of proximity to native categories. Results of two perceptual tasks show that learners are influenced by their native categories, but that regardless of level, they can still modify their representations. However, the success in categorization varies by sound based on acoustic distance and multiple category competition.

KEYWORDS: speech perception; vocalic contrast; category development; phonemic processing; L2 phonology; adult acquisition.

1. Introduction

The ultimate native-like attainment of the speech categories of a second language is a notably difficult achievement in the process of language acquisition, with rare successful cases and a generalized trend to accented perception and production of L2 sounds (Bongaerts *et al.* 1997; Colantoni *et al.* 2015; Escudero 2007; Strange & Shafer 2008). Two main factors cause this: age and the influence of L1 speech categories. However, research has shown that learners can adapt their L2 speech categories during their lifetime and that phonological representations can change (Flege 1995, 2003; Singleton & Ryan 2004). This article aims to study the effect of different levels of language instruction on the perceptual discrimination and categorization of L2 English vowel pairs by L1 Spanish/Basque speakers.

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1.1. Age and L1 effect

In lay terms, “younger is better” has been a constant in second language acquisition and pedagogy. The Critical Period Hypothesis (Lennenberg 1967) established a sharp window between age 2 and puberty, after which a second language cannot be acquired due to brain lateralization (Singleton & Ryan 2004). The acquisition of L2 phonology has been considered especially prone to decline, as neuromotor constraints like gestures solidify early (Archibald 1998). Aside from a critical period, maturational states and sensitive periods have been described, where the capacity to acquire L2 phonology gradually declines. Different age windows have been given, but most show a steeper decline in early adolescence.

Other theories focus on role of the L1. Speech processing capacity is influenced early and heavily by first language exposure. As a result, the representation of speech categories depends on perceptual mappings specific to this language (Bradlow 1995; Escudero 2005; Guion-Anderson 2013; Strange & Shafer 2008). Humans can perceive any fine-grained phonetic differences at birth and shortly after. However, at age 1, the perceptual warping caused by massive exposure to the L1 directs attention to articulatory and acoustic information solely relevant to the discrimination and identification of native speech categories, ignoring non-relevant phonetic information (Strange & Shafer 2008). Thus, the level of attention to L2 phonetic information will depend on L1 phonological relevancy (Flege 2003).

Several L2 speech perception theories like the Perceptual Assimilation Model (PAM, Best 1995; Best & Tyler 2007) and the Speech Learning Model (SLM, Flege 1995) have looked at how this L1-specific warping affects L2 speech. Both share two important points: first, predictions can be made on the difficulty of specific L2 sounds based on the acoustic or articulatory similarity or distance between L1 and L2 speech categories. Second, the capacity to perceive L2 categories remains malleable during the learner’s lifespan (Archibald 1998; Escudero, Benders & Lipski 2009; Flege 1995, 2003; Guion-Anderson 2013). Assuming the possibility of successful L2 phonology acquisition, a specific analysis of the similarities and differences between English and Basque/Spanish vowels could elucidate which will be more challenging.

1.2. Comparison of English and Basque/Spanish vowels

English and Basque/Spanish vocalic inventories differ both qualitative and quantitatively. Basque and Spanish have a common 5-vowel inventory occurring in many other world languages (Maddieson 1984), and they do not present major inter-dialectal variation (Bradlow 1995; Hualde 2005). English has an unusually large inventory ranging from 11 to 13 depending on the variety (Bradlow 1995; Maddieson 1984). Unlike Basque and Spanish, it has a contrastive tense/lax distinction and in some dialects, a durational contrast. English also has lexical stress, which causes the centralization of atonic vowels to [ə]. Basque and Spanish vowels tend not to reduce despite stress placement. Midwestern American English has an inventory of 11 vowels, /i ɪ e ɛ æ ʌ ɑ ɔ o ʊ u/, which compared to Basque and Spanish, present a very crowded vocalic space (Flege 1995; Bradlow 1995; Iverson & Evans 2007) with the following distribution:

Table 1

Bradlow (1995): Spanish vowels produced by a male speaker

Phoneme	F1	F2
/i/	286	2147
/e/	458	1814
/a/	638	1353
/o/	460	1019
/u/	322	992

Table 2

Bradlow (1995):
English vowels produced by a male speaker in a CVC sequence

Phoneme	F1	F2	Phoneme	F1	F2
/i/	268	2393	/ɑ/	780	1244
/ɪ/	463	1995	/ɔ/	620	1033
/e/	430	2200	/o/	482	1160
/ɛ/	635	1796	/ʊ/	481	1331
/æ/	777	1738	/u/	326	1238
/ʌ/	640	1354			

The English vocalic space is more fronted and peripherally distributed in a trapezoidal shape (Hualde 2005). Seven English categories are not present in Basque and Spanish (/ɪ ɛ æ ʌ ɑ ɔ ʊ/) and /a/ is not present in this English variety. All languages share /i e o u/, but they are phonetically different. Basque and Spanish /i e o u/ are pure monophthongs: [i e o u]. In contrast, English /i/ and /u/ are longer and slightly diphthongized at the end: [iʲ uʷ] (Hualde 2005). English /u/ is also fronted to a more central position, [ʉʷ], in some varieties including the Chicagoland area (Cummings Diaz 2019). English /e/ and /o/ is diphthongized in American varieties, [eʲ] and [oʷ]. The former is also a middle point of a phonological contrast in Spanish between /e/ and /ei/ (ex: *des* 'that you give' vs. *deis* 'that you all give'), which does not exist in American English (Hualde 2005). All four English vowels have lax counterparts /ɪ ɛ ɔ ʊ/. A key difference between Basque/Spanish and Midwestern English vowels is that while the former only have one central low vowel, /a/, English has no central low vowel, but three front and back low vowels.

1.3. Previous literature on Spanish-English perception

The unconventionally large vocalic inventory and distribution of English poses difficulties to L2 learners with smaller 5-vowel inventories (Cenoz & García Lecumberri 1999), as evidenced by several studies on L2 English L1 Spanish perception. Due to this mismatch, the acoustic characteristics of Spanish native vowels can be perceived as more than one L2 counterpart. Analyses of acoustic differences between

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L2 English and L1 Spanish vowels show that distance between categories in the vocalic space is a significant marker for perceptual discrimination (Flege, Munro & Fox 1994). The dependency of perception on L1 has further been researched in multi-language studies, which show that native speakers learning an L2 will fare better in perceiving the same phonological categories present in their language, as opposed to native speakers who do not have that category in their inventory (Flege, Bohn & Jang 1997).

Assuming the SLM (Flege 1995) premises that speech perception is malleable during one's lifespan and that L1 and L2 categories are not separate, many researchers have investigated how experience and exposure to the L2 can aid in the accommodation and development of L2 categories in vocalic spaces (Flege 1991; Flege, Bohn & Jang 1997; Levey & Cruz 2004). Other factors to measure the effect of experience have been age of arrival (AOA) and length of residence (LOR) in an English-speaking country. In general, experienced learners that have a longer LOR are more successful in perceiving English categories (Boomershine 2013; Flege, Bohn & Jang 1997; Levey & Cruz 2004), but not always (Flege 1991; Flege, Munro & Fox 1994).

Researchers have also looked at experience as L2 proficiency and instruction level, with mixed results: more proficient L1 Spanish learners of English have been found to have a vocalic space resembling a native English speaker, suggesting a gradual modification in the perceptual dimensions used in the identification of vowels (Fox, Flege & Munro 1995). Archila-Suerte *et al.* (2011) found a higher rate of between-categorization of L2 English sounds among more proficient learners. Even when learning other L2s, proficient L1 Spanish speakers have outperformed inexperienced learners (Escudero *et al.* 2009). Other studies have found no correlation between L2 proficiency and perceptual abilities (Cebrian 2006; Escudero & Wanrooij 2010; Kondaurova & Francis 2008; Morrison 2008). However, these studies have had small, uneven, or binary distributions of proficiency levels.

Experience outside of an English-speaking country or an EFL setting has been studied along with the age factor. It is estimated that language learning in a formal setting is both qualitatively and quantitatively in an 18-year disadvantage when compared to naturalistic language learning (Singleton & Ryan 2004). However, an advantage to a late starting age has also been observed (Bongaerts *et al.* 1997; Fullana & Muñoz 1999; Gallardo, García Lecumberri & Cenoz 2006; García Lecumberri & Gallardo 2003; Mora & Fullana 2007). Gallardo *et al.* (2006: 66) state: "starting age is not as important as other variables such as quantity, intensity and quality of exposure, teaching methodology or cognitive development." Therefore, factors like cognitive maturational levels (García Lecumberri & Gallardo 2003) and metalinguistic knowledge of EFL learners resulting from their formal instruction (Cebrian 2006) could aid foreign language learners in acquiring and developing L2 perception, and longer periods of exposure studying the language could mean an advantage in perceptual development in foreign language contexts (Bongaerts *et al.* 1997; Cebrian 2006; Singleton & Ryan 2004). Also, some studies comparing learners in naturalistic and formal settings did not find significant differences in L2 perception (Boomershine 2013; Cebrian 2006).

2. Methods

2.1. Participants

Two sets of participants were recruited for this experiment: the stimuli group and the experimental group. The stimuli group were 5 native English speakers from the Midwest who were recruited to record the stimuli. The experimental group were 45 L2 English learners from the Basque Country (mean age: 32, range: 20-59), whose L1 was Basque and/or Spanish.[1] Participants were divided in three groups by instruction level: beginner (17), intermediate (13), and advanced (15). Placement was determined by a combination of a cloze test from MELICET (CaMLA 2018) and their self-reported level. Further information on certifications and use and exposure to English were collected when needed. An experimental native control group (4) from the Midwest was also recruited as a baseline.

2.2. Vowel pairs

The vowel pairs under study were the following: /i-ɪ/, /u-ʊ/, and /ʌ-ɔ/. These were chosen due to their functional load (phonemic opposition, frequency of opposition and environmental occurrence, Brown 1991) and to the different results garnered in previous literature: Munro & Derwing (2006) found that functional load was a conducive effect for perceptual discrimination. /i-ɪ/ is considered to have a high functional load (Gilner & Morales 2010), which could result in confusion in communication exchanges due to errors in the pair's perception. In previous studies, English /i/ was found to be a near-identical category to Spanish /i/, whereas English /ɪ/ was similar to both Spanish /i/ and /e/ (García Lecumberri & Cenoz 1997; Escudero & Chládková 2010). The pattern of /u-ʊ/ mirrors that of /i-ɪ/: English /u/ is nearly identical to Spanish /u/, and English /ʊ/ was similar to Spanish /u/ and /o/ (Escudero & Chládková 2010). However, this pair has one of the least functional loads (Brown 1991; Gilner & Morales 2010). Moreover, evidence of goose-fronting for has been found in the Midwest (Cummings Ruiz 2019), which could distance these categories from their Basque/Spanish counterparts. Finally, /ʌ-ɔ/ has a mid-low functional load, as it has a few minimal pairs, but these are relatively frequent (Gilner & Morales 2010). Escudero & Chládková (2010) found both sounds to be assimilated to Spanish /a/ and /o/, but in different proportion. Thus, this vowel pair would be considered similar to Basque/Spanish /a/ and /o/ or two single category assimilation scenarios.

2.3. Procedure

The experiment was divided in two rounds: stimuli data and experimental data extraction. The stimuli data was collected at a sound-attenuating booth at the Phonetics and Phonology Laboratory at the University of Illinois at Urbana-Champaign. Each participant recited 364 words, 52 contained the target vowels.

[1] Due to the same vowel inventory across languages, L1 was not considered a factor.

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For the experimental data, participants first completed an ABX discrimination task on PsychoPy (Peirce 2007). Participants heard 86 minimal pair sequences: 60 filler and 26 target pairs (10 for the /i-ɪ/ pair, 6 for the /u-ʊ/ pair and 10 for the /ʌ-ɔ/ pair). They heard the target pair sequences twice. Participants heard the minimal pair produced by one native speaker (AB), followed by one of the words produced by another native speaker (X). Participants responded which word the second speaker repeated. Each word of the vowel pair had an allocated sequence where it was the correct answer. The task took 30 minutes, had two breaks and the order of sequences was randomized.

Secondly, participants completed a category assimilation task and the MELICET test. In the first task, they heard 114 words in randomized order in PsychoPy (Peirce 2007). These words the same from the X column in the ABX task. 50 were target words, 18 for the /i-ɪ/ pair, 12 for the /u-ʊ/ pair, and 20 for the /ʌ-ɔ/ pair. Participants were asked to choose which Basque/Spanish vowel they heard. They also could choose "none". After, they gave a goodness rating for the vowel from 1 (not a good example of the vowel) to 5 (perfect). When choosing "none", they did not rate it. Both answers were combined to calculate a fit index score. In the second task, participants completed the MELICET. This test included 30 multiple-choice questions and a cloze test with 20 fill-in-the-gap multiple choice items. The score cut-off was 0-20 for beginner, 21-35 for intermediate, and 36-50 for advanced learners.

2.4. Data analysis

2.4.1. Stimuli data

First, the vowel of each target word was manually segmented on *Praat* (Boersma & Weenink 2009) establishing boundaries considering both the waveform and the spectrogram. The midpoint F1 and F2 values were extracted with a script. Z-score normalization was done to the F1 and F2 values to to avoid non-parametric data due to gender differences. After, an interlanguage analysis was done to compare the differences in F1 and F2 between English and Basque/Spanish vowels. These data came from recordings in Spanish from the experimental participants done for another study and were normalized with Z-scores (Figure 1).

As learners use their native language prototypes to perceive English vowels (García Lecumberri & Cenoz 1997), the mean F1 and F2 values of both the English and the Spanish recordings would show the following phonetic relationship (Table 3):

- /i-ɪ/: English /i/ is closer to Spanish /i/ and English /ɪ/ is closer to /e/. The closest vowel relationship is of English /i/ and Spanish /i/: there is a 6hz difference for both F1 and F2 values. The difference of English /ɪ/ and Spanish /e/ is of 61hz for F1, and 181hz for F2.
- /u-ʊ/: English /u/ is closer to Spanish /u/: The F1 difference is of 13hz and the F2 is of 55hz. English /ʊ/ is close to both Spanish /u/ and /o/. Spanish /o/ is closer to /ʊ/ (F1 distance = 67hz). The F2 difference between /ʊ/ and Spanish /u/ and /o/ is the same.
- /ʌ-ɔ/: For both English vowels, Spanish /a/ has the closest F1 values, and Spanish /o/ has the closest F2 values.

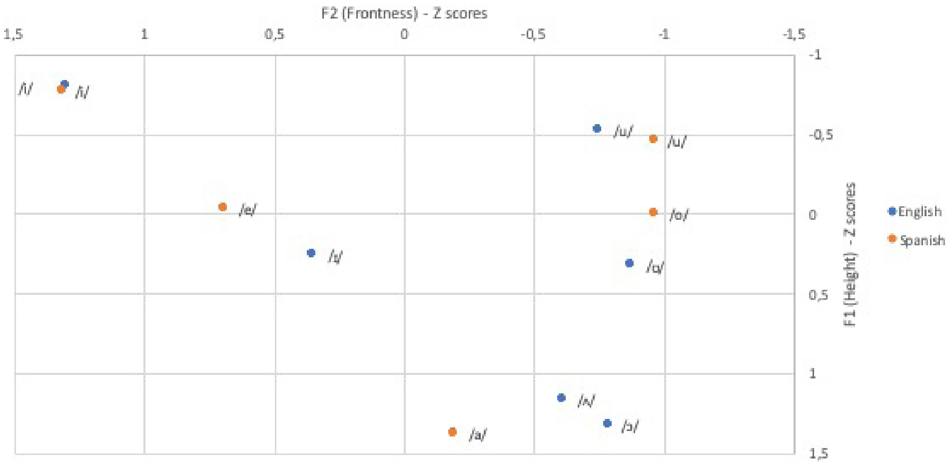

Figure 1

Z-score normalized mean English and Spanish F1 and F2 values

Table 3

Mean F1 and F2 values for English stimuli and closest Spanish equivalent(s) from L1 Spanish speaker recordings

English Vowel	English Values		Spanish Vowel	Spanish Values	
	F1	F2		F1	F2
/i/	314	2486	/i/	320	2492
/ɪ/	535	1885	/i/, /e/	320, 474	2492, 2066
/u/	373	1112	/u/	386	1057
/ʊ/	549	1191	/u/, /o/	386, 482	1057, 1056
/ʌ/	725	1278	/a/, /o/	769, 482	1542, 1056
/ɔ/	758	1167	/a/, /o/	769, 482	1542, 1056

The cross-linguistic categorization is expected to be the following (Table 4):

Table 4

Expected cross-linguistic categorization of English vowels as Basque/Spanish categories based on formant proximity

(Near-)identical		Similar	
English	Basque/Spanish	English	Basque/Spanish
/i/	/i/	/ɪ/	/i/ /e/
/u/	/u/	/ʊ/	/o/, /u/
		/ʌ/	/a/, /o/
		/ɔ/	/a/, /o/

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2.4.2. ABX discrimination task

This analysis aimed to see the differences across vowel pairs and instructional levels. There were 52 target responses per participant. Each response was analyzed by vowel pair, instruction level, and the correct vowel of the sequence. Responses were coded for correct/incorrect and reaction time. Responses exceeding RT by 5 seconds were discarded. A logistic regression (glm) was run for the response data. The dependent variable was response accuracy. A linear mixed effects regression (lmerTest) was run for RTs. The dependent variable was reaction time in milliseconds. The fixed factors were vowel pair (/i-ɪ/, /u-ʊ/, /ʌ-ɔ/) and instruction level (advanced, intermediate, beginner, native). Random factors were participant and word. Tukey-LSD post-hoc pairwise comparisons were done to the logistic regression.

2.4.3. Category assimilation task

This analysis aimed to see how each vowel is perceived and rated by instructional level, and it was done in two steps. First, 2227 tokens were analyzed by response and goodness rating. Average responses and goodness ratings were calculated for each target English vowel depending on the Basque/Spanish category. Ratings went from 1 (not a good example of vowel) to 5 (perfect example of native vowel). For instance, English /i/ was categorized as Basque/Spanish /i/ 88.52% of the times, and the mean goodness rating was 4.16/5, which would indicate English /i/ to be a good fit for Basque/Spanish /i/. However, as vowels could be categorized as a certain native vowel but be rated as a bad fit, a fit index was calculated (Cebrian 2006; Guion, Flege, Akahane-Yamada & Pruitt 2000). The fit index combines the categorization and the goodness rating into one. It multiplies the proportion of L2 vowel categorization to an L1 category (ex: /ɪ/ as /e/) by the mean goodness rating of said categorization. The previous example would be 0.88 × 4.16 = 3.68. Mean fit indexes and standard deviations were calculated as in Guion *et al* (2000). Only fit indexes for vowel categorization responses higher than 25% were calculated. Fit indexes above one standard deviation from the mean were considered good fits. Differences across levels of instruction were also analyzed.

3. Problem statement and research questions

3.1. Problem statement

The vowel inventories of Basque/Spanish and Midwestern English vary both in quantity and quality. As the former have less categories, many English vowels are perceived as native Basque/Spanish categories with varying difficulty (Flege 1991; Cenoz & García Lecumberri 1999; García Lecumberri & Cenoz 1997; Iverson & Evans 2007). Factors affecting L2 perception in foreign settings have sometimes been overlooked. This experiment aimed to fill a gap by focusing on general instruction level in an EFL setting, by analyzing the perception of beginner, intermediate and advanced L1 Spanish/Basque-L2 English learners in a foreign-language environment. A combination of instruction level and vowel pairs with different levels of difficulty, this study aims to help learners and instructors tailor L2 phonological teaching and learning to improve communication and avoid perceptually-based confusion.

3.2. Research questions and hypotheses

1. Which vowel pairs will be most difficult to discriminate?

Considering the acoustic proximity between English and native categories and the functional load of the vowel pairs, as well as that only /i/ and /u/ are prototypes between L1 and L2 categories, it is expected that /i-ɪ/ will be easiest to discriminate, followed by /u-ʊ/. As both /ʌ/ and /ɔ/ are similar but not prototypical to any native Basque/Spanish category and are equally close to both native /a/ and /o/, this pair will be the most difficult to discriminate.

2. Which English vowels will be assimilated more to native categories?

Since they are identical or near-identical categories, English /i/ and /u/ will be assimilated more than similar categories.

3. Does instruction level influence the perception of L2 English vowels?

Few studies (Archila-Suerte *et al.* 2001; Flege *et al.* 1997) have researched the link between general proficiency/instruction level and L2 perception, but a better perception is observed in high proficiency bilinguals and experienced learners. It is thus expected advanced learners will that show better perceptual results than intermediate and beginner learners.

4. Results

4.1. Discrimination task

4.1.1. Vowel pair effects

The first analysis focused on the effect of vowel pair (/i-ɪ/, /u-ʊ/, /ʌ-ɔ/). Reaction times and response accuracy (correct/incorrect) were analyzed. The reference level was /ʌ-ɔ/. The linear regression on reaction times showed a significant effect of vowel pair (Table 5):

Table 5

Lmer model for the effect of vowel pair on reaction times

Coefficients	Estimate	Std. Error	Df	T value	Pr (>|t|)
(Intercept)	1.21	0.16	48.65	7.44	< 0.001***
Vowel pair /i-ɪ/	–0.21	0.05	23.34	–4.23	< 0.001***
Vowel pair /u-ʊ/	–0.20	0.05	22.95	–3.50	0.002**

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The /ʌ-ɔ/ vowel pair was significantly different from the other two, particularly /i-ɪ/. A post-hoc analysis showed that reaction times were the fastest with vowel pair /i-ɪ/ (m = 137ms), followed by /u-ʊ/ (m = 138ms) and lastly, /ʌ-ɔ/ (m = 158ms) (Figure 2). Out of each vowel pair, /i/ (m = 126ms), /u/ (m = 133ms) and /ʌ/ (m = 156ms) had the fastest reaction times.

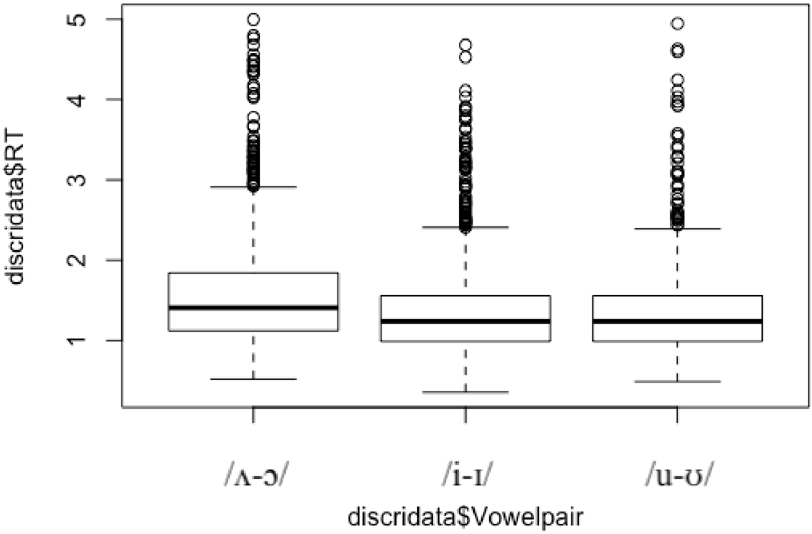

Figure 2

Average reaction time per vowel pair in discrimination task

The logistic regression on response accuracy also showed a significant vowel pair effect (Table 6):

Table 6

Glm model for the effect of vowel pair on response

Coefficients	Estimate	Std. Error	Z value	Pr (>|z|)
(Intercept)	1.88	0.26	7.05	< 0.001***
Vowel pair /i-ɪ/	1.08	0.11	9.41	< 0.001***
Vowel pair /u-ʊ/	1.41	0.14	9.53	< 0.001***

As with reaction times, /ʌ-ɔ/ significantly differed in accuracy from the other vowel pairs, but a post-hoc analysis showed that there was no significant difference between /i-ɪ/ and /u-ʊ/. Participants were the most accurate with /u-ʊ/ (88.83%), followed by /i-ɪ/ (85.15%) and /ʌ-ɔ/ (66.21%) (Figure 3). Out of each vowel pair, participants were the most accurate when the target vowel was /i/ (96.41%), /u/ (94.16%) and /ʌ/ (70.13%).

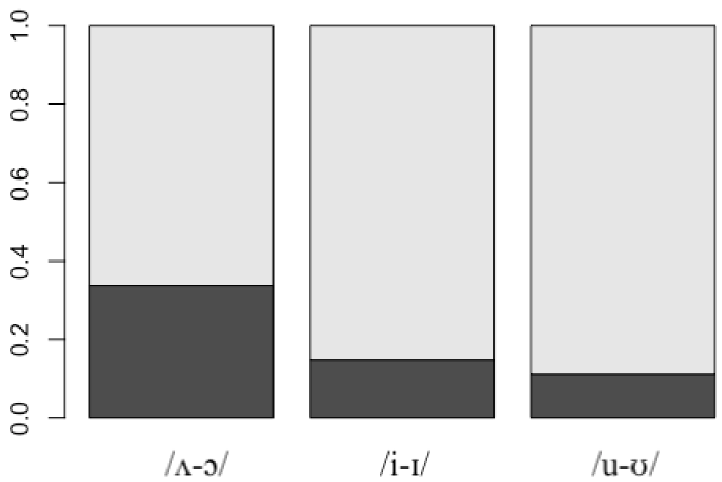

Figure 3

Average proportion of correct (grey)
and incorrect (black) responses per vowel pair in discrimination task

In sum, the analysis on vowel pair shows that the vowel pair /i-ɪ/, and individually, the vowel /i/ had the fastest reaction times. The vowel pair /u-ʊ/, and individually, the vowel /i/ were discriminated most accurately.

4.1.2. Instruction level effects

The second analysis focused on the effect of instruction level (advanced, intermediate, beginner, native). The same dependent variables were analyzed. The reference level was changed to "native" to compare it to L2 instruction groups. The linear regression on reaction times showed a significant effect of instruction level (Table 7):

Table 7

Lmer model for the effect of instruction level on reaction times

Coefficients	Estimate	Std. Error	Df	T value	Pr (>|t|)
(Intercept)	1.21	0.16	48.65	7.44	< 0.001***
Beginner	0.44	0.17	44.82	2.53	0.01*
Intermediate	0.49	0.18	44.82	2.68	0.01*
Advanced	0.31	0.17	44.83	1.73	0.08

Compared to L2 instruction groups, the reaction times of the native group were significantly faster than the beginner and intermediate group, but not the advanced group. A post-hoc analysis also showed no significant difference between the beginner and intermediate groups. The fastest group was the native group (m = 108ms),

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followed by the advanced (m = 138ms), beginner (m = 153ms) and intermediate groups (m = 157ms) (Figure 4).

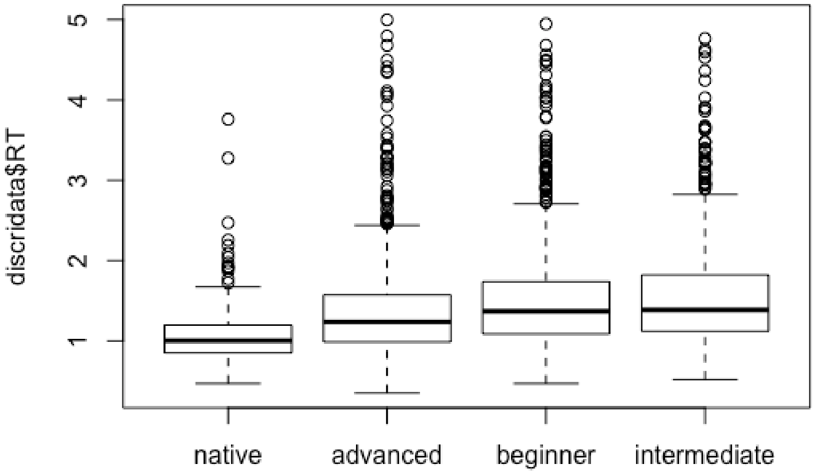

Figure 4

Average reaction time per instruction level group in discrimination task

The logistic regression on response accuracy also showed a significant effect of instruction level (Table 8):

Table 8

Glm model for the effect of vowel pair on response

Coefficients	Estimate	Std. Error	Z value	Pr (>|z|)
(Intercept)	1.88	0.26	7.05	< 0.001***
Beginner	–1.23	0.27	–4.45	< 0.001***
Intermediate	–1.46	0.27	–5.22	< 0.001***
Advanced	–1.19	0.27	–4.26	< 0.001***

The native group was significantly different in response accuracy from all L2 groups. However, a post-hoc analysis showed that there were no significant differences across L2 groups. The native group discriminated accurately 92.15% of the time, followed by the advanced (78.91%), beginner (78.29%) and intermediate groups (74.46%) (Figure 5).

In conclusion, instruction level did show significant differences in reaction times. The advanced group was the fastest of all L2 groups and was not significantly different from the native control, unlike the beginner and intermediate groups. The advanced group was the most accurate from the L2 groups, but this was not statistically significant. The intermediate group was the slowest and least accurate.

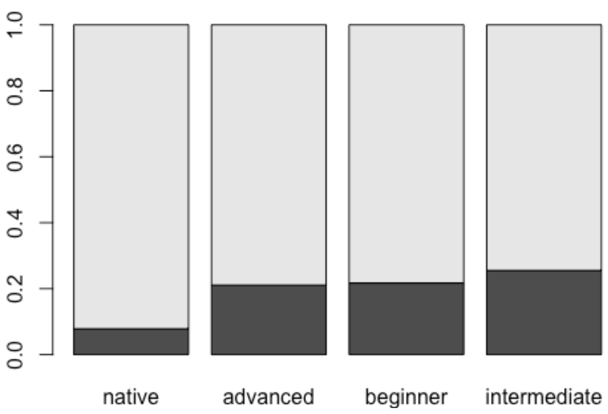

Figure 5

Average proportion of correct and incorrect responses per instruction level group in discrimination task

4.2. Category assimilation task

4.2.1. General vowel effects

In this task, vowels were analyzed separately. Participants decided whether the English vowel they heard sounded like Basque/Spanish /a/, /e/, /i/, /o/ or /u/ (or none of them). The results were the following: English /i/ and /u/ were consistently rated as native /i/ and /u/ respectively (88.52%, 85.19%). /ɪ/ and /ʊ/ were rated as two native categories each (/ɪ/: native /i, e/, /ʊ/: native /o, u/), but with a stronger preference towards one (/ɪ/ as native /i/: 56.24%, /ʊ/ as native /o/: 54.1%). Finally, /ʌ/ and /ɔ/ were both equally rated as /a/ and /o/. After choosing a native category, participants rated the vowel in terms of closeness to the chosen prototypical native category. Category assimilation (over 25%) and goodness rating were combined into a fit index (Table 9).

Table 9

Fit indexes derived for English vowels in terms of Native categories

English vowel	Native choice	Identification percentage (%)	Goodness rating	Fit index
/i/	/i/	88.52	4.16	3.68
/u/	/u/	85.19	3.78	3.22
/ɪ/	/i/	56.24	3.52	1.98
/ʊ/	/o/	54.10	3.51	1.90
/ʌ/	/o/	46.40	3.84	1.78
/ʌ/	/a/	45.27	3.17	1.44
/ɔ/	/a/	45.19	3.25	1.47
/ɔ/	/o/	44.52	3.63	1.62
/ɪ/	/e/	38.10	3.36	1.28
/ʊ/	/u/	31.34	3.19	0.68

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The mean fit index for all vowels was 1.91 (sd = 0.89). Therefore, the English vowels that had a good fit index (1.91+0.89 = 2.8) for Basque/Spanish native categories were English /i/ for Basque/Spanish /i/ and English /u/ for Basque/Spanish /u/.

4.2.2. Instruction level effects

For this analysis, the category assimilation and goodness rating data were separated by instruction level. Assimilation percentages over 25% and their goodness rating are as follows (Table 10):

Table 10

Assimilation percentages per stimuli vowel
and goodness rating (/5) per vowel choice and instruction level

Instruction level	English vowel	Native choice	Identification percentage (%)	Goodness rating
Beginner	/i/	/i/	83.46	4.08
	/ɪ/	/e/	56.55	3.57
		/i/	35.13	3.49
	/u/	/u/	72.55	3.81
	/ʊ/	/o/	64.00	3.59
	/ʌ/	/o/	47.62	3.78
		/a/	41.67	3.56
	/ɔ/	/a/	45.83	3.52
		/o/	42.26	3.85
Intermediate	/i/	/i/	88.46	4.29
	/ɪ/	/i/	60.94	3.81
		/e/	32.81	3.57
	/u/	/u/	85.90	4.02
	/ʊ/	/o/	55.13	3.65
		/u/	37.18	3.28
	/ʌ/	/a/	48.06	3.32
		/o/	46.51	4.07
	/ɔ/	/o/	47.69	3.61
		/a/	46.92	3.46
Advanced	/i/	/i/	94.17	4.13
	/ɪ/	/i/	76.55	3.34
	/u/	/u/	98.89	3.60
	/ʊ/	/u/	44.44	3.18
		/o/	42.44	3.21
	/ʌ/	/a/	46.94	2.65
		/o/	44.90	3.73
	/ɔ/	/o/	44.30	3.42
		/a/	42.95	2.72

There is a higher consensus in choice for English /i/ and /u/ as instruction level increases (ex: for English /u/, native /u/ is chosen by 98.89% of advanced, 85.9% of intermediate, and 72.55% of beginner learners). The preferred native categories for /ɪ/ and /ʊ/ were /e/ and /o/ for beginner learners but /i/ and /u/ were chosen as instruction level increased. Finally, regardless of instruction level, both /ʌ/ and /ɔ/ were equally categorized as native /a/ and /o/. Regarding goodness ratings, advanced learners give lower ratings to all vowels, except to English /i/ and /u/. The intermediate group had the highest goodness rating for /u/ and /ʊ/, and the beginner group had the highest ratings for the remaining English vowels. In sum, the analysis shows that while an advanced instruction level renders more consensus in choice, that goodness ratings are lower. Conversely, beginner and intermediate learners showed less consistent choices but higher goodness ratings.

5. Discussion and conclusion

The findings of this experiment show that L2 learners were able to differentiate the English vowels and that their differentiation is influenced by their native Spanish. This confirms the malleability of the perceptual space (Flege 1995), and that learners can attune their vocalic space to accommodate the characteristics of L2 categories. However, the differences between the vowel pairs under study show that this attunement is sensitive to acoustic distance and categorization patterns of non-native sounds.

The hypothesis of the SLM that identical sounds will be directly transferred from the L1 to the L2 is confirmed by the high discriminability and fit index of English /i/ and /u/. These vowels are consistently well discriminated by participants and their fit index is good. This finding also confirms that the relation between the L1 and L2 categories is acoustic by nature, and not phonological (Flege 1995). As peripheral vowels, /i/ and /u/ "serve as attractors with respect to less extreme vowels" (Polka & Bohn 1996: 589), which explains the preference for /i/ and /u/ over /ɪ/ and /ʊ/ in the discrimination and assimilation tasks.

The expected relationship between L1 and L2 categories (Table 4) showed that vowels /ɪ ʊ ʌ ɔ/ would be considered similar to one or two native categories. Unlike expected, /ɪ/ was better assimilated to native /i/. This was consistent with previous work (Boomershine 2013; Escudero 2005; Gallardo, García Lecumberri & Cenoz 2000; García Lecumberri & Cenoz 1997; Morrison 2008). Instead of a two-category assimilation scenario, this vowel pair shows a category-goodness assimilation scenario. English /i/ is he preferred exemplar for native /i/, but there is not a difference in accuracy in the discrimination between /i/ and /ɪ/. This confirms the SLM's second tenet: as phonetic differences are discerned, a new category needs to be created. Native /o/ was preferred for /ʊ/. Therefore, as English /u/ is preferred for native /u/, the /u-ʊ/ vowel pair does show a two-category assimilation scenario (PAM). The differences between the categorization of /ɪ/ and /ʊ/, in which the former is in a category-goodness scenario and the latter in a two-category scenario, also matches that when the target was /ʊ/, the discrimination was better than for /ɪ/. Finally, the expected outcome for /ʌ-ɔ/ was confirmed. This pair was the most difficult to discriminate, and individually, they had the least accurate discrimination ratings. Both are close to native /a/ in terms of F1 and to /o/ in F2 and were assimilated to both with low fit indexes. They are categorized as diaphones for both native /a/ and /o/. Per-

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ceptually, these vowels are in a single-category assimilation scenario (PAM) or equivalence classification (SLM).

The findings in terms of vowel perception support the hypotheses of research questions 1 and 2 to an extent. English /i/ and /u/, the closest categories to native vowels, were the easiest to discriminate and had the best fit index. Unlike expected, the vowel pair/u-ʊ/ was the easiest to discriminate. This is likely because participants assimilate these vowels to two separate native vowels (two-category assimilation), as opposed to the two other vowel pairs, where category-goodness assimilation and single-category assimilation scenarios occur. The findings support the outcomes of PAM: two-category assimilation scenarios result in good perceptual discrimination, single-category assimilation scenarios signal bad perceptual discrimination, and category-goodness assimilation is an intermediate stage between the previous two. Something that was not confirmed was that the larger the functional load, the easier it would be to discriminate the vowel pair. It could be suggested that without exposure and frequency, functional load effects are cancelled out.

Regarding general instruction level effects, an advanced level correlated with shorter reaction times, but not with response accuracy in the ABX task. The advanced group was the most accurate in response, but not significantly. The beginner group was the second fastest and most accurate. This does not confirm the hypothesis: the correlation between better L2 perception and a higher instruction level is not linear. Cebrian (2006), Escudero & Wanrooij (2010), Kondaurova & Francis (2008) and Morrison (2008) did not find a positive correlation between L2 category perception and L2 general instruction level either. Regarding category assimilation, advanced learners had a higher consensus in choosing a native equivalent. Beginner and intermediate learners were more divided. This suggests a shift from a two-category assimilation to a category-goodness assimilation scenario as instruction level increases. A new category is still not formed (representational task), but the mapping of the sounds is changing and being created (perceptual task) (Escudero 2005).

Regarding the non-linearity of the results by instruction level, U-shaped patterns in perceptual learning have been observed (Boomershine & Kim 2018): Bilingual infants have been observed to discriminate Catalan /e-ɛ/ at month 4 but not at 8, and this ability is regained by month 12 (Ramon-Casas *et al.* 2016) Speech processing mechanisms could also explain the non-linearity. Flege (1995) identifies three successive perception levels: auditory, phonetic, and phonemic. Auditory differences need to be perceived first, followed by characteristics of gestural realizations, and finally, a phonological contrast is established. Lexical representations and L2 lexicon development could also affect L2 speech development (Guion-Anderson 2013; Strange & Shafer 2008). Unlike advanced learners, beginners have a limited lexicon in quantity, so they may rely on phonetic differences, not lexical retrieval and phonological information. Their perception could purely be in the auditory stage and they do not access internalized category to identify the stimuli (Flege 1995). It is likely that the mechanism of advanced learners to discriminate sounds is based on the more established phonemic categorizations they have acquired when establishing L2 lexicon. Intermediate learners may be progressing from an auditory to a phonetic and phonemic mechanism. The combination of phonetic and lexical knowledge in a perception task can have a confounding effect and hinder the task (Strange & Shafer 2008). Consequently, the findings above support the hypothesis for research question 3 concerning reaction times, but not accuracy. That said, it seems that instruction level in an EFL setting does not affect perception the same way as in a naturalistic setting. Nonetheless, the succession of perception mechanisms (Flege 1991) seems to hold in this study, so perceptual development can occur in a foreign language setting.

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