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A longitudinal study of individual difference in foreign language pronunciation development: The case of vowel production in Ecuadorian learners of English

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This study investigated the development of the English vowel contrasts /i – ɪ/, /u – ʊ/, /ɛ – æ/, and /ɑ – ʌ/ produced by Ecuadorian Spanish speakers enrolled in the First and Second Language Teaching program at a State University in Ecuador. Recorded at six-month intervals at the end of the third, fourth, and fifth semesters, they produced 40 isolated English monosyllabic words. Each block of vowel contrasts had familiar words representing five words per vowel in a CVC and CVCC context. To examine pronunciation differences in the acoustic vowel space development over time, the Euclidean distance between the four groups of vowel contrasts was calculated based on F1 and F2 frequency values, which were Lobanov-normalised and analysed using a mixed-effects model. The results showed that Ecuadorian learners' pronunciation did not vary in the general learning trajectories over the three recordings, and did not match the native English criteria by the end of the study. However, Ecuadorian learners showed high variability *within* subjects and *between* subjects in the production of each vowel contrast over time. In summary, these results suggest that within-group, not all Ecuadorian learners followed the same developmental trajectories and varied depending on the vowel contrast.

Keywords: individual differences, L2 language, developing, vowel contrast

1 Introduction

English is a widespread international language with many second language (L2) speakers from different countries who commonly differ on how accurately they produce English vowel sounds. This level of accuracy difference has also been reported in many studies pointing out that L2 English learners' difficulty in perceiving or producing specific sounds (consonants or vowels) can vary depending on the first learners' language (Flege et al., 1997; McAllister et al., 2002). Furthermore, several studies on group observation have reported that L2 learners' pronunciation improvement may occur at the beginning of the learning process in a naturalistic environment (Flege et al., 1997; Thomson & Derwing, 2015). Although research on group data is highly informative, we believe there is much to be gained by examining individual differences in L2 pronunciation in a non-naturalistic setting. To identify specific predictors of phonological acquisition, studies on L2 learners' variability have focused on learner-internal factors such as the role of awareness in pronunciation, motivation, language use, anxiety, aptitude, among other factors (Baran-Łucarz, 2014; Elliott, 1995; Saito et al., 2019). However, the results of these studies reflect neither learner-external factors such as the quantity and quality of input and opportunity of language use (e.g., Flege & Wayland, 2019; Moyer, 1999; Muñoz, 2011), nor their impact on learner's developmental trajectories (Pesantez & Dellwo, 2022). Moreover, literature on L2 individual variation is limited and focused more on L2 perception (Kim et al., 2018; Kogan & Mora, 2022; Mayr & Escudero, 2010; Morrison, 2009; Munro et al., 2015) than L2 production (Lima, 2019; Munro et al., 2015). For example, Morrison (2009) found that L1 Spanish L2 English listeners who had exposure to the same Canadian English dialect followed an indirect developmental path in perception patterns. Furthermore, Munro et al. (2015) found high variability in consonant clusters for both onset and coda developmental performance within Mandarin and Slavic learners of English.

The current study extends previous longitudinal research on the development of English vowels produced by Brazilian learners (Lima, 2019). Both Portuguese and Spanish learners of English have problems producing vowel contrasts (Rallo Fabra & Romero, 2012). Data from several studies suggest that L1 Spanish speakers rely on vowel duration as acoustic cues to make difference between vowels, even though contrast on durational cues does not exist in the Spanish language (e.g., Escudero & Boersma, 2004). We will explore longitudinal learner performance on the English vowel contrasts /i – ɪ/, /u – ʊ/, /ɛ – æ/, and /ɑ – ʌ/ produced by a group of L1 Ecuadorian (EC) Spanish speakers. They share the same number of years of exposure in a classroom setting and have the same exposure to Spanish-accented English teachers. The choice of these vowel contrasts is intentional as they are crucial for L2 English intelligibility (e.g., Levis, 2020; Munro & Derwing, 2008; Rallo-Fabra & Romero, 2012). The study also explores individual learner development, i.e., it assesses L2 learners on their own individual pronunciation problems instead of focusing on group errors.

2 Methodology

2.1 Research questions

The study aims to answer the following research questions:

- **RQ1**: Do Ecuadorian learners vary in their general learning trajectories (i.e., pronunciation changes over time) as they advance in their studies?
- **RQ2**: To what extent do Ecuadorian learners vary in their developmental trajectories across the four groups of vowel contrasts?

2.2 Participants

Two groups of speakers were analysed, an L1 English group and an L2 English group. The first group was made up of six L1 American English (NE) speakers who were studying Spanish as a second language in Ecuador, including one who was an English teacher. The three females and three males had a mean age of 23.6 years (range: 19–43). The L2 group consisted of twenty-four undergraduate students enrolled in the First and Second Language Teaching program at a State University in Ecuador. They were L1 Ecuadorian (EC) Spanish monolinguals who had never been in an English-speaking country. In this paper, we present only the data for the female participants (n = 16), because vowel formant ranges vary with gender. Their ages ranged from 18 to 28 years old with a mean of 21.13. Fourteen participants reported having not studied any foreign language other than English, but two participants had studied Portuguese and Quechua. They also had experience with English learning, having had four hours per week at secondary school in Ecuador with non-native English input most of the time. All participants gave their written informed consent at each recording session and were paid for their participation.

2.3 Description of the learning context

The participants were recorded at six-month intervals at the end of the third semester (recording 1), fourth semester (recording 2), and fifth semester (recording 3). Each semester had sixteen weeks of classes (excluding weeks of mid-term exams and final exams). They studied Research Methodology, TEFL, Communicative Grammar, Reading, and Writing – among other courses – from the first to the fifth semesters, as well as Phonetics in the fourth semester and Phonology in the fifth semester. In Phonetics, the participants learnt about the sounds of the English language without a context; they focused on using phonetic symbols (vowels and consonants) to understand English pronunciation. In Phonology, they focused on the organisation of English sound patterns and those present in L2 English speech. Over the period of the three recordings, the participants had only the L2 input from L1 Spanish teachers of English in their classes. At the end of each testing session, they completed a general language background questionnaire to measure their exposure to the English language in the classroom (number of English courses taken), input (native or non-native), and the frequency of their use of English.

2.4 Production task

The experiment was conducted at the radio station of the State University in Ecuador. The participants produced 40 isolated English monosyllabic words with no carrier phrases. The instructions were written in English and appeared on the first slide. Each vowel pair tested 10 familiar words: five words per vowel in a CVC and CVCC context, and 5 disyllabic words added as distractors. The test words included:

- /i – ɪ/: *sheep–ship, cheap–chip, keys–kiss, feet–fit, seat–sit*;
- /u – ʊ/: *boot–book, fool–full, pool–pull, food–foot, suit–soot*;
- /ɛ – æ/: *bet–bat, pen–pan, men–man, send–sand, beg–bag*;
- /ɑ – ʌ/: *dog–dug, hot–hut, caught–cut, boss–bus, lock–luck*.

A Zoom H2n Handy recorder at 44.1 kHz sampling, 16-bit quantisation was used for the three recordings. Before starting the recordings, participants were familiarised with the task in a preliminary trial, where the presented words were unrelated to the words of the study. No recording was made during the familiarisation phase. Using a computer screen, the pictures

were presented in a random order (mostly tense vs. lax vowel) with their Spanish translation next to them, to avoid the effects of orthography in the production of the English segment phonemes (Bassetti, 2017; Flege et al., 1997). In cases where the participants did not say the expected word, the researcher said "No" and the participant could self-correct by saying the correct word. All the participants repeated each word two times to counter frequent hesitations during the initial production. They were asked to say the words in a natural way and at a normal volume. NE speakers followed the same procedure.

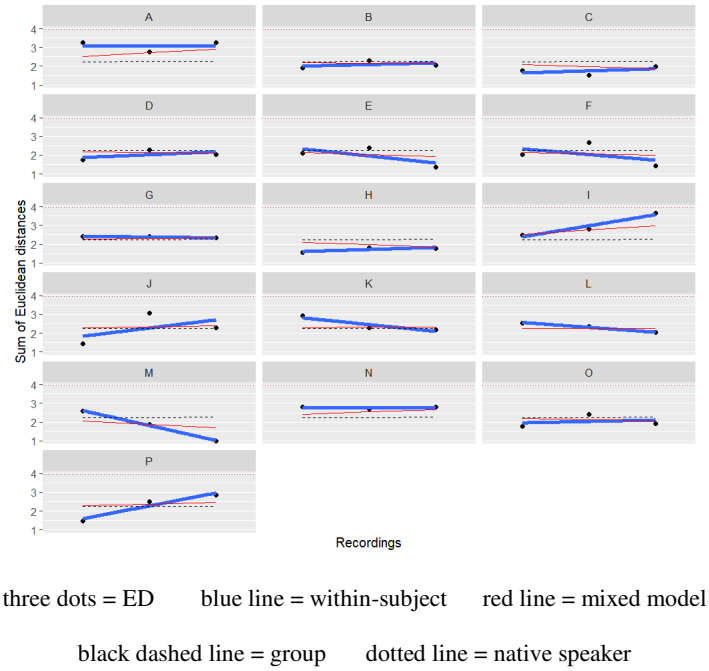
2.5 Acoustic measurements

Our approach to evaluating L2 speakers' performance relies on Euclidean distance (ED) values of the vowel contrasts. We compared the ED values with values from English native speakers which served as baseline. However, the native speakers' data was not used in the statistical models. The NE values were only used for comparison, as the aim of the study was not to test participants' native-likeness.

To compare the individual changes in the spectral characteristics over time, the onset and offset of each vowel segment were manually annotated by following standard phonetic criteria, using waveform, spectrogram, and auditory discrimination cues in Praat (Boersma & Weenink, 2022). The F1, F2, and F3 formants means were extracted using an automatic formant measurement method in Praat. The same parameters used by Kartushina and Martin (2019) were also applied in this study. The F1 and F2 mean values obtained by each vowel setting were examined to see if their values were within the speaker's vowel formant gender ranges. F1 and F2 formants were Lobanov-normalised by semester and grouped by speakers using the visible vowel website (Heeringa & Van de Velde, 2018). The ED between the four groups of vowel contrasts was calculated based on F1 and F2 frequency values. Then the ED values for each vowel contrast were plotted to trace individual vowel development over time (see Figure 1). The distance values were fitted into a linear-mixed effects model to the data.

Figure 1

Mixed-Effects Model of the Sum of ED of the Four Pairs of English Vowels by Recording for Each Speaker



Notes. Time is ordered, from left to right. The speaker code-letter is in the strip above each panel.

3 Results

R core Team (2022) was used for statistical analysis and figure plotting. For the purposes of RQ1 (i.e., to look at the variability in the general vowel development of the group), the sum of the ED of the four target pairs of vowels was used to fit a linear mixed-effects model (LMM) to the data. The fixed effect was coded as Recordings, and a random effect for subject and a random effect for the slope with respect to recordings (see Bates, 2010, for a review). In Figure 1, the three black dots are the sums of ED for each recording, and the blue line (which is the tendency line for each speaker from a simple within-subject linear model) indicates little evidence of vowel development. The general tendency of the group (the black dashed line) which is repeated in every individual plot, does not reflect an increasing slope over the three recordings. The red line is the result of the LMM fitted for each speaker's data. It indicates no subject-to-subject variation over the three recordings. Finally, the dotted line, with no slope and repeated in all individual plots at 3.96, marks the sum of the ED of the six NE speakers showing how each participant differs from NE data. The results of the LMM showed no significant individual difference in the general learning trajectories over the three recordings $F(1, 28.79) = 0.0041$; $p > 1$.

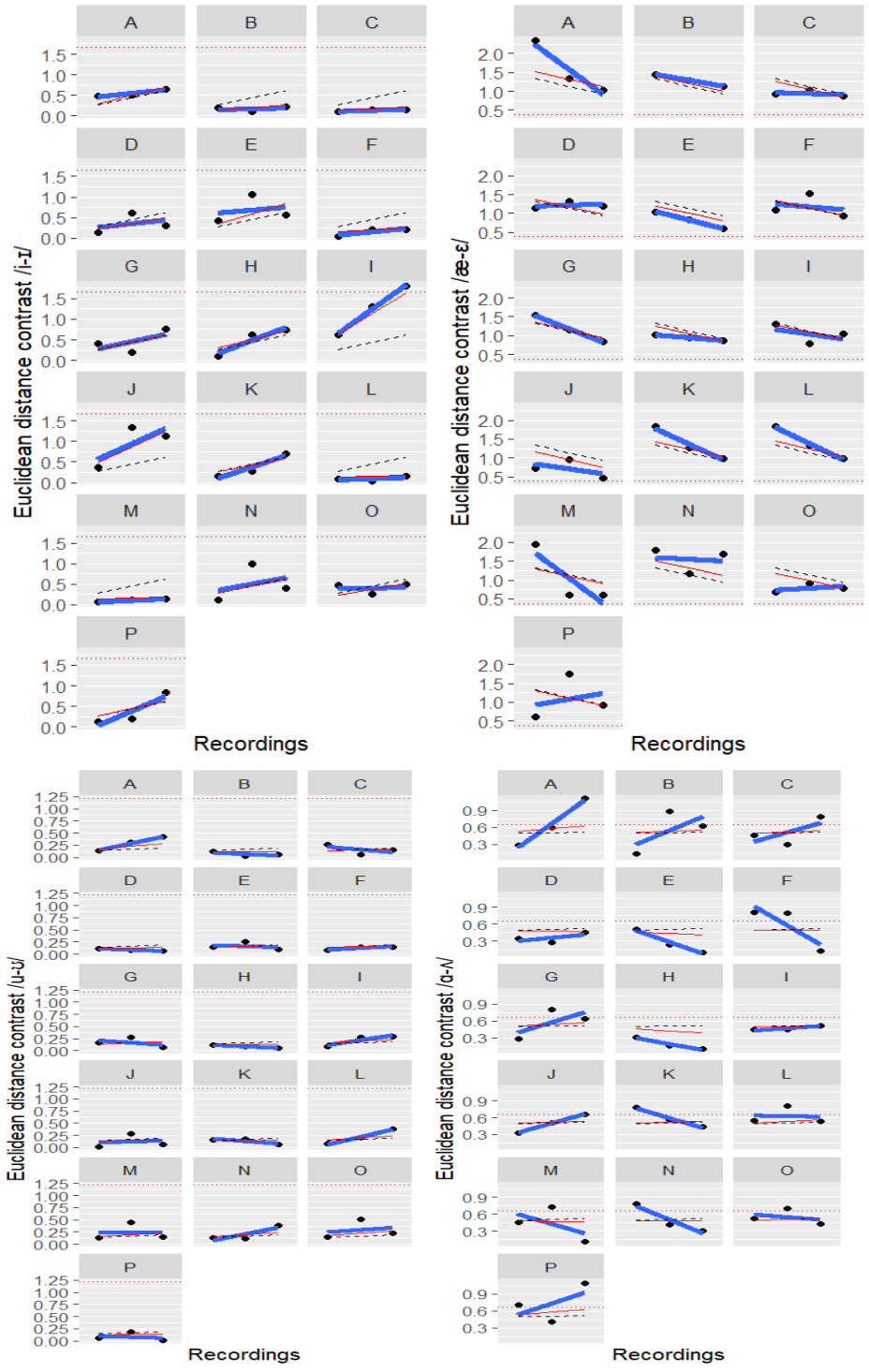
We can also observe different learning trajectories within-subject (the blue line). For example, of the sixteen EC participants, six started with ED values comparable to the mean of the group and four of them showed no improvement in recording 2 and 3 (B, D, G, O). Interestingly, only three participants improved the ED values over the three recordings (I, J, P). Nonetheless, there were some participants who decreased their ED values (E, F, K, L, M) over the three recordings. Furthermore, four participants got ED values above or below the

population (A, C, H, N). In general, these data suggest that there are all types of L2 developmental routes within subjects, even though in the group no general different change rate was found.

For the purposes of RQ2, i.e., to explore how EC learners vary in their developmental trajectories across the four groups of vowel contrasts, we used an LMM per each vowel contrast. Figure 2 shows changes in the ED values (three black dots) per each participant, and with the tendency to increase (blue line) for some participants (simple within subject linear model) for the contrast /i – ɪ/ and /ɑ – ʌ/, a clear trend of decreasing for the /æ – ɛ/ and a steady trend for /u – ʊ/. What stands out in these figures is the difference in the subject-to-subject variation over the three recordings (red line, representing the result of the LMM fitted for each speaker's data) and the variability within-subject with respect to the general tendency of the group. Finally, the dotted line with no slope for the /i – ɪ/, /u – ʊ/ (left panels), for /ɑ – ʌ/ and /æ – ɛ/ (right panels) represent the NE's ED at 1.66, 1.22, 0.66, and 0.38, respectively. The results of the LMM were significant for the /i – ɪ/ F (1, 38.015) = 10.381; $p < .01$, and for the /æ – ɛ/ F (1, 31) = 11.239; $p < .01$, but not for the /u – ʊ/ F (1, 44.372) = 1.271; $p > 1$, and /ɑ – ʌ/ F(1, 42.651) = 0.0637; $p > 1$.

Figure 2

Mixed-Effects Model of ED for the /i/–/ɪ/, /æ/–/ɛ/, /u/–/ʊ/ and /ɑ/–/ʌ/ of the English Vowels by Recording for Each Speaker



Note. Time is ordered, from left to right. The speaker code-letter is in the strip above each panel.

Of the four groups of vowel contrasts, the /i – ɪ/, /æ – ɛ/ and /ɑ – ʌ/ showed higher within-subject variability in their L2 production. As observed in Figure 2, for the /i – ɪ/ contrast, six participants (B, D, G, K, N, O) started with ED corresponding to the mean of the group and only four participants followed the developmental performance of the group. Interestingly, only one participant (I) reached NE standards in recording 3. For the contrasts /æ – ɛ/, three participants (B, F, I) started with ED comparable to the mean group and three followed the developmental performance of the group. For the /ɑ – ʌ/ pair, there were three participants (C, E, I) who started with ED similar to the group mean, but only one (I) followed the development of the group. For the /u - ʊ/ pair, most of the participants started and kept the development of the group, but only four participants slightly increased the ED over the three recordings (A, I, L, N). These findings mean that these participants show higher variability in L2 speech development in front vowel contrasts than the back vowels over the three recordings.

4 Discussion

Our study provides evidence of EC learner's pronunciation not changing over time. This finding is consistent with Herrero and Delicado (2022) whose L2 learners also showed minimal change in the quality of the vowels. The relatively stable L2 productions in the sum of the ED found here may reflect that EC learners need more years of English instruction to improve their L2 production of the vowel contrast (Muñoz, 2011). However, it might be also related to a degree of early fossilisation that occurred during the first or second semester, as has been reported in other studies (Derwing & Munro, 2014; Munro & Derwing, 2008). To determine which vowel contrasts show high variability in the developmental performance between EC learners, we analysed each vowel contrast separately. The results for the front vowel contrasts showed statistically significant differences in learners' developmental path, but not for the back vowel contrasts. For the contrasts /æ – ɛ/, we expected that EC learners would start with larger spectral difference than NE speakers due to the influence of Spanish /e/ in the English /ɛ/ production. This finding is consistent with that of Flege et al. (1997), where Spanish participants produced larger spectral differences than did the group of native speakers. The results in our study differ from Lima (2019) who found that most participants created separate categories for the vowel pairs over the four recordings and maintained them in most cases. In our study, participants did not produce vowel contrasts with similar ED values to NE speakers over the three recordings, and those who could increase the ED values lost them in the second or third recording. Moreover, in Lima's (2019) study, many participants started in the first recording by producing a vowel contrast for the /i – ɪ/, whereas none of our participants started with higher ED values in recording 1 for this vowel pair. However, both studies show the high degree of variability in L2 acquisition and in the type of developmental patterns L2 learners follow. We did not analyse intra-subject variability statistically per each vowel, but as Figure 2 shows, most EC learners vary in their own developmental trajectory (blue line) for the vowel pair /ɑ – ʌ/. For example, speaker P started with an ED (three dots) comparable to NE speakers in recording 1, changed the order in recording 2, and surpassed NE in recording 3.

In general, this study showed that over the three recordings fewer than four participants followed the mean trend of the group for each vowel pair. Given this finding, a more individualised approach would be a more effective pedagogical strategy for these speakers, especially for /i – ɪ/ and /æ – ɛ/. In the context of foreign language acquisition with major L2 foreign-accented input, it would be better to start with phonetics and phonology classes from the beginning of instruction to avoid fossilised errors in pronunciation. In addition, integrating applications of automatic speech recognition into pronunciation instruction can help teachers to pinpoint problems in L2 sounds, and at the same time make L2 learners aware of their own pronunciation challenges.

5 Conclusion

This study explored EC speakers' variability in the development of eight English vowels in an instructed foreign language context, with most input supplied by non-native English teachers over five semesters. In most such classrooms, L2 learners have major exposure to foreign-accented input. The nature of that L2 input is crucial in the process of speech learning, with adults' performance depending on the quantity and quality of input (Flege & Bohn, 2021). Studies tracking L2 learners and their non-native English teachers might give a better understanding of how foreign-accented input activates L2 phonetic acquisition.

Valuable insight is gained about learners of English in the instructed foreign language context of Ecuador, a country underrepresented in the field of L2 English. However, the small sample size means that conclusions cannot be generalised to all L1 Spanish learners. Nonetheless, this paper contributes to an important line of L2 pronunciation research related to individual differences and their changes over time, showing that not all vowels are acquired at the same rate and that very few learners follow the mean of the group. More research with larger sample sizes and more words representing each vowel needs to be conducted in both perception and production, to further examine long-term L2 development.

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References

Baran-Łucarz, M. (2014). The link between pronunciation anxiety and willingness to communicate in the foreign-language classroom: The Polish EFL context. *Canadian Modern Language Review*, *70*, 445–473. http://doi.org/10.3138/cmlr.2666

Bassetti, B. (2017). Orthography affects second language speech: Double letters and geminate production in English. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *43*(11), 1835–1842. https://doi.org/10.1037/xlm0000417

Bates, D. M. (2010). *lme4: Mixed-Effects Modelling with R*. Available online at: http://lme4.r-forge.r-project.org/lMMwR/lrgprt.pdf

Boersma, P., & Weenink, D. (2022). Praat: doing phonetics by computer [Computer program]. Version 6.2.21. http://www.praat.org/

Derwing, T., & Munro, M. J. (2014). Once you have been speaking a second language for years, it's too late to change your pronunciation. In L. Grant & D. Brinton (Eds.), *Pronunciation myths: Applying second language research to classroom teaching* (pp. 34–55). University of Michigan Press.

Elliott, A. R. (1995). Foreign language phonology: Field independence, attitude, and the success of formal instruction in Spanish pronunciation. *The Modern Language Journal*, *79*(4), 530–542. https://doi.org/10.1111/j.1540-4781.1995.tb05456.x

Escudero, P., & Boersma, P. (2004). Bridging the gap between L2 speech perception research and phonological theory. *Studies in Second Language Acquisition*, *26*(4), 551–585. https://doi.org/10.1017/S0272263104040021

Flege, J. E., Bohn, O-S., & Jang, S. (1997). Effects of experience on non-native speakers' production and perception of English vowels. *Journal of Phonetics*, *25*(4), 437–470. https://doi.org/10.1006/jpho.1997.0052

Flege, J. E., & Wayland, R. (2019). The role of input in native Spanish late learners' production and perception of English phonetic segments. *Journal of Second Language Studies*, *2*(1), 1–44. https://doi.org/10.1075/jsls.00004.fle

Flege, J. E., & Bohn, O-S. (2021). The revised Speech Learning Model (SLM-r). In R. Wayland (Ed.), *Second language speech learning: Theoretical and empirical progress* (pp. 3–83). Cambridge University Press. https://doi.org/10.1017/9781108886901

Heeringa, W. & Van de Velde, H. (2018). Visible Vowels: A tool for the visualization of vowel variation. In *Proceedings CLARIN Annual Conference 2018* (8-10 October, Pisa, Italy). CLARIN ERIC.

Herrero de Haro, A., & Delicado Cantero, M. (2022). Longitudinal study of Spanish vowel acquisition by Australian students. *Language Teaching Research*. Advance online publication. https://doi.org/10.1177/13621688221140106

Kartushina, N., & Martin, C. D. (2019). Third-language learning affects bilinguals' production in both their native languages: A longitudinal study of dynamic changes in L1, L2 and L3 vowel production. *Journal of Phonetics*, *77*, 1–21. https://doi.org/10.1016/j.wocn.2019.100920

Kim, D., Clayards, M., & Goad, H. (2018). A longitudinal study of individual differences in the acquisition of new vowel contrasts. *Journal of Phonetics*, *67*, 1–20. https://doi.org/10.1016/j.wocn.2017.11.003

Kogan, V. V., & Mora, J. C. (2022). The effects of individual differences in native perception on discrimination of a novel non-native contrast. *Laboratory Phonology*, *24*(1), 1–28. https://doi.org/10.16995/labphon.6431

Lima, R. M., Jr. (2019). A longitudinal study on the acquisition of six English vowels by Brazilian learners. In S. Calhoun, P. Escudero, M Tabain, & P. Warren (Eds.), *Proceedings of the 19th International Congress of Phonetic Sciences* (pp. 3180–3184). Australasian Speech Science and Technology Association Inc.

Levis, J. (2020). Revisiting the intelligibility and nativeness principles. *Journal of Second Language Pronunciation*, *6*(3), 310–328. https://doi.org/10.1075/jslp.20050.lev

Mayr, R., & Escudero, P. (2010). Explaining individual variation in L2 perception: Rounded vowels in English learners of German. *Bilingualism: Language and Cognition*, *13*, 279–297. https://doi.org/10.1017/S1366728909990022

McAllister, R., Flege, J. E., & Piske, T. (2002). The influence of L1 on the acquisition of Swedish quantity by native speakers of Spanish, English and Estonian. *Journal of Phonetics*, *30*(2), 229–258. https://doi.org/10.1006/jpho.2002.0174

Morrison, G. S. (2009). L1-Spanish speakers' acquisition of the English /i/–/ɪ/ contrast II: Perception of vowel inherent spectral change. *Language and Speech*, *52*(4), 437–462. https://doi.org/10.1177/0023830909336583

Moyer, A. (1999). Ultimate attainment in L2 Phonology: The critical factors of age, motivation, and instruction. *Studies in Second Language Acquisition, 21*(1), 81–108. https://doi.org/10.1017/S0272263199001035

Munro, M. J., & Derwing, T. M. (2008). Segmental acquisition in adult ESL learners: A longitudinal study of vowel production. *Language Learning*, *58*(3), 479–502. https://doi.org/10.1111/j.1467–9922.2008.00448.x

Munro, M. J., Derwing, T. M., & Thomson, R. I. (2015). Setting segmental priorities for English learners: Evidence from a longitudinal study. *International Review of Applied Linguistics in Language Teaching*, *53*(1), 39–60. https://doi.org/10.1515/iral-2015-0002

Muñoz, C. (2011). Input and long-term effects of starting age in foreign language learning. *International Review of Applied Linguistics in Language Teaching*, *49*, 113–133. https://doi.org/10.1515/iral.2011.006

Pesantez, A., & Dellwo, V. (2022). L2 phonetic accuracy development in a foreign language setting: a longitudinal study. In B. Blecua, J. Cicres M. Espejel & M. J. Machuca (Eds.), *Propuestas en fonética experimental: enfoques metodológicos y nuevas tecnologías* (pp. 225–228). https://dugi-doc.udg.edu/handle/10256/20770

R Core Team (2022). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/.

Rallo Fabra, L., & Romero, J. (2012). Native Catalan learners' perception and production of English vowels. *Journal of Phonetics*, *40*, 491–508. https://doi.org/10.1016/j.wocn.2012.01.001

Saito, K., Suzukida, Y., & Sun, H. (2019). Aptitude, experience and second language pronunciation proficiency development in classroom settings: A longitudinal study. *Studies in Second Language Acquisition, 41*, 201–225. https://doi.org/10.1017/S0272263117000432

Thomson, R. I., & Derwing, T. M. (2015). The effectiveness of L2 pronunciation instruction: A narrative review. *Applied Linguistics*, *36*(3), 326–344. https://doi.org/10.1093/applin/amu076

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Alexandra Pesantez is a PhD student at the Computational Linguistics Lab-University of Zurich. Under the supervision of Professor Dr. Volker Dellwo, she is carrying out a longitudinal study to explore Ecuadorians' L2 language speech development. Through acoustic analysis, she has examined which English vowels are easily acquired and which ones are acquired at a later stage. These data are part of an extensive project on foreign language acquisition.

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