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An Airflow Analysis of Spanish and English Anticipatory Vowel Nasalization among Heritage Bilinguals

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Abstract: Gestural timing overlap between a vowel and subsequent nasal consonant results in the vowel being articulatorily nasalized. Research has shown that such degree of coarticulation varies cross-linguistically (e.g., English exhibits a greater gestural timing overlap than Spanish). This phenomenon has mainly been investigated in monolingual samples, and with only a small number of studies focusing on second and heritage language gestural timing patterns of nasality; the role of bilingualism in this respect is thus an open question, which is the focus of the current study. Sixteen second-generation US-born heritage bilinguals participated in this experiment. Their degree of bilingualism was assessed via the Bilingual Language Profile. They completed two separate read-aloud tasks: one in Spanish (heritage language) and one in English (second language). Simultaneous oral and nasal airflow were collected via pressure transducers from words that included phonetically oral and nasalized vowels. Results indicate that heritage bilinguals increment the degree of vocalic nasalization from Spanish to English. Nevertheless, their degree of bilingualism did not yield statistical significance in phonetic performance. The current study is the first one implementing aerodynamic methods with a heritage bilingual population and presents data for the possibility to possess two segment-to-segment timing strategies in heritage grammars.

Keywords: coarticulation; vowel nasalization; airflow; heritage phonology; Spanish and English in contact

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1. Introduction

Vowel quality is a property that involves the combination of muscles such as the tongue (Recasens 1999), lips (Farnetani 1999), lower jaw (Fletcher and Harrington 1999), pharynx and the velum (Barlaz et al. 2018), among others. The concern of the present study is with the oral and nasal gestural patterns of vowels followed by nasal consonants in languages where a phonologically oral versus nasal vowel binary contrast does not exist.

One of the main articulatory correlates of nasal vowels is that the lowering of the velopharyngeal opening needs to occur (Barlaz et al. 2018; Chafcouloff and Marchal 1999), thus allowing for air exhalation to happen through both the oral and nasal cavities. A vocalic segment (V) that is contiguous to a nasal consonant (N) is phonemically oral. However, due to coarticulation and timing gestures, the onset of the nasal gesture will occur during the time-course of V and before its final completion. Thus, both oral and nasal gestures will happen simultaneously for a period of time. As such, the underlyingly oral vowel becomes nasalized. Sampson (1999) terms this type of coarticulation 'universal' and 'unavoidable' because it happens due to the timing gestures and biomechanical production of the segments.

Previous research has shown that this conditioned coarticulatory nasalization varies cross-linguistically (Clumeck 1976), and such research, in turn, has targeted monolingual populations. A large body of the studies that have focused on second language (L2) or heritage language (HL) phonology have investigated segmental phonology such as individual vowel or consonant production, or suprasegmental features such as tone and intonation. However, L2 or HL research focusing on the inter-effect between neighboring segments (i.e., coarticulation), has not been abundant. I posit that investigating coarticulation may result in a more reflective description of language use as opposed to segmental descriptions. Additionally, considering that heritage bilinguals have been found to possess phonemic robustness (Cheng 2021), investigating coarticulatory processes in both languages may elucidate new phonetic implementation patterns in bilingual speech and bring forward the literature on context-dependent variation or phonetic detail acquisition by heritage bilinguals.

The implementation of articulatory methods with heritage bilinguals is essential to broaden our understanding of bilingual and heritage grammars. Not only would it add a novel dimension to phonetic and phonological acquisition, but it would also allow us to visualize and combine fields such as articulatory phonetics, second language acquisition, and sociolinguistics.

The present paper is structured as follows: in Section 2, a literature review with its relevant theoretical framework and background on heritage phonology and coarticulation is included; in Section 3, the research questions and hypotheses are postulated; in Section 4, the methodology is presented; in Section 5, I report results and complement them with their relevant discussion in Section 6 and conclusions in Section 7.

2. Literature Review

2.1. Theoretical Framework

One might think that theories about sound articulation in L2 and HL speakers are abundant considering the increasing interest these populations have received in recent years. The reality is otherwise, as most theories within the field of sound articulation revolve around L1 production, such as Browman and Goldstein's (1992) Articulatory Phonology. This theory considers that the phonology of a language is simply a gesture of commands that 'overlap' with each other across time and result in different types of (co)articulatory outcomes. Figure 1 shows a gestural representation of the word *pan* [p^{h}ãn] following Articulatory Phonology.

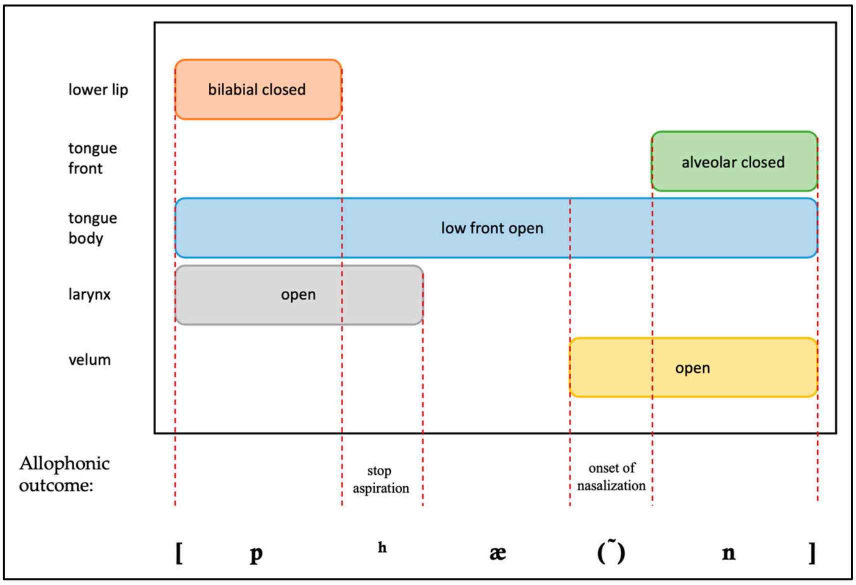

Figure 1. Gestural representation of English *pan* (adapted from Goodin-Mayeda 2016, p. 39).

As previously indicated, Articulatory Phonology does not make predictions about how the articulatory constraints of the two languages of a bilingual speaker may interact. A theory that considers sound articulation and includes non-monolingual populations is Honikman's (1964) Articulatory Settings Theory. Honikman considers that speakers possess complete motor speech control at the time of speech production in each of the languages they speak. Further studies such as Colantoni et al. (2021) and Wilson and Gick (2014) implemented this theory to their own respective groups of bilingual speakers. The latter corroborated the idea that higher L2 proficiency correlated with greater articulatory control in the L2. Considering that heritage speakers usually show an early onset for the acquisition and use of their two languages, we should expect similar results from this population and the acquisition of foreign coarticulatory systems.

Moreover, Flege's (1995) Speech Learning Model, which was recently revisited and adjusted as the SLM-r (Flege and Bohn 2021), posits that L1 and L2 sounds coexist in a shared mental space, that early bilinguals show greater plasticity for new phonetic category formation, and that phonetic systems adapt throughout life depending on the phonetic input they receive at a given time. This allows us to make predictions regarding the acquisition of new patterns in heritage bilingual speakers. If the acquisition of coarticulatory patterns is equated to that of context-dependent sound patterns, we can connect the possible outcomes of coarticulatory acquisition with the postulates of the SLM and SLM-r, which should predict a more successful acquisition at an early age.

2.2. Heritage Speaker's Phonetics and Phonology

The term 'heritage speaker' (HS) is quite broad. As Chang (2021, p. 581) points out, the term "is used to refer to (sub)populations of language users that share the core characteristic of an 'interrupted' trajectory of exposure to their L1, where the discontinuity is brought about by intensive exposure to the L2". The mentioned discontinuity and linguistic "switch" occurring has also allowed linguists to label these speakers as "switch-dominance bilingual speakers" (Casillas and Simonet 2016). Depending on the circumstances, HSs may have two L1s that are learned near-simultaneously, or their L2 may be learned later in life, as is usually the case with L2 learners. Yet, as pointed out by Montrul (2015), because of societal reasons, the 'new' language becomes the dominant language and 'outshines' the HL, which is eventually restricted to familial and more private environments. As is usually the case in linguistic contact scenarios, transfer is inevitable. In HL research, the term *transfer* is generally used as 'dominant language transfer' (Romano 2021, p. 946). Nevertheless, HS bilinguals may exhibit vast (socio)linguistic diversity as well as divergence in competence skills in various linguistic areas (Polinsky and Scontras 2020). Thus, new research avenues should also consider the study of 'weak language transfer' as it is known that the dominance of each language spoken may affect linguistic development (Puig-Mayenco et al. 2018).

Among the linguistic skills that heritage bilinguals usually exhibit, the phonetics and phonology are usually considered the most 'native-like', while their morphology and syntax show more 'gaps' (Montrul 2008). However, within HSs' phonological grammars, research has found variability in the stability of certain areas. While vowel duration, vowel space expansion, and speech style are similar to those of monolingual speakers (Ronquest 2016), vowel quality (Ronquest 2013), consonants and their features such as VOT (Amengual 2012) or spirantization (Amengual 2019; Rao 2014), and lexical stress (Kim 2019) are vastly affected and possess distinctive features. Furthermore, a large number of HL studies have focused on presenting non-dominant HLs and comparing them to monolingual native speakers of the respective non-dominant HL (see Chang 2021 and references therein). Under these circumstances, can we objectively compare linguistic groups where one is comprised of monolingual speakers of a language and the other one includes non-dominant HSs of that same language to draw veridical conclusions?

Unfortunately, a relatively small body of literature has focused on coarticulatory and/or context-dependent features of speech in heritage bilinguals. Amengual (2018, 2019) investigated these types of variants in heritage speech and found that bilingualism degree was correlated with 'native-like' performance. Amengual (2018) observes the variation of /l/ in onset position, that is, [l], and coda position, that is, [ɫ] (velarized), in various generations (G1, G1.5, G2, G3) of HSs speaking Spanish and English. His results exhibit that most HSs can distinguish between allophonic variants cross-linguistically. However, when in 'bilingual mode', in which the task consisted in reading sentences in Spanish and translating them into English or vice versa, the production of their non-dominant language shifts towards their dominant one, indicating cross-linguistic transfer. In his more recent study, Amengual (2019) compares the production of phrase initial [b, d, g] and intervocalic voiced approximant variants [β, ð, ɣ] by early sequential bilinguals (L1 Spanish, L2 English) to simultaneous bilinguals (2L1 Spanish, English) and L2 learners (L1 English, L2 Spanish). Amengual uncovers that speakers who had exclusively used Spanish from an early age were leniting their voiced plosives more, thus following phonological spirantization rules of Spanish. This contrasts with the more constricted productions of the simultaneous bilingual and L2 groups, which is a typical feature of English. Amengual (2018, 2019) shows that: (i) the type of bilingualism and age of acquisition is a crucial factor to consider in phonetic production; (ii) HSs acquire cross-linguistic context-dependent differences; and (iii) cross-linguistic interferences can occur when linguistic coactivation is present. Of note is that the two processes undertaken by Amengual (2018, 2019) illustrate allophonic variation, that is, context-dependent and *categorical* productions that have been phonologized in English and Spanish, such as /l/ velarization and voiced stop spirantization, respectively. The phonological status of anticipatory nasalization may be a more complex process to describe cross-linguistically because of the physiological nature of the phenomenon itself.

2.3. Anticipatory Vowel Nasalization across Languages

The way in which pre-N vowels result in articulatory nasalized vowels is another exemplar of context-dependent variation. This phenomenon is interesting because the alignment between oral and nasal gestures is unlikely to be perfectly synchronized and interspeaker variation is expected to be found in relation to articulatory control. Research has shown that languages vary in the degree of gestural timing overall between V and N (Clumeck 1976; Sampson 1999). Early studies such as Clumeck (1976) investigated vocalic nasalization in various languages such as American English, Swedish, Metropolitan French, Amoy Chinese, Hindi, and Brazilian Portuguese. These languages exemplify distinct scenarios where the phonological feature [+NASAL] arises in vowels. For instance, while the [+NASAL] feature is contrastive in French, Hindi, or Portuguese, it is not in English and Swedish. Clumeck (1976) alludes that the lack of contrastiveness between oral and nasal vowel counterparts allows for greater coarticulatory overlap between V and N as there is no phonemically [+NASAL] V competitor (Desmeules-Trudel and Brunelle 2018; Zellou and Chitoran 2023). Clumeck's results meet his predictions. Additionally, concurring with Sampson (1999), languages whose vowels do not possess the [+NASAL] phonological feature show varying degrees of gestural overlap between oral-nasal gestures cross-linguistically.

The languages under study in the present paper are Spanish and English, in which differences in the timing settings of nasalized vowels have been encountered. Solé (1992), for example, investigated coarticulatory vowel nasalization in American English and Peninsular Spanish and found varying patterns cross-linguistically as a function of speech rate. While in English vowel nasalization increases with vowel duration, that pattern is not found in Spanish, in which the temporal extent of nasalization remains stable. Observing the results and patterns across speech rates, Solé concludes that coarticulatory vowel nasalization has been phonologized in English, while it is only phonetic in Spanish, or as Solé considers it, "an unintended effect" (39). Notwithstanding, Solé's studies include small sample sizes with three speakers per language and should therefore be considered cautiously. Indeed, recently, Bongiovanni (2021a, 2021b) puts the phonological status of anticipatory vowel nasalization in Spanish up for debate. She obtained nasometry data from one velarizing and one non-velarizing Spanish variety. Her sample includes 28 speakers from Santo Domingo, Dominican Republic, and 26 speakers from Buenos Aires, Argentina, respectively. The results indicate that Spanish speakers from the velarizing variety of Santo Domingo exhibit an earlier onset of nasalization versus that of the Argentine speakers, which Bongiovanni takes as a cue to propose that anticipatory vowel nasalization is phonologized in the former variety, and thus, allophonic and categorical, but phonetic in the latter, that is, coarticulatory and gradient.

To date, few studies have analyzed time settings of nasality in Spanish from a bilingual perspective (see Martínez 2021; Beristain 2022, forthcoming). Nevertheless, the results of those studies coincide, which is validating for future research predictions. Martínez (2021) observes the production of nasalized vowels in HL Argentine Spanish and L2 Brazilian Portuguese as the dominant language and found that HSs show distinct coarticulatory systems in the two languages. However, cross-linguistic bleeding is apparent when compared to monolingual speakers of the two languages spoken. For instance, while Portuguese phonemically [+NASAL] vowels show a very early onset of the nasality gesture, the onset of the gesture for nasalized /VN/ vowels appears significantly later in monolingual Portuguese speakers. Martínez points out that this is done to potentially avoid any perceptual similarities across conditions, as presented in the *Principle of Perceptual Distinctiveness* (Clumeck 1976; Solé 1992). L1 Spanish data show earlier onsets of nasalization for /VN/ structures than in L1 Portuguese /VN/ structures. Notice that there is no [+NASAL] vowel competitor in Spanish. The HSs showed clear distinctions between Portuguese and Spanish /VN/ sequences. However, HSs' patterns in Spanish showed more delayed onsets of nasality in Spanish than monolingual speakers did, thus possibly implying Portuguese transfer. In Beristain (2022, forthcoming), they compared /VN/ sequences in English and Spanish among several bilingual groups. Note that neither language has [+NASAL] as a contrastive feature in vowels. They found that the two highly proficient bilingual groups, among which the HSs were found, showed distinct coarticulatory systems in Spanish and English. Heritage gestural patterns resembled monolingual-like patterns in both languages.

3. Research Questions

Previous research shows that advanced bilingual speakers can adjust the articulatory settings of the languages they speak (Honikman 1964). Additionally, more recent L2 speech models such as the SLM-r (Flege and Bohn 2021) propose that early bilinguals are more prone to phonetic system adjustability that may be affected by the type of input received throughout life. The current study investigates whether heritage bilingual speakers can possess two gestural timing settings in their HL and L2 and whether their degree of gestural overlap correlates with their degree of bilingualism.

The research questions (RQs) and framing of the present study are based on the considerations presented in Chang (2021, p. 595): (i) group or population comparisons will be avoided and the focus will be solely on heritage speakers; and (ii) individual-centric analyses should be prioritized in HL populations considering the vast variability and interspeaker variation we encounter within this group.

- *RQ 1*: Can heritage speakers acquire distinct time setting patterns of nasality in /VN/ structures of English and Spanish?
- *Hypothesis 1*: Yes. According to Martínez (2021) and Beristain (2022, forthcoming), I expect that HL speakers will show the ability to adjust their two timing settings in relation to /VN/ structures. These participants have an early language acquisition onset and have long been using both languages, and are therefore expected to show distinct categories for nasalized vowels in Spanish and English. The fact that anticipatory nasalization is phonologized in English and phonetic in Spanish should allow for this differentiation to happen more easily. It is expected that the gestural overlap of English /VN/ sequences will be greater than those of Spanish, thus resulting in higher proportion of nasal airflow in the former.
- *RQ 2*: Is there correlation between degree of bilingualism and degree of anticipatory vowel nasalization?
- *Hypothesis 2*: Yes. Considering Amengual's (2018, 2019) findings, speakers showing a more 'balanced' bilingualism should exhibit more distinct results between the two languages. The more dominant a heritage speaker is in one language, the greater shift towards that language's expected patterns we should encounter. That is, participants

that show higher dominance scores, thus being more English-dominant, will exhibit a greater degree of nasalization overall, whereas speakers that present lower dominance scores, thus being more Spanish-dominant, will display a lower overall degree of nasalization.

4. Methodology

4.1. Participants

The present study includes 16 Spanish heritage speakers of Mexican descent. There were nine cisgender females and seven cisgender males. Their average age is 20 (SD: 1.16). They are all second-generation (G2) bilinguals from the Chicagoland area living in a household with parents that were born in Mexico and emigrated to the USA. Participants were recruited from two student pools at a large research university in the Midwest: (i) upper-level Spanish courses, and (ii) a Latinx student organization the author of the study had connections with on campus. Participants recruited from university courses were compensated monetarily by receiving a total amount of $5 or by receiving extra credit for the course they were registered in; participants from the student organization could only be compensated by the same monetary amount.

At the completion of the experiment, participants filled out the Bilingual Language Profile, henceforth BLP (Birdsong et al. 2012). This questionnaire assesses language dominance and considers speakers' degree of bilingualism on a continuum that ranges from [−218, +218] rather than making a binary distinction. The questionnaire considers four modules to infer one's degree of bilingualism: (i) language history, which includes age of acquisition, years of schooling in each language, etc.; (ii) language use, which involves frequency of use of each language in contexts such as family, friends, and other social networks; (iii) language proficiency, which was self-rated; and (iv) language attitudes, which observes the identification with each culture. This way, the score we obtain provides a comprehensive background check of each speaker which is told by the participant, rather than being assumed by the researcher. Table 1 provides a summary of each participant's overall BLP Scores. Table A1 in Appendix A lists all individual characteristics of each of the four modules.

Table 1. Speakers and their overall BLP Scores, arranged from most English-dominant to most Spanish-dominant (*zero-threshold*: balanced bilingual).

Speaker	BLP Score	
	[−218, 218]	
65	96.26	(English-dominant)
8	93.63	
53	68.57	
26	60.75	
52	55.66	
30	45.31	
20	26.88	
42	25.61	
55	23.52	
3	14.08	
27	7.37	
72	−0.72	
1	−2.80	
54	−6.62	
6	−22.60	
58	−69.28	(Spanish-dominant)

As can be seen, although all participants are G2 bilingual speakers, there is wide interspeaker variation as far as their degree of bilingualism. While some speakers are considerably English-dominant (see 3, 8, 20, 26, 30, 42, 52, 53, 55, 65), a few are Spanish-dominant (see 6, 58), and others are more 'balanced' (see 1, 27, 54, 72). This categorical group distribution is simply for description purposes and will not be considered for any type of analysis.

4.2. Materials

Participants produced target words embedded in carrier phrases in two separate sessions. Each session corresponded to each language under study. The read-aloud task is the most effective technique herein to avoid potential participant fatigue in the experimental setting caused by the articulatory equipment (see Section 4.3). Target tokens were common, real words and included each one of the five vowels of Spanish /i, e, a, o, u/ and the American English vowels that were closest to those acoustically, /i, e, ɑ, o, u/ (Bradlow 1995). They included vowels that were phonetically oral (/C**V**(C)/ in English or /C**V**CV/ in Spanish) or nasalized (/C**V**N/ in both). The wordlist was obtained from Beristain (2022). Tables 2 and 3 list the tokens in Spanish and English, respectively. Importantly, the meaning of the words was explained to the participants prior to the data collection process in case they were unfamiliar with any of the words.

Table 2. Target tokens in Spanish.

	CVCV	**CVN**
/i/	*tita* 'aunt' (informal)	*patín* 'rollerblade'
/e/	*cateto* 'ignorant'	*ten* 'you have, IMP.'
/a/	*tato* 'little brother'	*tan* 'so'
/o/	*pitote* 'fuss'	*botón* 'button'
/u/	*batuta* 'baton'	*atún* 'tuna'

Table 3. Target tokens in English.

	CV(C)	**CVN**
/i/	*tea*	*teen*
/e/	*tape*	*attain*
/ɑ/	*top*	*futon* [1]
/o/	*toe*	*tone*
/u/	*two*	*tune*

[1] I acknowledge that the word *futon* shows a distinct accentual pattern where the nasalized vowel is in an unstressed syllable (as opposed to in the stressed one). A post hoc inspection of the data revealed no substantial differences within that context and such data will be kept in order to be able to conduct cross-linguistic comparisons within each speaker and cross-linguistic contexts.

The carrier phrases in which target words were produced were I say TARGET twice and Digo TARGET ligeramente 'I say TARGET softly'. Ligeramente /lixeɾamente/ was chosen as the posterior word in Spanish in order to preserve the alveolar place of articulation of /n/ because there is a nasal place neutralization rule in Spanish (Hualde 2014, p. 174).

4.3. Equipment

Aerodynamic data were collected via BIOPAC's (2020) TSD160A pressure transducers (Beristain 2022; Carignan et al. 2011; Shosted 2009; Shosted et al. 2012). The transducers were connected to a vented Scicon OM-2 mask which had a separator between the nasal and oral cavity. Thus, separate and concurrent oral and nasal airflow data were obtained to observe gestural timing overlap across time. Additionally, simultaneous acoustic data were collected for segmentation purposes solely via an AKG C520 head-mounted microphone that was located approximately 3 cm (1 inch) away from participants' mouths.

4.4. Data Collection and Procedure

In order to avoid linguistic co-activation, a 'monolingual-like' mode was stimulated in the lab (Grosjean 2008). This was carried out by (i) sending email reminders in the target language; (ii) having only researcher(s) in the lab that were native speakers of the target language;[1] and (iii) scheduling the two experimental sessions in two separate weeks (always 72 h away from each other, at least). The experiments took place in a sound-attenuating booth inside the phonetics laboratory of a large research university in the Midwest. Before completing the experiment, each participant filled out a consent form in which they agreed to participate in the two required sessions.

Approximately 15–30′ before every session, the BIOPAC machine was manually calibrated by the author of this study. This was done via an AFTA6A Calibration syringe, which expelled a precise volume of air: 600 mL (Beristain 2022; Shosted 2009). Two measurements were considered for the signal calibration: (i) the correction value of the signal, and (ii) the integral area of the amount of air expelled by the syringe. The former was collected to remove any pre-existing voltage and to consider the air pressure conditions during that instant and was obtained by segmenting a 'flat' or 'null' voltage area before the production of target tokens' initial /t/ segment. The latter was obtained so that electric voltage could be converted into velocity units. The completion of these two tasks ensures the reliability of the data collected.

Instructions were given to participants and they were shown how to operate the equipment. Participants held the mask on their own and a strip was placed around their head to ensure no air leakage was present. Additionally, prior to the experimental session, a trial session was conducted where participants produced structures such as tata /tata/, tan /tan/, and nana /nana/. These three structures are expected to exemplify three distinct airflow contours: tata should be completely and solely oral, and no (or virtually non-existent) nasal airflow should be present; tan includes a nasalized vowel followed by a fully nasal consonant; and finally, nana should show fully nasal airflow contours due to nasal consonants and carryover nasalization onto the vowels. If any speakers exhibited abnormal results such as fully nasal airflow contours in tata or non-existent nasal airflow in nana, the datapoints of such speakers would be discarded as they could be possible indicators of velopharyngeal disfunction. None of the participants in the current study showed unexpected results. Speakers then produced the target words within the carrier phrases one after the other. After every minute, the recording was stopped in order to avoid fatigue as participants were breathing into a mask. No participant mentioned or showed any signs of discomfort. The total number of target tokens collected was 640 tokens: 16 speakers × 5 vowel conditions [i; e; a/ɑ; o; u] × 2 contexts [CV(CV); CVN] × 2 languages [Spanish; English] × 2 repetitions.

The software AcqKnowledge (v. 3.9.1) was used to collect the data. This medical software allows you to obtain various types of data from different sources simultaneously. Thus, three different channels were established: (i) nasal airflow, (ii) oral airflow, and (iii) audio/acoustic signal. The airflow data came from each one of the cavities of the OM-2 mask connected to the BIOPAC system, while the audio signal was recorded via the head-mounted microphone that was connected to a Grace M101 microphone preamplifier and was digitized at 2 kHz.[2]

After the data were collected, those files were converted to .wav files using the audiowrite function in MATLAB (2020) where the three channels were kept. Praat (Boersma and Weenink 2020) was employed for data inspection and segmentation. The onset of the vowel was chosen by considering the laryngeal gesture (i.e., voicing). This is because nasal airflow is only audible in Spanish and English when it is voiced. The onset was easily recognizable by observing the oral airflow channel and onset of F0 (and therefore, voicing). Notice that, in this case, the use of the spectrogram or audio signals is not so advantageous because of the sampling rate of the equipment.[3] By utilizing both oral airflow and F0, which is an algorithmically determined boundary via autoregressive correlation, we promote more replicable conditions for future studies to follow and avoid inconsistencies that could arise from manual boundary selection in low-resolution acoustic data (see Martínez 2021: 37 as a sample study that used F0/voicing as a boundary). All target nasalized vowels were followed by /n/ segments. Therefore, the offset of the vowel was considered when the oral airflow finalized and the nasal airflow increased, indicating the V→N transition. Figure 2 includes sample segmentations.

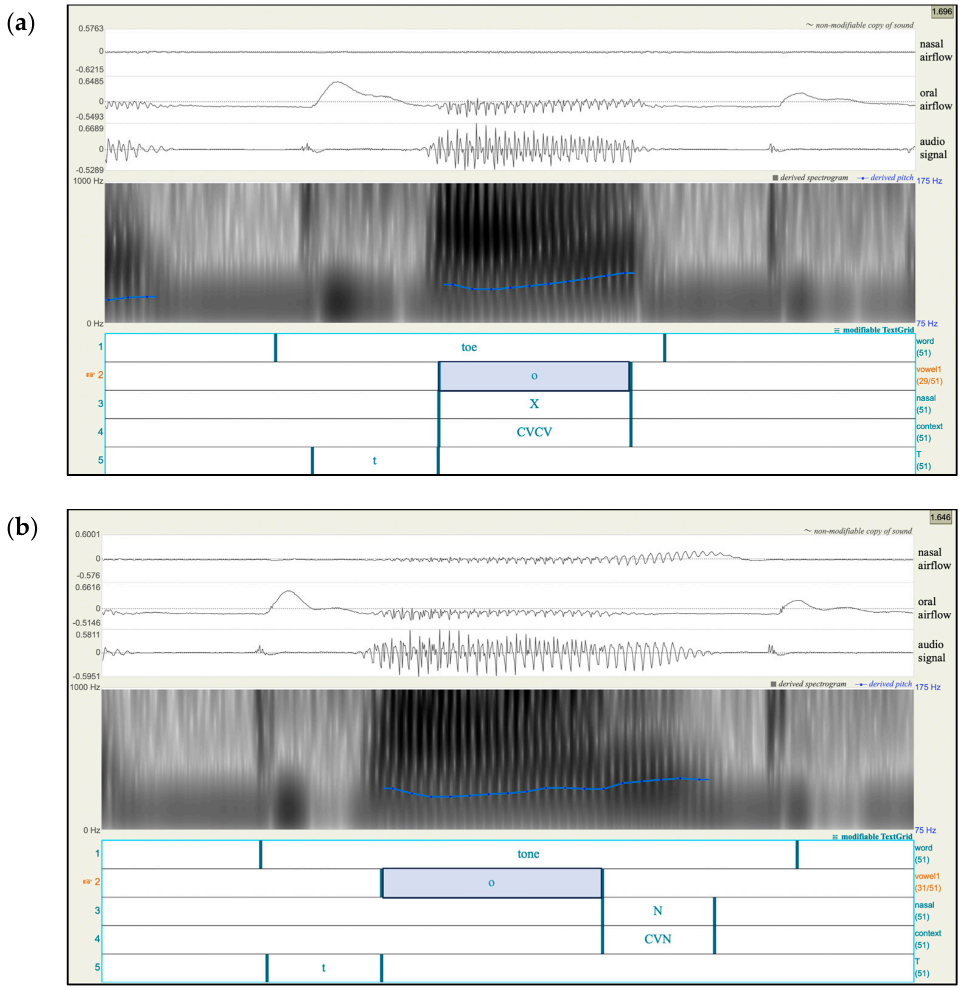

Figure 2. Sample segmentation of CV and CVN sequences: (**a**) toe; (**b**) tone. (Speaker #1, Rep. #1).

4.5. Data Analysis

4.5.1. Signal Processing

The original, raw signal was synthesized in MATLAB taking into consideration various conditions. The convertion equation implemented to obtain the new calibrated and filtered signal is presented in (1):

$$s' = \mathit{filtfilt}\ (\mathrm{s}\ \times\ \frac{v}{\int s} + \mathrm{c}) \tag{1}$$

where s' is the new, resulting signal; *filtfilt* is the MATLAB function; s is the original, unaltered signal; $\int$ means integration in order to calculate the area under the signal curve; v is the total volume of the syringe (=600 mL), and c is the correction number (specific to every word).

As explained in MATLAB (2020), the *filtfilt* function "performs zero-phase digital filtering by processing the input data, x, in both the forward and reverse directions. After filtering the data in the forward direction, *filtfilt* reverses the filtered sequence and runs it back through the filter". A signal cut-off was applied at 50 Hz to avoid any interference such as vocal fold vibration or noise in airflow contours (Beristain 2022; Shosted 2009). Integral and correction values were saved in a separate spreadsheet that was later read onto the MATLAB script that performed the data extraction. Following Shosted (2009), the areal integral was calculated using the *trapz* function in MATLAB (2020).

4.5.2. Statistical Analysis

There are two RQs in this study, and both questions had proportion of nasal airflow to total airflow as their dependent variable. This was calculated the following way: $\int \frac{nasal}{(nasal + oral)}$ airflow. For RQ1, that is, whether HSs show cross-linguistic adjustability of segment-to-segment time strategies, a linear mixed-effect statistical model (Kuznetsova et al. 2015) was run in RStudio (R Core Team 2020; R Studio Team 2020). For RQ2, an individual-centric, exploratory, and descriptive analysis will be conducted in which the productions of each participant will be compared vis-à-vis their bilingual status.

Initially, models with different structures were considered. These models included the maximal structure of fixed factors, that is, LANGUAGE (English; Spanish), VOWEL (i; e; a; o; u), CONTEXT (CVCV; CVN), SEX (Female; Male), and BLP SCORE (as a continuous variable), and simplified versions of it as well as various structures of random intercepts and slopes. The model with the lowest AIC score (Akaike 1974) was selected as the optimal one. Eventually, the optimal model consisted of an interaction between LANGUAGE and CONTEXT, and has the fixed factor BLP SCORE and random intercepts for SPEAKER and WORD, as well as random slopes including BLP SCORE within SPEAKER and LANGUAGE and CONTEXT within WORD to account for intra-speaker variability across languages and contexts. The inclusion of random slopes was made following Barr et al.'s (2013) suggestions about optimal random slope structure for linear mixed-effect models.

For visualization and descriptive purposes solely for RQ #2, a time-series analysis was conducted in the data. Each vocalic segment was further divided into 40 equidistant points from where the time dynamics of both the oral and nasal airflow were analyzed. Thus, 25,600 data-points are considered when describing the time dynamics of airflow. Considering the individual centric analysis provided in this study, no inferential statistics are presented on the time-series data at this time.

5. Results

5.1. RQ1 Cross-Linguistic Time Settings Adjustment: Group Analysis

A greater degree of overall nasalization for the vowels in the /CVN/ context than for the oral control /CV(CV)/ is found in both languages (see Table 4). As is observed, the overall proportion of nasalization within the vowel is greater in English than in Spanish, 0.22 (=22%) versus 0.11 (=11%), respectively. Figure 3 shows a visual depiction of such results.

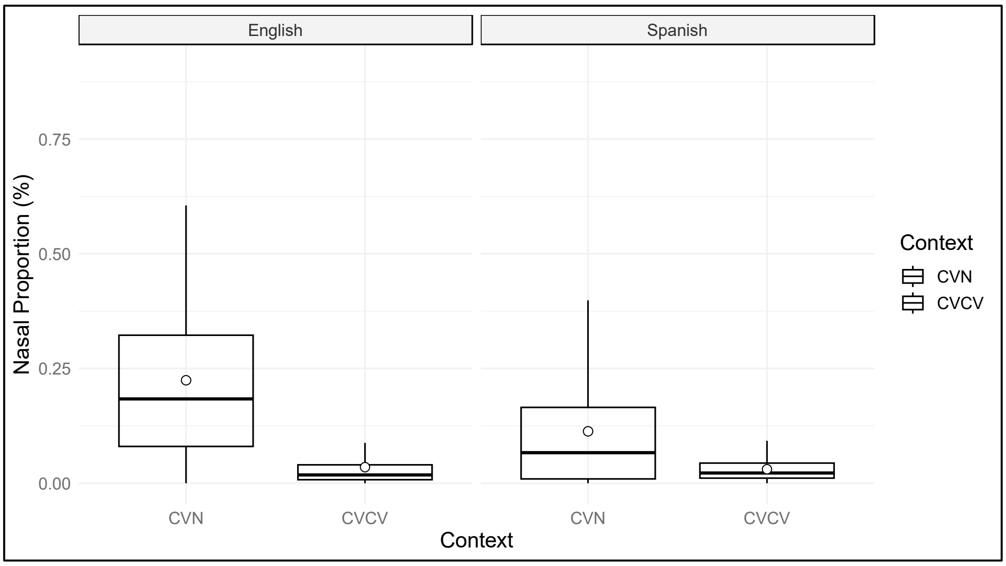

Figure 3. Nasalized proportions by Language and Context [white dot represents mean].

Table 4. Nasal airflow proportions in English and Spanish.[4]

	English M (SD)	Spanish M (SD)
CVN	0.22 (0.19)	0.11 (0.13)
CV(C)(V)	0.04 (0.05)	0.03 (0.03)

The linear mixed-effect model revealed a robust difference for CONTEXT and LANGUAGE, indicating that participants exhibit significantly greater degrees of nasalization in vowels within /CVN/ structures versus /CV(CV)/ as shown in Table 4 and Figure 3, and distinct coarticulatory systems across languages in /CVN/ sequences (see Table 5 for model output). These results agree with previous literature on nasalization patterns in Spanish and English.

Table 5. Output of statistical model (Fixed Effects).

Fixed Effects	Est. (β)	Std. Error	df	t-Value	*p*-Value
(Intercept)	0.22	0.03	9.59	7.54	<0.001
LANGUAGE: Spanish	−0.11	0.04	7.92	−3.04	<0.05
CONTEXT: CVCV	−0.19	0.03	8.51	−6.87	<0.001
BLP SCORE	0.0003	0.0003	5.69	0.85	0.42
LANGUAGE x CONTEXT	0.11	0.04	9.58	2.76	<0.05

5.2. RQ2 Effect of Degree of Bilingualism: Individual-Centric Analysis

As seen in Table 5, the linear mixed-effect model revealed no significant effect of the BLP Score. Nevertheless, following current trends in HL acquisition research and the suggestions made in Chang (2021), an individual centric analysis is provided below.

Table 6 presents the summary of the means and standard deviations of the proportion of nasal airflow in the nasalized vowels in /CVN/ sequences in English (left) and Spanish (right) per speaker. The order of the speakers corresponds to language dominance, which goes from more English-dominant to more Spanish-dominant.

Table 6. Nasal airflow proportion per speaker.

Speaker	BLP Score	English	Spanish
		M (SD)	M (SD)
65	96.26	0.61 (0.26)	0.48 (0.34)
8	93.63	0.49 (0.32)	0.51 (0.44)
53	68.57	0.41 (0.25)	0.47 (0.38)
26	60.75	0.47 (0.31)	0.38 (0.24)
52	55.66	0.68 (0.31)	0.53 (0.33)
30	45.31	0.23 (0.15)	0.37 (0.38)
20	26.88	0.68 (0.29)	0.42 (0.38)
42	25.61	0.41 (0.29)	0.46 (0.42)
55	23.52	0.32 (0.27)	0.18 (0.16)
3	14.08	0.31 (0.27)	0.33 (0.29)
27	7.37	0.39 (0.19)	0.42 (0.38)
72	−0.72	0.53 (0.23)	0.43 (0.3)
1	−2.80	0.48 (0.33)	0.5 (0.33)
54	−6.62	0.36 (0.35)	0.42 (0.42)
6	−22.60	0.41 (0.26)	0.21 (0.2)
58	−69.28	0.52 (0.33)	0.40 (0.29)

Results show that overall nasalization degree ranges from 0.68 (Participant 20, English-dominant) to 0.31 (Participant 3, English-dominant) in English and from 0.53 (Participant 52, English-dominant) to 0.18 (Participant 55, English-Dominant). At first sight, no clear correlational pattern is found between BLP Score and nasalization degrees in English and Spanish. A more detailed report is provided in the discussion section.

Moreover, as mentioned in Section 4.5.2, the time dynamics of oral and nasal airflow patterns in nasalized vowels was further explored. In Figure 4, the x-axis represents normalized time, which includes 40 points per vowel segment from onset to offset, while the y-axis represents the velocity of the nasal and oral airflow (in L/s). The plots are organized following linguistic dominance, as presented in Table 6. The blue line represents nasal airflow while the grey line represents oral airflow. Notice that the oral airflow exhibits greater magnitude than the nasal one, which is to be expected as the oral aperture (the mouth) is larger than the nasal one (two nostrils).

As expected, speakers show greater degree of oral airflow than nasal airflow. Moreover, an increment in the nasal airflow is visible as the N gesture approaches. Such rise is more pronounced in English than in Spanish. Of note is the wide variability we encounter in the raw oral airflow of vowels, especially in Spanish, which has clear consequences on the overall lower nasality proportions in that language. Notice participants 53, 52, 20, 55, 27, and 6, whose oral airflow productions are significantly greater than the rest of the participants'. The implications of this puzzling finding are discussed in the discussion section.

The BLP Score was considered within a continuum. Although the linear mixed-effect model did not yield significant effects for that score, a Pearson correlation test between degree of vocalic nasalization within /CVN/ sequences and BLP Score was conducted to further investigate the influence of degree of bilingualism. Figure 5 shows the correlation between degree of nasality proportion (*y*-axis) and BLP Score (*x*-axis). No strong correlation value was found in either of the languages (Spanish: $R = 0.13$, $p = 0.11$; English: $R = 0.16$, $p = 0.05$). As shown in Figure 5, a clear effect of language is apparent. The tendency to increment nasality degree appears as participants' BLP Scores increase, and are therefore more English-dominant, but the difference is not significant. Therefore, HSs behave in similar ways cross-linguistically.

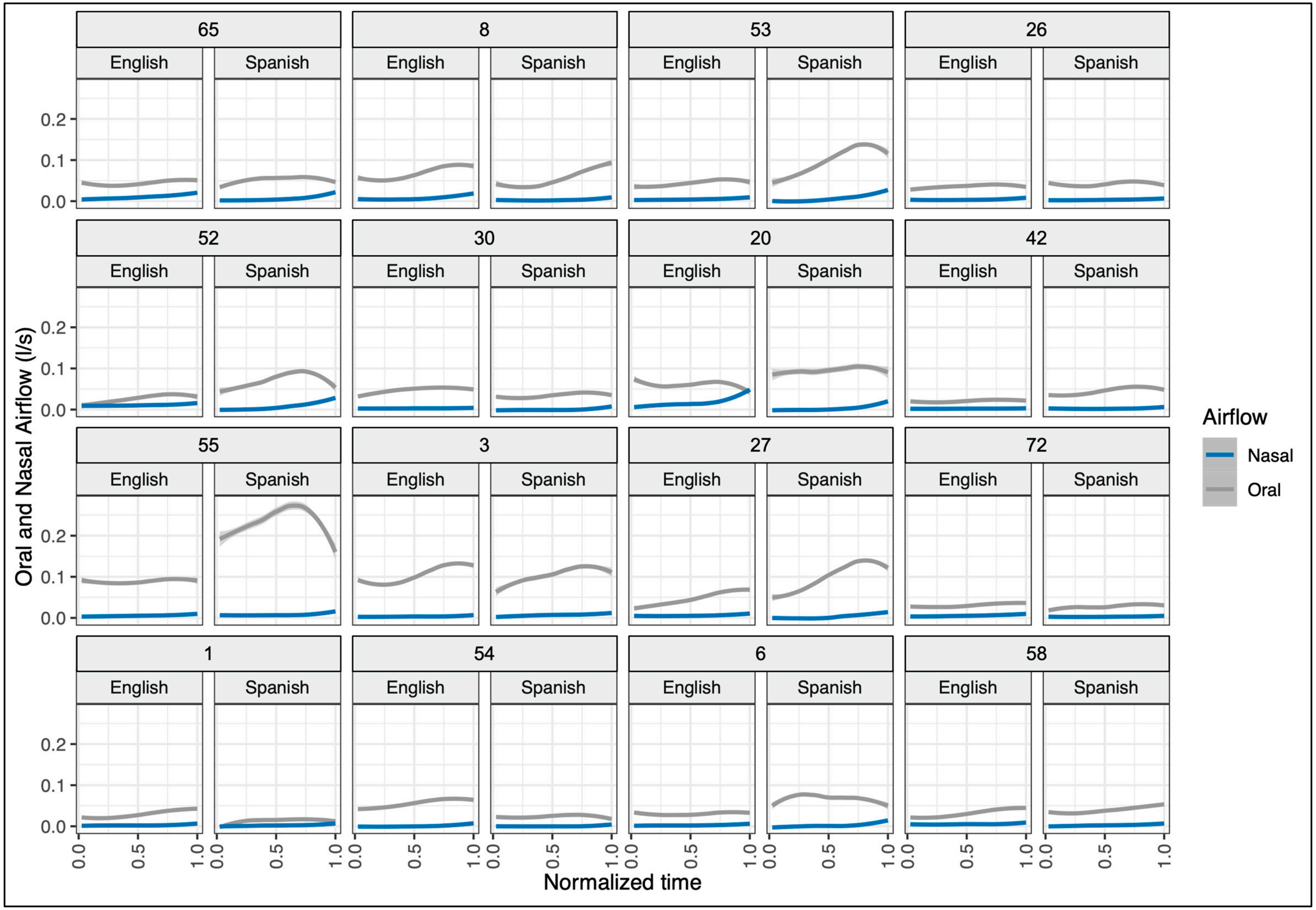

Figure 4. Time dynamics of oral (grey) and nasal (blue) airflow by speaker in /CVN/ structures.

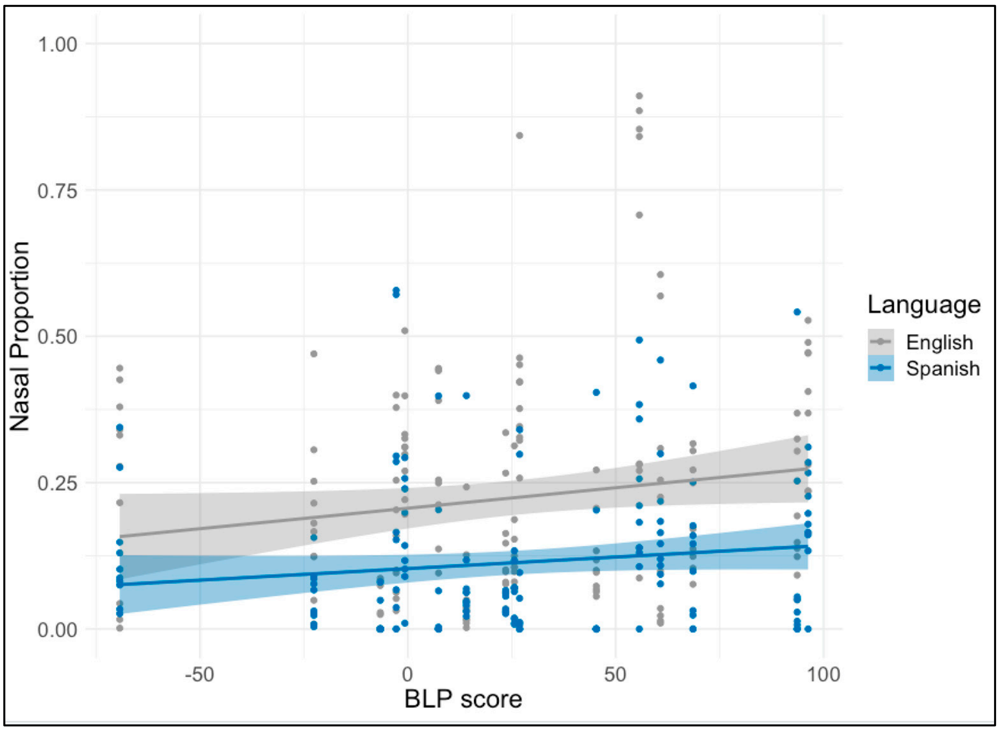

Figure 5. Correlation between nasality degree and BLP Scores in English (grey) and Spanish (blue).

6. Discussion

Let me first revisit the two RQs and hypotheses of the present study. First, I seek to answer whether heritage bilinguals can possess distinct coarticulatory systems for Spanish and English nasalized vowels. Following what previous literature has put forward, where Honikman's (1964) Articulatory Settings Theory and Flege's (1995) (and Flege and Bohn's (2021)) (r-)SLM are included, I hypothesized that they would. This comes down to (i) the speakers having an early age of acquisition onset for both languages and exhibiting a high level of bilingualism, and (ii) since coarticulatory vowel nasalization shows distinct statuses in Spanish and English (phonetic in the former, but phonological in the latter), creating a new category should be more easily achievable. Secondly, I asked whether language dominance plays a role in phonetic performance, and considering that previous studies such as Amengual (2018, 2019) correlate higher linguistic proficiency and degree of bilingualism with more native-like phonetic performance, it is my belief that degree of bilingualism will show similar effects in the current study.

The present study demonstrates that heritage bilinguals show distinct coarticulatory vowel nasalization patterns with regards to nasalized vowels in English and Spanish (*RQ1*, *H1*). A large majority of previous studies have investigated nasalization patterns in each of the languages individually, yet not bidirectionally, and have found that English shows a greater degree of nasalization in nasalized vowels than Spanish does (Clumeck 1976; Solé 1992). Because of the changing and stable patterns according to speech rate in Spanish and English, respectively, Solé (1992) concludes that while coarticulatory vowel nasalization is phonetic in Spanish, it has been phonologized in English.[5] Only more recent studies such as Martínez (2021), and Beristain (2022, forthcoming) have observed this variable in the context of bilingualism. The results of the aforementioned studies align with the present ones. This study shows that heritage bilinguals possess two coarticulatory systems in their bilingual grammar. The fact that heritage bilinguals are able to produce distinct patterns follows the argument of Honikman (1964) in which it is posited that the more accustomed to the use and presence of both languages, the more articulatory control a speaker will exhibit. These participants, albeit presenting varying degrees of Spanish usage patterns currently, had received both Spanish input from an early age at home, and

English input at a school age, which should facilitate the acquisition of the two systems under study. As far as Flege and Bohn (2021) postulate, we can visualize that HSs exhibit two different categories for their Spanish and English nasalized vowels. Although these coarticulatory vowel nasalization patterns are not contrastive in either of the languages under study, they show distinct statuses in each language. HSs exhibit the skillset to adjust and increment the degree of nasalization from Spanish (HL) to English (L2), following the phonetic and phonological grammars of their HLs and L2s, especially considering that the latter is now the dominant language in society. By observing different coarticulatory patterns cross-linguistically in heritage bilinguals, we can conclude that the acquisition of coarticulation, or 'beyond-segmental' features, is achievable in L2s and HLs. This is similar to what has been proposed for segmental acquisition in additional languages. A finding like this can help us elucidate whether coarticulatory features are a part of what is known as a "foreign accent". It might be the case that small context-dependent variations are present when listeners perceive other speakers. A study along those lines was presented in Beristain (2022, forthcoming), where such a correlation was found.

Notably, the reason why some speakers show lesser overall nasalization degree values in Spanish is not necessarily because their raw nasal airflow was lesser, but because their raw oral airflow increased. Participants 53, 52, 20, 55, and 27, and to a lesser extent Participants 6 and 42, show similar nasal airflow contours cross-linguistically. However, oral airflow significantly increases in Spanish. Thus, the overall nasalization percentage in Spanish is smaller. No extraordinary characteristics are found within those particular speakers. Interestingly, participant 54 shows the opposite pattern where oral airflow in English is significantly greater than in Spanish. These scenarios pose the question of what the articulatory encoding of nasalized vowels is. One could hypothesize that for a nasalized sound to be *less nasal*, straightforwardly, its airflow ought to be [=ORAL][-NASAL]. The current data exhibit a diverging pattern where less nasalized vowels can be reinterpreted as being [+ORAL][=NASAL]. This debate pertains to the articulation and time settings of gestures involved in speech production. A future study could combine simultaneous airflow and acoustic data to observe the properties of oral, nasalized, and nasal vowels.

The second research question investigated whether degree of bilingualism in heritage speakers played a significant role in phonetic performance with regards to anticipatory vowel nasalization. Following previous studies such as Amengual (2018, 2019), I expected to find such an effect. The data in the current study did not exhibit the patterns I expected. Likewise, the score of the BLP did not yield significant effects in the statistical model nor was a strong correlation found between degree of nasalization and the BLP. If my predictions were met, the expected patterns would be: (a) greater nasalization percentages for English than for Spanish, (b) more English-like patterns for English-dominant bilinguals, and (c) more Spanish-like patterns for Spanish-dominant bilinguals. Although group results exhibit a significant difference between English and Spanish, where the former presents a greater degree of nasalization than the latter (as predicted), I find varying results in the by-speaker analysis. Table 6 reveals three possible sub-groupings (notice that acronyms between brackets indicate linguistic dominance, where *Eng.*: English-dominant, *Spa.*: Spanish-dominant, *bal.*: balanced [BLP −10–10 range]): (i) greater nasalization degree in English than in Spanish, where we find participants 65 (Eng.), 53 (Eng.), 26 (Eng.), 52 (Eng.), 20 (Eng.), 55 (Eng.), 72 (bal.), 6 (Spa.), 58 (Spa.); (ii) similar nasalization degree patterns across languages, where we find participants 8 (Eng.), 3 (Eng.), 27 (bal.), 1 (bal.); and (iii) greater nasalization degree in Spanish than in English, where we find participants 53 (Eng.), 30 (Eng.), 42 (Eng.), 54 (bal.). Pattern (i) was expected if participants followed the phonetic and phonological rules of each language regardless of bilingualism degree or language dominance. My predictions were that the effect of the latter would be seen in the *difference* of nasalization degrees across languages; pattern (ii) was expected for those speakers that are significantly dominant in a given language, thus transferring the language-specific patterns to the non-dominant language; pattern (iii) was unexpected, as there is no phonetic reason or evidence to believe that Spanish nasalized vowels would be more nasal than those in English. It could be hypothesized that this pattern is a hypercorrection, where participants' Spanish might have been affected by what they hear in their surroundings, i.e., English speech. Impressionistic data or self-reflection reports with regard to vowel nasalization would have aided with shedding light on this issue, but such data were not collected as it was outside the scope of the goals of the initial study.

These results illustrate that no direct correlation was found between degree of nasalization and bilingualism. As previously indicated, a clear effect of language was present, where English nasalized vowels were more nasalized. Although the categorical distribution of the participants was done merely for descriptive purposes, different types of language users/bilinguals can be found within each of the groupings. While it is true that more English-dominant heritage speakers are those who also exhibit greater degrees of nasalization for Spanish nasalized vowels (see participants 65, 8, 53, 52) there are other participants such as Speaker 1 that are closer to the zero-threshold, indicating 'balanced bilingualism', which suggests that they still nasalize their Spanish nasalized vowels considerably more than the most English-dominant speakers. On the other side, it was expected that the less nasalized vowels in Spanish would have been produced by the most dominant Spanish speakers or balanced bilinguals (six out of 16 participants), but this was not the case. From these results, we cannot conclude anything specific about the relationship between degree of nasalization and BLP Scores.

Altogether, these findings are not completely unexpected. This could be the result of the amount of data we are contemplating. Although 16 participants comprise a sound sample for an articulatory study (Kochetov 2020), trying to ascertain or corroborate the correlation between variables in such a diverse, non-uniform group with considerable individual variation is not an easy task. This is not a novel claim, as previous literature on HL phonetics and phonology has warned about the 'risks' of and considerations for undertaking HL research. Therefore, as proposed by Chang (2021), individual descriptions should be used to complement the general, broad picture that is described in the data. It is my hope that the current paper has achieved such a goal by presenting the data organized according to linguistic dominance and exhibiting inter-speaker variation and providing detailed time-series data.

The limitations of the current study cannot go unnoticed. The number of tokens was not large, and consequently, general deductions are being made via few words produced by each speaker. In this regard, preference was given to increasing the number of participants as a source of variability in real life as opposed to having fewer speakers producing a larger number of target tokens, which is usually the case in articulatory phonetics research. A future study should consider the effect of generational immigration, as in Amengual (2018), with a larger sample. The present study only focused on G2, but as could be seen from their linguistic profiles, great variation was present in linguistic profiling. Triangulating the development of HL and L2 coarticulatory patterns with their linguistic status, as well as combining sociolinguistic methods and articulatory phonetics, would benefit greatly the understanding of heritage phonetics, phonology, and sociophonetics.

7. Conclusions

Two of the aims of the current paper were to investigate whether second-generation Spanish heritage bilinguals of Mexican descent in the US were able to acquire an L2 (English) gestural timing system regarding nasalized vowels on top of their HL (Spanish), and also to find out whether degree of bilingualism played a significant role in phonetic performance expected for each language.

The preset data, by means of articulatory methods that included an airflow analysis, exhibit that heritage bilingual speakers can adjust the degree of nasalization of nasalized vowels in Spanish and English. In alignment with previous research that indicates that English nasalized vowels display more nasalization degree than those in Spanish, this study shows that bilingual speakers accommodate the segment-to-segment timing strategies and can adjust how nasalized their vowels are in the two languages HSs speak. Yet, against my predictions, linguistic dominance (described in a continuum) solely did not predict phonetic performance in favor of the patterns expected in the dominant language.

The current paper provides novel articulatory data to better understand velum control and gestural timing of oral and nasal gestures in HLs and L2s. The less commonly studied group of heritage bilinguals was considered, as opposed to monolingual speakers, which is usually the case in articulatory phonetics research. The study was complemented with both a group and individual-centric analysis. Additionally, Spanish and English were analyzed, which are languages that do not possess a binary phonological contrast between nasal and oral vowels.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board of University of Illinois Urbana-Champaign (protocol code #20071 and 08/16/2019) for studies involving humans.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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Conflicts of Interest: The author declares no conflict of interest.

Appendix A

Table A1. Participants organized by decreasing BLP Score (the closer to the zero threshold, the more 'balanced' bilingual a speaker is; negative score means more Spanish-dominant, positive score means more English-dominant).

Speaker	Sex	History		Use		Proficiency		Attitudes		BLP Score
		weight = 0.454		weight = 1.09		weight = 2.27		weight = 2.27		[−218, 218]
		EN	SP	EN	SP	EN	SP	EN	SP	
65	F	42.67	26.33	49.05	5.45	54.45	22.7	54.48	49.94	96.26
8	M	43.13	27.24	47.96	6.54	54.48	29.51	54.48	43.13	93.63
53	M	42.67	24.51	49.05	5.45	54.48	52.21	54.48	49.94	68.57
26	M	43.13	21.79	44.69	9.81	54.48	47.67	47.67	49.94	60.75
52	M	48.12	10.89	34.88	14.17	54.48	52.21	49.94	54.48	55.66
30	M	37.22	27.24	39.24	15.26	54.48	36.32	43.13	49.94	45.31
20	M	42.22	34.95	37.06	17.44	49.94	40.86	43.13	52.21	26.88
42	F	30.87	29.05	41.42	13.08	54.48	52.21	45.4	52.21	25.61
55	M	32.68	28.60	39.24	15.26	54.48	40.86	34.05	52.21	23.52
3	M	29.96	30.87	38.15	16.35	54.48	52.21	45.4	54.58	14.08
27	F	25.88	37.68	42.51	11.99	47.67	43.13	36.32	52.21	7.37
72	F	36.77	39.96	35.97	18.53	54.48	40.86	11.35	49.94	−0.72
1	F	24.51	36.77	37.06	18.53	45.4	45.4	40.86	49.94	−2.80
54	F	38.13	39.95	33.79	27.25	45.4	45.4	40.86	52.21	−6.62
6	F	19.06	42.22	34.88	20.71	52.21	54.48	36.32	47.67	−22.60
58	F	15.89	39.95	26.16	30.52	43.13	54.48	20.43	49.94	−69.28

Notes

[1] It needs to be mentioned that the author of the current study is a native speaker of Spanish and was the main and only person in charge when the experiment occurred in Spanish. When the experimental session was in English, two of the author's six research assistants conducted the sessions. They were all native speakers of Chicagoland English, which was the variety spoken by the participants as well.

[2] This is the highest sample rate that is allowed in *AcqKnowledge*. No further analyses were conduced in the acoustic data; it was only used for segmentation purposes to add an additional layer of veracity to segment boundaries.

[3] The misalignment between the voicing band, F0, and audio signal could be due to the presence of the mask participants were wearing.

[4] The range of the dependent variable is 0–1, with 1 representing 100% nasal airflow proportion. Thus, if the nasal proportion is 0.25, this would equal 25% of nasal airflow proportion out of the total airflow produced.

[5] Recently, Bongiovanni (2021a) has found that it is in velarizing varieties such as Dominican Spanish where anticipatory vowel nasalization has been phonologized, but not in non-velarizing ones, such as the one under study in the current paper.

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