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Effects of language dominance in Catalan-Spanish-English trilinguals' vowel-initial glottal marking: A Principal Components Analysis approach

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Crosslinguistic influence (i.e., CLI, henceforth) in trilingual speakers is multidirectional and shaped by factors such as the amount of exposure to, and use of, each of the speakers' languages. This study investigates whether relative dominance explains progressive and regressive CLI in trilingual speakers. To this purpose, we examine the production of word-external vocalic sequences (i.e., /V#V/) in L3 English speakers who are Catalan-Spanish bilinguals. Participants completed a reading task in English, Spanish, and Catalan that elicited vowel-to-vowel sequences along four levels of stress (i.e., stressed-stressed, unstressed-stressed, stressed-unstressed, unstressed-unstressed). Alongside the production task, they filled out a trilingual version of the Bilingual Language Profile (i.e., BLP, henceforth) (Birdsong et al. 2012). The resulting vocalic sequences were classified as instances of glottal marking (i.e., creaky phonation or complete glottal stop) or modal phonation. To examine the role of dominance, we ran a Principal Component Analysis on the questionnaire data, identifying four principal components that explained 57.9% of the variance. We compared L3 English vowel-to-vowel sequences with those of Spanish-English bilinguals who speak Catalan as an L3, as well as with L1 English monolinguals. We ran dominance-based logistic regressions for each language. In English, our results show that L3 English speakers differ from their L3 Catalan Spanish-English bilingual counterparts in unstressed-stressed vowel sequences, but differ across all four stress levels when compared to L1 English monolinguals. Dominance-related principal components do not predict the rate of glottal marking in L3 English. In L1 Catalan and L1 Spanish, the use of glottalization is predicted by the average rate of glottal marking in the speakers' L3 English productions, as well as by higher scores on the principal component associated with L3 English dominance. In Spanish, vowel-initial glottal marking is predicted by scores associated with low Spanish dominance. These findings highlight that dominance mediates CLI in trilingual speakers, which in turn reflects the dynamic nature of CLI in multilingual speakers.

1 Introduction

The phonetic and phonological grammars of multilingual speakers are considered to coexist within an integrated system (e.g., Flege 1995; Natvig 2021; Flege & Bohn 2021; Archibald 2023a), allowing for multidirectional CLI across language-specific sounds and their grammars. First, phonetic and phonological properties from previously acquired languages may be transferred or redeployed during the acquisition of an additional language. This has been observed in speakers learning the sound systems of an L2 or L3, who exhibit features from the L1 or L2 (see Ortega-Llebaria 2024; Steele 2024; Gut & Wrembel 2024: for recent reviews). Second, despite the early attunement to the L1 phonetic system (Werker & Tees 1984; Best et al. 1995), which assumes a relative stability of the L1 systems, research has shown that newly acquired sound systems can also influence those acquired earlier. These effects could be attributed to processing-related CLI (see Antoniou et al. 2012; Simonet 2014; Olson 2016; Elias et al. 2017; Amengual 2018; Muldner et al. 2019: for code-switching and bilingual mode effects), arguably due to simultaneous language activation of the speakers' target and non-target grammars during speech production (Costa et al. 2000; Kroll et al. 2000; Hoshino & Kroll 2008), or to CLI impacting the underlying phonological structure (e.g., de Leeuw et al. 2012; Bergmann et al. 2016; de Leeuw 2019).

In trilingual speakers, CLI offers a unique view into how multiple languages interact in the speakers' minds. It reveals how an L1 and an L2 affect an L3 (i.e., progressive CLI) and how an L3 can, in turn, influence the earlier-acquired languages (i.e., regressive CLI). This provides insight into how stable or vulnerable previously acquired sound systems may be to new sound representations. Much research on L3 acquisition has focused on identifying the sources of progressive CLI, whereas fewer studies have examined the influence of the L3 on regressive CLI. Alongside determining the sources of CLI, models of L3 acquisition have sought to explain the factors underlying this influence. Crucially, understanding the factors that facilitate or constrain CLI can also shed light on the entrenchment of phonetic and phonological encoding in both earlier-and later-acquired sound systems. To this purpose, this study investigates the acquisition of vowel-initial glottal marking in L3 English by Catalan-Spanish bilinguals, focusing on the influence of Catalan- and Spanish-like repair strategies for vowel sequences, as well as the impact of L3 glottal marking on their L1 Catalan and Spanish systems. Moreover, we explore the role of dominance in the multilinguals' three languages as a predictor of CLI.

1.1 Progressive CLI in the L3 sound system

Models of progressive CLI have sought to understand the source(s) of transfer into the L3. Early research on L3 acquisition suggested a privileged role for the L1, as proposed in the L1 transfer scenario (Hermas 2014), which, although not formally proposed as a model (Puig-Mayenco et al. 2022), predicts that, due to the robust state of the L1 and its greater entrenchment relative to the L2, the L1 is most often selected as the initial state in L3 acquisition (Llisterri & Poch-Olivé

1987; García Lecumberri & Gallardo 2003; Hermas 2014; Kopečková et al. 2023). Another set of findings showed that the L3 is most likely influenced by the L2 (Gut 2010; Llama et al. 2010; Wrembel 2010). In line with these results, the L2 Status Factor Model (Bardel & Falk 2007; Bardel & Sanchez 2017) suggests that the L2 has a more significant influence on the L3 than the L1, arguably due to the greater cognitive similarity between the L2 and the L3. This cognitive similarity can be attributed to differences in the types of memory involved in learning the L1 versus a foreign language (Paradis 2008). A competing hypothesis is presented in the Typological Primacy Model (Rothman 2011; 2015), which postulates that transfer arises in a wholesale manner from the most structurally similar language, with later refinements of the model suggesting that property-by-property transfer may emerge as a secondary strategy following initial wholesale transfer (Rothman et al. 2019). Support for an initial wholesale transfer of the typologically most similar language is found in Schwartz & Sprouse' (2021) revision of the Full Transfer/Full Access model (Schwartz & Sprouse 1996), which assumes the initial state of the L2 to be the final state of the L1. Schwartz & Sprouse (2021) posit that a substantial part of one of the previously acquired languages is transferred in the L3 initial state (i.e., onset of the L3 state), while subsequent CLI may arise due to performance strategies under limited resources. Under this model, both previously acquired languages are available for initial transfer. The parser makes 'the big decision' based on a typological similarity scale (Rothman 2015), which includes factors such as the lexicon, phonological and phonotactic cues, functional morphology, and syntactic structure to assess similarity. In the context of the English-Catalan-Spanish language combination, it has been argued that when Catalan-Spanish bilinguals are exposed to L3 English, the parser may rely on shared phonological and phonotactic features between Catalan and English (e.g., frequency of consonant-final words, vowel reduction, or rhythmic patterns) to select Catalan as the source language for initial transfer (see Puig-Mayenco & Marsden 2018: 508).

Contrary to the view that the new L3 cognitive state is a complete or substantial copy of a previously acquired language, property-by-property CLI models propose that the L3 system is built piece by piece and that both languages are available for CLI. The Cumulative Enhancement Model (Flynn et al. 2004) puts forth that language learning is cumulative and that properties of both languages can influence an L3. Previous languages enhance subsequent language learning, which results in facilitative transfer from the L1 or L2 into the L3. Therefore, L3 learners draw upon the entire range of available sounds to acquire a third language, with facilitative transfer occurring on a property-by-property basis. Under this model, non-facilitative transfer is not predicted to occur. Nevertheless, the existence of non-facilitative transfer in L3 acquisition research (Cabrelli & Pichan 2021; Puig-Mayenco et al. 2022) and the fact that facilitative transfer can be confounded with acquisition in intermediate-advanced L3 learners (Cabrelli & Pichan 2021) have put into doubt the predictions of the Cumulative Enhancement Model. Consistent with evidence showing non-facilitative transfer, the Linguistic Proximity Model (Westergaard

2021) emphasizes structural similarity and proposes that acquisition occurs incrementally on a feature-by-feature, basis, allowing both facilitative and non-facilitative transfer. This leads to initially weak representations that gradually strengthen. More recently, Archibald (2023c) resorts to an underspecified minimal Universal Grammar, containing primary linguistic data and domain-general strategies to posit that the parser updates the L3 in an error-driven fashion, structure-by-structure.

Individual factors, such as exposure and use of each language, are also key to understanding CLI in trilingual speakers. For instance, the Scalpel Model (Slabakova 2017) proposes that the L1 and L2 do not have an *a priori* privileged status but rather compete to influence L3 acquisition based on their relative predominance of communicative use (i.e., activation levels) (Slabakova 2017: 656). To strengthen the explanatory power of L3 acquisition models, the Scalpel Model highlights not only the role of cognitive factors, such as structural linguistic complexity, but also the importance of experiential variables, including language activation and use. A similar approach is taken in the Language Communication Model (Fallah et al. 2016; Fallah & Jabbari 2018), in which the source of CLI is determined by the dominant language, regardless of whether it is the L1 or the L2. This model is supported by the findings of early Mazandarani-Persian bilinguals, which demonstrate that syntactic CLI in initial stages of L3 English originates from the dominant language of communication (Fallah & Jabbari 2018). Drawing on the Activation Threshold Hypothesis (Paradis 1993), Ghobadirad & Jabbari (2021) suggests that these findings may be explained by the fact that languages or linguistic features used more frequently have lower activation thresholds, making them more readily accessible for transfer. The more recent Abbreviated Grappling Period Model (Sprouse & Schwartz 2023) integrates principles from both the Typological Primacy Model (Rothman 2011; 2015) and the Language Communication Model (Fallah et al. 2016; Fallah & Jabbari 2018). It proposes that the parser undergoes a brief period of evaluation during which it determines which previously acquired languages will be relied upon when acquiring a new one. During this decision process, two possible routes emerge: one relies on the learner’s initial perception of lexical or phonotactic similarity between the new language and their previously acquired languages, while the other, when such similarity is not perceived, assumes that the grammar of the dominant language serves as the default source of transfer. As such, language dominance becomes a key construct for examining trilinguals’ CLI.

1.2 Regressive CLI in the L3 sound system

Despite early perceptual attunement to the L1, evidence of regressive CLI, where later-acquired languages influence previously learned ones, suggests that earlier language systems may remain vulnerable throughout the lifespan of multilingual speakers (e.g., Kartushina & Martin 2019; Brown-Bousfield & Chang 2023; Stoehr et al. 2024: among others).

This type of CLI raises important questions about the stability of early-acquired sound systems and offers a unique window into how maturational constraints interact with language stability (Cabrelli 2023: 326). To account for such instances of CLI, the Phonological Permeability Hypothesis (Cabrelli Amaro & Rothman 2010), together with the Differential Stability Hypothesis (Cabrelli Amaro 2017), which extends the former to other modules in the grammar, posits that grammatical systems acquired later are more susceptible to L3 influence than those acquired earlier. Cabrelli Amaro (2017) investigated the perception and production of L3 Brazilian Portuguese word-final vowel reduction in two bilingual groups: L1 English-L2 Spanish and L1 Spanish-L2 English speakers. The study found perceptual stability in both groups; however, L2 Spanish speakers produced a Brazilian Portuguese-like vowel height in their Spanish back vowels. These findings support a weaker version of the Phonological Permeability Hypothesis, one in which regressive influence impacts production (i.e., processing level), while perceptual representations (i.e., underlying knowledge) remain intact.

The tenets of the Differential Stability Hypothesis have also been examined in early near-simultaneous bilinguals. Stoehr et al. (2024) investigated phonetic and lexical regressive CLI in early Spanish-Basque bilinguals with English as an L3. The study focused on VOT as the phonetic variable of interest. In both Spanish and Basque, voiceless stops are produced with short-lag VOT values (i.e., VOT values ranging from 0 to 30 milliseconds). In contrast, in English, voiceless stops are produced with long-lag values (i.e., VOT values around 70 milliseconds). The results showed a greater phonetic influence of L3 English (i.e., longer VOT) on L2 Basque production than on L1 Spanish production. In line with the Differential Stability Hypothesis, this pattern suggests that the L3 exerts a stronger influence on the L2 than on the L1, even among early bilinguals. It should be noted that investigating regressive CLI in early bilinguals presents particular challenges, as relative proficiency across languages is often dynamic in contexts of societal bilingualism, and age of acquisition may not reliably reflect current patterns of language use. As with progressive CLI, the incorporation of language dominance measures may offer insights into variability in regressive CLI.

1.3 The role of dominance in CLI

Language dominance has been operationalized as the asymmetry in the bilinguals' relative skills of one language over the other (Birdsong et al. 2012; Birdsong 2014; Birdsong & Amengual 2024). In the phonetic-phonological domain, language dominance has been found to be a predictor of speech production (Bedore et al. 2012; Simonet 2014; Amengual & Chamorro 2016; Amengual 2018; Hamann et al. 2019; Kim et al. 2020; Henriksen et al. 2021), and speech perception (Amengual 2016; Black et al. 2020; Chan et al. 2020; Carrasco-Ortiz et al. 2021). Language dominance can be measured directly or indirectly (Peña et al. 2021). Direct tests of dominance typically evaluate vocabulary, grammar, or narrative abilities and are administered in both languages to extract measures of relative dominance. For example, the Multilingual Naming Task (Stasenko et al. 2019) is a picture-naming task that assesses dominance in vocabulary knowledge by calculating a relative score between the bilinguals' two languages. Indirect measures test dominance using self-reported questionnaires and offer the advantage of faster administration (Peña et al. 2021). Various questionnaires have been used to assess indirect language dominance, including the LEAP-Q (Marian et al. 2007) and the Bilingual Language Profile (BLP, henceforth) (Birdsong et al. 2012). The BLP is a self-reported tool that calculates a language dominance index based on language history, language use, language identity, and language attitudes. The BLP uses a subtraction method to provide a continuous measure of dominance (–218 to +218), with 0 being the value for balanced bilinguals. Using a sample population of Spanish-English bilinguals, Olson (2023) showed that the BLP presents excellent levels of test-retest reliability.

The use of language dominance as a predictor of CLI in L3 acquisition research is more recent than in L2 acquisition, with more studies conducted in the morphosyntactic domain (Fallah & Jabbari 2018; Puig-Mayenco et al. 2018; 2022; Angelovska et al. 2023) than in the phonetic-phonological domain (Lloyd-Smith et al. 2017; Cabrelli & Pichan 2021; Cabrelli et al. 2023). Studies in L3 acquisition have examined the dominance effects of the previously acquired two languages. Cabrelli & Pichan (2021) examined dominance effects in the production of intervocalic voiced stops (i.e., /b d g/) by Spanish-English bilinguals at the initial stages of L3 Brazilian Portuguese or Italian. Intervocalic voiced stops are [–cont] segments in Brazilian Portuguese, Italian, and English, and [+cont] in Spanish. In L3 Brazilian Portuguese, Spanish-English bilinguals transferred from Spanish (i.e., the globally more similar language), but in L3 Italian they showed transfer from English (i.e., the globally less similar language). However, neither dominance, proficiency in the non-dominant language, nor bilingual experience had significant effects on the patterns of L3 Brazilian Portuguese or L3 Italian stop production. To further explore the influence of individual factors, Cabrelli et al. (2023) examined the roles of explicit knowledge and dominance, as assessed by the BLP, on the production of intervocalic voiced stops (i.e., /b d g/) in Spanish-English heritage speakers learning L3 Italian. Their results show that, at the individual level, L3 Italian learners who are Spanish-English heritage speakers show [-cont] English-like intervocalic stops. In addition, their results could not be explained by relative Spanish to English dominance. However, their study included mostly English-dominant heritage speakers, a factor that may have driven the English-like results and masked possible dominance effects that could emerge in a group with greater variability in language dominance.

In contrast, different outcomes have been observed regarding regressive CLI. Kartushina & Martin (2019) examined vowel production in the Spanish, Basque, and English of Spanish-Basque balanced bilinguals, who learned English through immersion. With respect to regressive CLI, their results showed that the bilingual speakers presented temporary vowel shifts in their two L1s due to English influence. However, Spanish-dominant bilinguals, who used Spanish approximately 30% more than Basque, showed vowel drift exclusively in their Basque production.

Results are interpreted in line with a self-organizing dynamical system model (Tobin et al. 2017), suggesting that active language use prevents an L3 from influencing the more intensively used native language.

Research on dominance in L3 learners has largely focused on L1-L2 dominance, often without considering how it interacts with emerging dominance in the L3. Although L1-L2 dominance is particularly relevant in studies that assess learners in the early stages of L3 acquisition (Cabrelli & Pichan 2021; Puig-Mayenco et al. 2022; Cabrelli et al. 2023), overlooking L3 dominance beyond initial exposure may hide its influence on production patterns and the dynamic of shifting dominance among the three languages.

To investigate the effects of dominance in L3 speakers beyond initial exposure, Helms (2023) recently analyzed language dominance as a continuous variable in the three languages of trilingual speakers. The study focused on the production and perception of stress in L1 English-L2 Spanish-L3 English speakers and early Catalan-Spanish bilinguals learning L3 English. Using a Principal Components Analysis approach, Helms (2023) found that while trilinguals with sufficient exposure to all three languages could use stress cues in a target-like manner, their relative dominance influenced the subtle use of these cues. For example, all speakers used duration to mark lexical stress, but the strength of this cue varied depending on their relative dominance in each language. English-dominant speakers produced longer word-final syllables compared to the less dominant speakers in English. In contrast, Spanish-dominant and Catalan-dominant speakers exhibited an inverse pattern, showing a greater use of duration in the penultimate syllables. To investigate the effects of dominance on CLI in trilingual speakers, this study focuses on a relatively unexplored aspect of multilingual phonology: the production of vocalic sequences between words (i.e., /V#V/), which form a word-external hiatus.

1.4 Repairs of vowel-to-vowel sequences

The production of /V#V/ sequences in English contrasts with that of Catalan and Spanish. In these sequences, English shows vowel-initial glottalization associated with prominent positions (Shattuck-Hufnagel 1995; Dilley et al. 1996; Garellek 2014; Bird & Garellek 2019; Davidson 2020). Therefore, /V#V/ sequences with a stressed second vowel (e.g., *see **o**tters*) are often realized with glottalization at the onset of the word 2 vowel (Davidson & Erker 2014). The articulatory realization of this glottal marking can vary, ranging along a continuum from creaky phonation to full glottal stops (Garellek 2013; Malisz et al. 2013; Davidson 2020). This variation in the degree of constriction is likely influenced by factors such as speech rate, prosodic emphasis, and formality (Garellek 2013; Malisz et al. 2013; Davidson 2020). From a phonological standpoint, vowel-initial glottalization in /V#V/ contexts is analyzed as an epenthetic process used to repair a word-external hiatus, which constitutes an ill-formed syllabic structure (Bell & Hooper 1978). Inserting a glottal stop before the vowel of the second word (e.g., *see otters* [i.ˈʔɑ]) provides the first syllable with an onset, effectively breaking the hiatus. Davidson & Erker (2014) compared stressed (e.g., [i#ˈɑ]) and unstressed cases (e.g., *he abjected* [i#ə]), categorizing the responses into modal phonation, global creak, creak in the second vowel, and glottal stops. Their results showed fewer instances of modal phonation for stressed vowels than for unstressed vowels in the second word, indicating a preference for glottal marking in words with initial stress.

Vowel-initial glottalization in /V#V/ sequences does not appear to serve as a strategy for marking prominence or repairing ill-formed structures in varieties of Catalan and Spanish that have not been in contact with languages exhibiting glottal marking. Both languages prefer to avoid word-external hiatus through reduction processes such as diphthongization (e.g., don **[u] # [ə]** legries ‘I make someone happy’ to [wə]), deletion (e.g., trent **[ə] # [a]** nys ‘thirty years’ to [ˈa]), or coalescence (e.g., compr **[u] # [u]** lleres ‘I buy glasses’ to [u]) (Aguilar 1999; Jenkins 1999; Cabré & Prieto 2005; Souza 2010). The use of each process depends on factors such as frequency, semantic coherence, discourse context, stress, and speech rate (Cabré & Prieto 2005; Alba 2006; Souza 2010). Furthermore, prosodic prominence appears to influence vowel-to-vowel resolutions: hiatus is maintained in stressed-stressed sequences (e.g., xamp **[u] # [ɔ]** ptim ‘optimal shampoo’ to [ˈuˈɔ]) and in cases in which the second vowel bears nuclear stress (e.g., parl **[ə] # [a]** ra ‘he/she speaks now’ to [əˈa]) (Cabré & Prieto 2005). Thus, hiatus resolutions are sensitive to stress, similar to vowel-initial glottalization in English. It is important to note that in an electroglottographic study, Garellek (2014) found that both Spanish and English showed greater vocal folding in prominent vowel-initial words, indicating that word-initial vowels in both languages demonstrate laryngealization. Given that these findings contradict previous research showing that word-initial glottalization is more frequent in English than in Spanish, Garellek (2014) argues that, while laryngealization is present in both languages, glottal stops, which were not included in the coding, may still be more common in English. Therefore, the results are not in conflict with previous research indicating that *salient* glottalization is more likely to appear in English than in Spanish.

Vowel-initial glottalization is vulnerable to CLI in a wide range of bilingual contexts (Schwartz 2012; González & Weissglass 2017; Mohamed et al. 2019; Trawick & Michnowicz 2019; Repiso-Puigdelliura 2024). In sequential bilinguals, González & Weissglass (2017) examined the production of /V#V/ sequences in 25 L1 English-L2 Spanish learners before and after a 16-week semester, comparing them to 8 monolingual Spanish speakers. The L2 learners produced vowel-initial glottalization at a higher rate in both the pre-test (46%) and post-test (50%) than the control group (6%). These findings were interpreted as reflecting an initial L1 influence on the interlanguage of L2 speakers.

Vowel-initial glottalization has also been found to transfer in early bilinguals, particularly in heritage speakers whose majority language demonstrates glottal marking and whose heritage language does not. Repiso-Puigdelliura (2024) found that child heritage speakers produced a higher rate of vowel-initial glottalization in /C#V/ sequences (younger child heritage speakers: *M* = 30.86%, *SE* = 2.23%; older child heritage speakers: *M* = 20.12%, *SE* = 1.83%) compared to their monolingual counterparts (younger child monolinguals: *M* = 1.59%, *SE* = 0.56%; older child monolinguals: *M* = 1.68%, *SE* = 0.56%). In contrast, while bilingual adults also showed higher rates of glottalization (*M* = 10.23%, *SE* = 1.39%) than monolingual adults (*M* = 2.48%, *SE* = 0.68%), the difference was notably smaller than that observed in children. In contact with Arabic, Mohamed et al. (2019) explored a reverse scenario, where Spanish is the majority language and Arabic, a language that uses vowel-initial glottal marking, is a minority societal language. Their study found no significant differences in the use of glottalization in vowel sequences between Spanish monolinguals (N = 3) and Arabic-Spanish bilinguals (N = 5). However, language dominance emerged as a significant factor, with Arabic-dominant bilinguals producing more glottalization than Spanish-dominant bilinguals. Trawick & Michnowicz (2019) examined the use of Paraguayan vowel-initial glottal marking in the Spanish of Guaraní-Spanish bilinguals. The study revealed that glottal stops in Spanish were produced at an overall rate of 26%, with older speakers who had more contact with Guaraní being more likely to use glottal marking. Gynan & López Almada (2020) also investigated glottal stops in Spanish resulting from Guaraní CLI mediated by stress, focusing on prothesis (i.e., glottalization at phrase boundaries), as well as /C#V/, /V#V/ contexts, and word-internal positions. Stress was found to be a non-uniform factor in glottal stop insertion, showing significant effects in word-internal positions and /V#V/ contexts in Guaraní, and in prothesis and /C#V/ contexts in Spanish. In addition, the authors noted an asymmetrical influence of vowel identity, with [e] and [i] disfavoring word-internal and phrase-initial glottal stops in Guaraní, while [o] and [u] disfavoring phrase-initial and epenthetic glottal stops in Spanish.

While previous studies have examined CLI of vowel-initial glottalization among simultaneous bilinguals, research on its acquisition in L2 learners remains limited. Eger et al. (2019) examined the acquisition of /h/ and /ʔ/ by Italian L1 speakers learning German as an L2. While German shows glottal marking in vowel-initial syllables (e.g., *Affe* 'ape' /afə/ to [ʔafə]), Italian uses glottal stops primarily as phrase boundary markers or in hyperarticulated speech (Stevens et al. 2002; Bertinetto & Loporcaro 2005). The study tested both perception and production. In production, Italian speakers correctly produced /h/ and /ʔ/ 70% of the time, with glottal stop accuracy being 9.8% lower. This contrasts with the 6.4% occurrence of vowel-initial glottal stops in Italian. Regarding the perception of glottal stops in L2 speech, L1 Italian-L2 German speakers demonstrated reduced lexical access when /h/ and /ʔ/ were deleted, and they rated words with missing targets more negatively. These findings suggest that although /ʔ/ is non-phonemic in German, is absent from the orthography, and is likely excluded from explicit instruction, Italian speakers still significantly acquire it. The authors suggest that because glottal fricatives occur in paralinguistic sounds such as laughter and sighing, and glottalization functions as a boundary marker in hyperarticulated speech in Italian, L1 Italian speakers may repurpose existing motor routines to apply glottalization to a new function in German (Eger et al. 2019: 18). This is consistent with the redeployment hypothesis (Archibald 2005; 2023b; Wu 2024) by which existing features in previously acquired languages (i.e., L1 or L2) are used to acquire new phones in the L2 or L3.

In summary, findings from early bilinguals show CLI of vowel-initial glottalization from the majority to the minority language (e.g., English to Spanish in the United States) and from the minority to the majority language (e.g., Arabic to Spanish in Puerto Rico). Results from sequential bilinguals demonstrate that while vowel-initial glottalization has a non-contrastive phonemic status and is absent in the orthography, learners show acquisition of vowel-initial glottal marking. The relatively high availability of vowel-initial glottalization for transfer and acquisition may be linked to its acoustic salience, as it has been analyzed as a cue that contributes to prosodic prominence.

1.5 Goals of this study

In the present study, we examine CLI in the production of /V#V/ sequences among L3 English speakers who are early Catalan-Spanish bilinguals. In this study, we first ask whether progressive CLI occurs from the bilingual speakers' early acquired L1 Catalan and L1 Spanish to L3 English (RQ1) and whether this progressive CLI is mediated by dominance in the L3 (RQ2). We predict that Catalan-Spanish bilinguals acquiring English as an L3 will exhibit lower rates of vowel-initial glottal marking compared to baseline speakers, with these rates rising as English dominance in the L3 increases. We then ask whether we observe glottal marking in L3 English learners who are Catalan-Spanish bilinguals, as predicted by their rate of glottal marking in English (RQ3) and their L3 English dominance (RQ4). We hypothesize that higher rates of glottal marking in L3 English will be associated with higher rates of glottal marking in L1 Catalan and L1 Spanish. Similarly, greater dominance in L3 English is expected to correspond to increased glottal marking in L1 Catalan and L1 Spanish. Finally, we ask whether CLI is modulated by relative Catalan-Spanish dominance (RQ5). According to the Language Communication Model (Fallah et al. 2016; Fallah & Jabbari 2018) and the Abbreviated Grappling Period Model (Sprouse & Schwartz 2023), we predict that regressive CLI from L3 English will be greater in the language in which Catalan-Spanish bilinguals have lower dominance.

2 Methods

2.1 Participants

Twenty-three L3 English early Catalan-Spanish bilinguals (L3 Eng-Cat-Sp-bil 16F, 7M, M = 25.30 years, SD = 7.54 years) participated in the self-paced reading task. Of these, 12 currently reside in a Catalan-speaking territory, while the remaining 11 live in either English-speaking countries, Belgium, the Netherlands, or Spain. Two participants reported having more than 20 years of English instruction. When considering these participants as having received 21 years of instruction, the mean number of years of English instruction for this group is 10.78 years (*SD* = 5.75). In addition, they reported having spent an average of 3.04 years (*SD* = 5.33 years) in an English-speaking region. Participants were recruited online through Catalan social media accounts.

Given that glottal marking in English is not a categorical phenomenon, we included a baseline group to establish the reference rates for glottal marking in English in the absence of influence from Spanish or Catalan. This baseline group accounts for the effects of exposure to additional languages that do not use glottalization in vowel-to-vowel sequences. The English control group consisted of 12 monolingual English speakers (L1 EngMono; 8F, 4M, *M* = 37.30 years, *SD* = 15.63 years) who resided in the United States at the time of testing.

A second baseline group of L3 Catalan Spanish-English bilinguals was included to compare speakers who share the same three languages but differ in acquisition order and language dominance. A comparison of these two groups of trilinguals in their English productions allows us to investigate whether exposure to languages without glottal marking as a prosodic cue can shift speakers' preferences across their linguistic systems, potentially favoring modal phonation over glottalization. Specifically, if L3 Catalan Spanish-English bilinguals do not show vowel-initial glottal marking in prominent prosodic positions, it would suggest that glottal marking is costly to produce when speakers are exposed to languages with modal phonation in these contexts. To do so, we recruited 19 L3 Catalan-Spanish-English bilinguals (L3 Cat-Sp-En-bil; 11F, 7M, 1 non-binary, *M* = 28.55 years, *SD* = 6.26 years), who were exposed to English since birth and Spanish after the age of 6 (*M* = 12.21 years, *SD* = 3.39 years), with 16 participants exposed to Spanish from the age of 10 or thereafter. Participants reported having spent a mean of 1.16 years (*SD* = 1.64 years) in a Spanish-speaking family. One participant, exposed to Spanish from the age of 8, reported having lived in a family where Spanish was spoken for 7 years. At the time of testing, 9 participants resided in a Catalan-speaking territory (Catalonia, Valencia, Balearic Islands, Andorra), and 10 participants lived in non-Catalan-speaking territories (e.g., the United States, Canada). The average number of years spent in a Catalan-speaking region is 9.11 years (*SD* = 6.05 years). One participant reported having more than 20 years of Spanish instruction, while no participants reported more than 20 years of Catalan instruction. The mean number of years of Spanish instruction for this group is 9.11 years (*SD* = 6.05 years), while the mean number of years of Catalan instruction is considerably lower at 1.53 years (*SD* = 1.65 years). All participants were compensated for their participation.

While the English experiment included a monolingual control group, the Catalan and Spanish experiments did not. This is due to the difficulty of recruiting bilinguals who speak only Catalan or Spanish without exposure to English, as English is a compulsory foreign language in the Catalan school system (Department of Education and Professional Training of the Generalitat de Catalunya 2025). Therefore, rather than using Catalan-Spanish bilinguals with no prior English knowledge as a baseline for vowel-initial glottalization, we treat influence of L3 English language dominance on glottal marking as an indicator of CLI in Catalan and Spanish.

2.2 Linguistic background

The Bilingual Language Profile (Birdsong et al. 2012) was used to assess language dominance. A complete set of questions for a third language was added to capture language history, language use, language proficiency, and language attitudes in three languages. The adapted absolute values of the BLP, which sum scores for language history, use, proficiency, and attitudes, were calculated for Catalan, Spanish, and English in two groups of speakers. For the L3CAT-SP-EN-BIL group, the mean and standard deviation were: Catalan, M = 93.09 (SD = 15.74); Spanish, M = 110.84 (SD = 22.93); and English, M = 172.32 (SD = 12.72). For the L3ENG-CAT-SP-BIL group, the scores were: Catalan, M = 137.53 (SD = 13.87); Spanish, M = 155.46 (SD = 14.72); and English, M = 119.76 (SD = 23.00). **Figure 1** presents the means and standard deviations for each module in the three languages. The most significant differences between the two groups were observed in Catalan language history (ΔM = 33.22) and Catalan proficiency (ΔM = 16.80), both showing higher values for the L3CAT-SP-EN-BIL group, as well as in English language history (ΔM = 23.92) and English language use (ΔM = 20.44), which had higher values for the L3ENG-CAT-SP-BIL group.

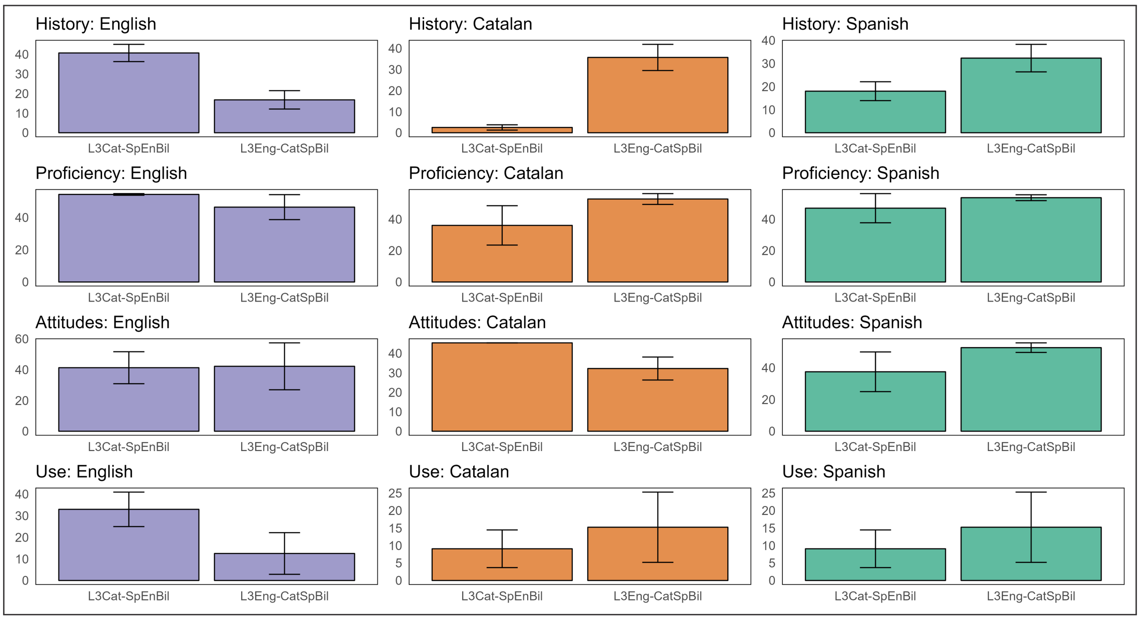


Figure 1: Means and standard deviations for each module component of the BLP adapted for three languages.

A Principal Components Analysis (i.e., PCA) was performed on the BLP questions in the three languages. A PCA is a statistical technique used to reduce the dimensionality of the questionnaire by transforming a set of potentially correlated variables into a smaller number of uncorrelated components. Although significant correlations were observed among language scores, a PCA allows key dimensions of linguistic dominance to remain uncorrelated in the analysis. Specifically, the Spanish and Catalan scores presented a weak negative correlation ($r(5918) = -.08$, $p < .001$, 95% CI [–.10, –.05]). Spanish and English scores showed a moderate positive correlation ($r(5918) = .31$, $p < .001$, 95% CI [.29, .34]). Catalan and English scores exhibited a small but statistically significant negative correlation ($r(5918) = -.12$, $p < .001$, 95% CI [–.15, –.10]).

We used a Python script (Helms 2023) to conduct the PCA for the adapted BLP. In the script, all the responses to the individual BLP questions are converted to numeric values by coding the lowest end of the scale as 0 and the highest end as 21. For example, the question ‘at what age did you start to feel comfortable using ENGLISH?’ offers 21 possible responses, ranging from ‘as early as I can remember’ (coded as 0), through each year given a corresponding numeric value, to ‘not yet’ (coded as 21). The PCA was performed in scikit-learn (Pedregosa et al. 2021), specifying 90% of the variance to be captured by the components. Each component and the variance explained were plotted on a scree plot. The scree plot (see **Figure 2**) displays the eigenvalues of each principal component (i.e., PC), indicating the amount of variance each component explains in the data. The steepest decrease in the explained variance (i.e., ‘elbow method’) identifies the optimal number of components. The scree plot shows an elbow in the fourth component. The four components explain a total of 57.9% of the variance (PC1: 22.80%, PC2: 14.79%, PC3: 11.81%, PC4: 8.56%). PC1 has the largest eigenvalue because it captures the greatest amount of variance in the dataset.

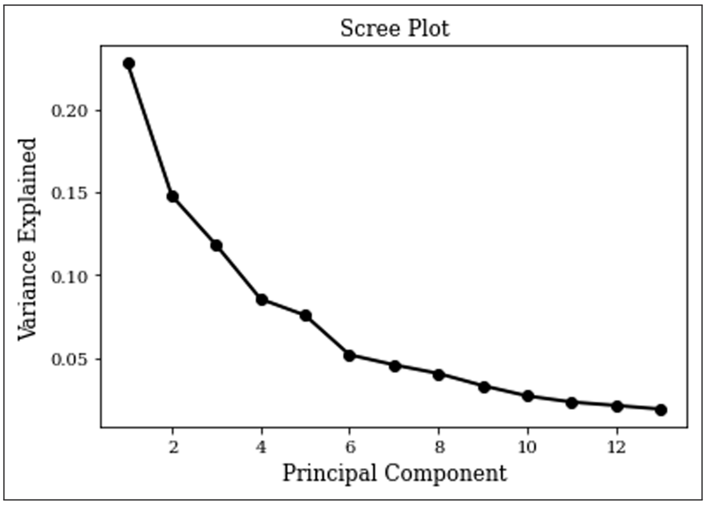


Figure 2: Scree plot showing a multidimensional solution with explained variance set as 0.9.

Subsequent components, such as PC2, explain progressively less variance as they capture the remaining dimensions of variation that were not explained by earlier components. While a second elbow is found at six components, the remaining PCs explained 7.58% and 5.20% of the variance, respectively, and were considered non-significant (see additional analyses with six components in the appendix of the supplementary materials). To interpret the PCs, we examined the coefficients (i.e., loadings) for each variable, which reflect the relative contribution of each variable to the component. Positive values indicate a positive correlation with the component, while negative values indicate a negative correlation. We applied a cut-off threshold of 0.4 (i.e., conventionally a threshold for moderate correlations Schober & Schwarte 2018; Akoglu 2018) to identify variables with meaningful contributions.

Regarding the interpretation of the PCs, PC1 exhibits a positive correlation with English in variables pertaining to frequency of use (e.g., frequency of use with friends, frequency of use at school, frequency in counting), proficiency (e.g., writing level, speaking level, reading level), identity (e.g., feelings of self-identity, cultural identification), and attitudes (e.g., desire to sound native). Conversely, it shows a negative correlation with variables related to language history (e.g., age of onset of acquisition, age of comfort), with higher values indicating lower relative dominance in these domains. In addition, PC1 correlates positively with Catalan in relation to age of acquisition and age of comfort, but negatively with frequency of self-talk and counting, use at school, and use with family and friends. Furthermore, PC1 exhibits a negative correlation with variables related to Catalan and Spanish language history, such as years spent in the region and years in the workplace. This component could be interpreted as relative English-to-Catalan/Spanish dominance.

PC2 exhibits a positive correlation with Spanish in variables related to language history (e.g., years in the region, years in the family), proficiency (e.g., speaking level, writing level), use (e.g., use with friends, use with family), and identity and attitudes (e.g., wanting to sound native, feeling like oneself, identifying with the culture). While PC2 also shows a positive correlation with Catalan in the context of language history (e.g., years in the region), it correlates negatively with Catalan in areas such as frequency of self-talk, frequency of counting, and use with family. This suggests that PC2 may reflect a scenario in which Catalan is less dominant in identity and family-related language use. Furthermore, PC2 demonstrates negative correlations with variables related to English proficiency (e.g., writing level), identity (e.g., wanting to sound native), and language history (e.g., years in the family, years in the region). Overall, PC2 could be interpreted as indicating Spanish dominance, particularly in the domains of use and identity, alongside reduced Catalan dominance in these same areas, and a slight negative association with English use and proficiency.

PC3 shows positive correlations with other languages learned with respect to the frequency of use at school, frequency of use with friends, and frequency of self-talk, while it shows negative correlations with Spanish and Catalan in the variables of self-talk (Spanish), speaking level (Catalan and Spanish), writing level (Catalan), and attitudes (wanting to sound like a native and be perceived as a native). Therefore, PC3 is associated with the use of languages other than Catalan, Spanish, and English. The participants with the higher scores for PC3 were P10 (7.432), who resided in France at the time of testing, and P05 (5.10), who reported 0 use of other languages but low scores in attitudes for Spanish.

PC4 has fewer moderate correlations with the variables in the questionnaire. PC4 correlates negatively with Catalan in the variables of frequency in counting, listening level, reading level, and years spent in a Catalan-speaking region, and positively with respect to years spent in a Catalan-speaking workplace environment. It correlates positively with Spanish with respect to years spent in a Spanish-speaking workplace and frequency of counting. PC4 also correlates negatively with the level of listening and writing in English, and positively with the age of acquisition of English. PC4 likely captures a profile of speakers with weaker proficiency in Catalan and English than in Spanish.

We thus interpret PC1 (22.80%) as representing general English-to-Catalan/Spanish dominance; PC2 (14.79%) as reflecting relative Spanish-to-Catalan dominance based on language use and identity; PC3 (11.81%) as associated with the use of other languages and negative identity or attitudes toward Catalan and Spanish; PC4 (8.56%) reflects a pattern of Spanish-to-Catalan and English dominance primarily driven by proficiency and frequency of self-talk.

Individual scores for each participant were extracted from each PC, representing their position along the underlying dimensions identified by the PCA. For instance, higher scores on PC1 reflect greater dominance in L3 English relative to L1 Catalan and L1 Spanish, while lower scores indicate reduced English dominance. These component scores were then used as continuous predictors in the statistical models, yielding four PC-based measures of language dominance.

2.3 Experimental task

Three reading tasks were designed in Catalan, Spanish, and English, each consisting of 2 × 4 × 4 conditions: two vowels, four stress patterns, and four repetitions. The three production tasks were designed to keep vowel qualities and stress patterns as consistent as possible across languages. In all three experiments, we selected sequences of high vowels (e.g., Catalan and Spanish: /i#u/, /u#i/; English: /i#u/, /ɪ#u/, /u#i/, /u#ɪ/) to minimize the likelihood of vowel-initial glottalization. This choice was based on evidence that non-high vowels are more prone to be produced with creaky voice than high vowels (Brunner & Żygis 2011; Michnowicz & Kagan 2016). Four stress patterns were defined: (1) primary stress on the final syllable of word 1 (stressed-unstressed), (2) primary stress on the initial syllable of word 2 (unstressed-stressed), (3) primary stress on both the final syllable of word 1 and the initial syllable of word 2 (stressed-stressed), and (4) no primary stress on either syllable (unstressed-unstressed) (see **Table 1** for

Experiment in Catalan		
	/iu/	**/ui/**
Unstress. – Unstress.	*gen*[i u]*rba* 'urban genie'	*resid*[u i]*ncert* 'uncertain residue'
Unstress. – Stress.	*cran*[i ˈu]*ltim* 'last cranium'	*resid*[u ˈi]*ntegre* 'whole residue'
Stress. – Unstress.	*ca*m[ˈi u]*rbà* 'urban path'	*Pe*r[ˈu i]*ncert* 'immense Peru'
Stress. – Stress.	*ca*m[ˈi ˈu]*ltim* 'last path'	*de*j[ˈu ˈi]*ntegre* 'complete fast'
Experiment in English		
Unstress. – Unstress.	*bus*[i u]*mami*	*ubunt*[u ɪ]*nspiration*
Unstress. – Stress.	*bus*[i ˈu]*zing*	*ubunt*[u ˈɪ]*mage*
Stress. – Unstress.	*s*[ˈi ˈu]*mami*	*tab*[ˈu ɪ]*nspiration*
Stress. – Stress.	*s*[ˈi ˈu]*zes*	*tab*[ˈu ˈɪ]*llness*
Experiment in Spanish		
Unstress. – Unstress.	*der*[i u]*rbano* 'urban derby'	*espírit*[u i]*nédito* 'original spirit'
Unstress. – Stress.	*bic*[i ˈu]*til* 'useful bike'	*espírit*[u ˈi]*ntimo* 'intimate spirit'
Stress. – Unstress.	*mani*qu[ˈi u]*rbano* 'urban mannequin'	*ver*m[ˈu i]*nédito* 'original vermouth'
Stress. – Stress.	*mani*qu[ˈi ˈu]*til* 'useful mannequin'	*ver*m[ˈu ˈi]*ntimo* 'intimate vermouth'

Table 1: Experimental items in Catalan, Spanish, and English by stress pattern and vowel combination. Stress is marked in the corresponding vowel of the target sequence.

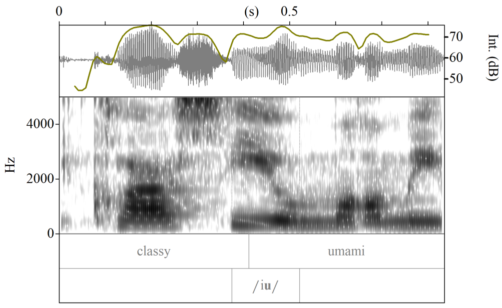
examples). Stimuli log frequencies, extracted using the web-based search engine NIM (Guasch et al. 2013), were approximately matched across languages (*M* log frequency Catalan: 1.65; *M* log frequency Spanish: 1.50; *M* log frequency English: 1.60). To ensure comparable vowel quality across languages, some English syllables with initial secondary stress were included (e.g., ˌuˈmamɪ). In addition, some cognate words were unavoidable. While vowel-initial glottalization occurs above the word level, it is sensitive to prosodic prominence. As such, cognates with asymmetric stress patterns across the three languages could introduce confounds. In particular, the Catalan items *urbà* 'urban' and *uniforme* 'uniform', and the Spanish items *usado* 'used' and *urbano* 'urban', may induce greater glottalization due to their initial stress in English. As such, any potential increase in glottalization due to these words being cognates would occur in contexts where glottalization is generally disfavored, and thus would not increase the contrast between V2-stressed and V2-unstressed conditions. Therefore, the presence of these cognates does not bias against the null hypothesis for stress, which posits no difference in glottalization rates between V2-stressed and V2-unstressed conditions.

The target sequences were embedded in carrier sentences, starting with an initial noun phrase (e.g., Eng: *the fathers*, *the daughters*, *the mothers*; Cat: *els pares* 'the fathers', *els avis* 'the grandparents', *les mares* 'the mothers'; Sp: *los hijos* 'the sons', *los padres* 'the fathers'), followed by the verb 'to say', the target sequence, and an adjunct phrase (e.g., Eng: *for you*, *for us*; Cat: *sense por* 'without fear', *d'un sol cop* 'all at once'; Sp: *muy bajito* 'very softly', *sin miedo* 'without fear'). Variations in the carrier phrases were introduced to better mask the target sequences.

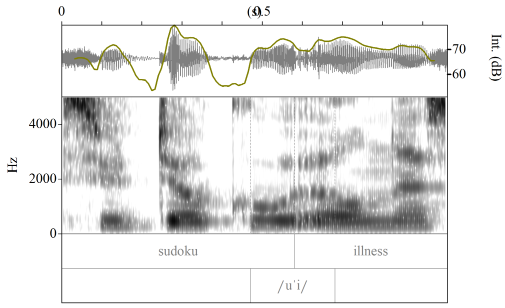
The experimental task was created using PsychoPy2 (Peirce et al. 2019) and hosted on Pavlovia Surveys (Open Science Tools 2025). Participants completed the three tasks over Zoom (Zoom Video Communications Inc. 2019) in three separate, non-counterbalanced sessions. All participants followed the same fixed order: Catalan, English, then Spanish, with a minimum interval of 48 hours between sessions to mitigate potential presentation order effects. To ensure a monolingual mode, we used language-specific instructions and experimental stimuli. The experimental sessions were conducted by an L1 English speaker (English session), a Catalan-dominant bilingual (Catalan session), and a Spanish-English bilingual (Spanish session). Participants recorded themselves using their smartphone and the phone application ShurePlus MOTIV®, which records in WAV format at a sampling rate of 48Khz and 16 bits by default. Participants were instructed to hold their phone approximately four inches from their mouth. The microphone gain was adjusted accordingly to avoid clipping in the audio. In addition to the present production task, participants completed a production and a perception task, the results of which are discussed in Helms (2023). The BLP was completed at the end of the three sessions. In the present study, only the results of the English session for the L3 Catalan Spanish-English bilingual group are analyzed. However, a complete analysis of the Catalan and Spanish tasks is found in the supplementary materials.

2.4 Data annotation

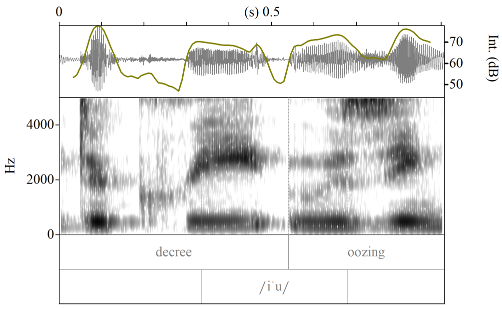
The resulting vocalic sequences were classified by a bilingual Spanish-English research assistant and the author of this paper, a bilingual Catalan-Spanish speaker. We created two categories for the analysis: tokens with modal phonation and tokens with glottalization within the sequence. Given that glottalization occurs along a continuum, from a full glottal stop to creaky voice within the vocalic interval, we further categorized the tokens into those exhibiting complete glottal stops and those showing creakiness (see **Figure 3**). Complete glottal stops were identified as a period of silence in the spectrogram shorter than 150 ms, based on Scarpace (2017), with possible evidence of creakiness in either vowel. Given that complete glottal stops are rare across languages (Ladefoged & Maddieson 1996), creakiness is often considered as an incomplete realization of the glottal stop (Davidson 2020). Therefore, all the realizations ranging from creakiness in the speech signal to pauses shorter than 150 ms were considered glottal marking realizations. Creakiness in the vocalic sequences was identified when the spectrogram showed discontinuities in the duration of the pulses (i.e., aperiodicity), wide pulses, or an alternation in the amplitude or frequency of the glottal pulses (Dilley et al. 1996; Davidson & Erker 2014; Keating et al. 2015; Huang 2023). Following Davidson (2021), in addition, a dip of intensity within the vocalic sequence was also considered a correlate of laryngealization.



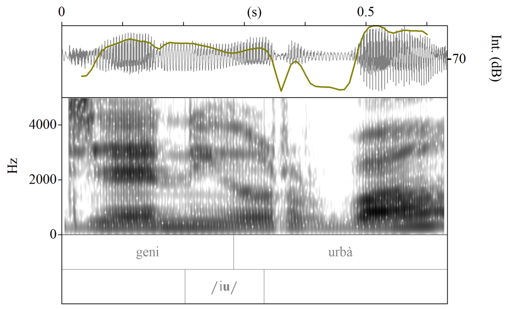
(a) Sequence *classy umami* ‘classy umami’ labeled as *modal phonation*



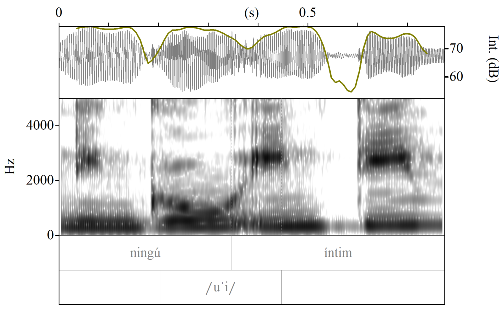
(b) Sequence *sudoku illness* labeled as *creaky phonation*



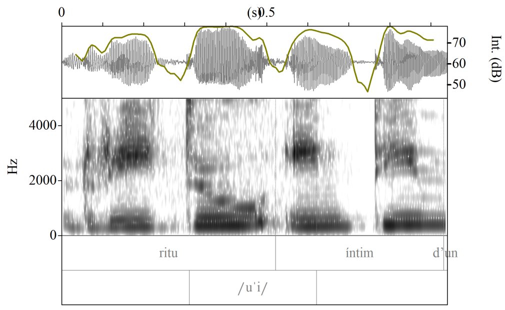
(c) English target sequence *decree oozing* labeled as *glottal stop*



(d) Catalan target sequence *geni urbà* ‘urban genie’ labeled as *modal phonation*



(e) Catalan target sequence *ningú íntim* ‘nobody intimate’ labeled as *creaky phonation*



(f) Catalan target sequence *ritu íntim* ‘intimate ritual’ labeled as *glottal stop*

Figure 3: Examples of sequences categorized by phonation type.

3 Results

From the complete data set, tokens containing periods of silence longer than 150 ms, disfluencies in the critical region, or productions that involved creakiness throughout word 1 and word 2 were removed. The final 5,920 tokens for the experimental group in the three languages (L1 Catalan = 2,002, L1 Spanish = 2,139, L3 English = 1779) and 2689 tokens for the baseline groups in English (L1 English monolinguals = 989, L3 Catalan Spanish-English bilinguals = 1,700) were submitted to analysis. Generalized Linear Mixed-Effects Models (i.e., GLMMs) were performed in R (R Development Core Team 2025) using the packages *lme4* (Bates et al. 2007) and *lmerTest* (Kuznetsova et al. 2017) to extract p-values. Extracting estimated marginal means and models' probabilities as well as exploring interactions was performed using the package *emmeans* (Lenth et al. 2020).

To answer RQ1, we fitted **Model A: English**, which included the fixed effects of GROUP (i.e., L3Eng-CatSpBil, L3Cat-SpEnBil, and L1 English monolinguals), STRESS (i.e., unstressed–unstressed, unstressed–stressed, stressed–unstressed, stressed–stressed), and their interaction[1]. The model was evaluated using the Akaike Information Criterion (AIC = 3507.00), corrected AIC (AICc = 3507.10), and the Bayesian Information Criterion (BIC = 3596.67). For RQ2, we fitted **Model B: English** using principal components (PC1–PC4) as predictors[2]. The model was assessed using Akaike Information Criterion (AIC = 960.73), corrected AIC (AICc = 1611.53), and Bayesian Information Criterion (BIC = 1666.24).

To answer RQ3, RQ4, and RQ5, we fitted **Model A': Catalan** and **Model A': Spanish** with data from the L3ENG-CAT-SP-BIL group, each including principal components (PC1–PC4), average English glottalization per participant (i.e., AVGENGLISHGLOTTAL), STRESS, and their interaction. AVGENGLISHGLOTTAL was standardized (i.e., mean-centered) to address convergence difficulties and significantly large odds ratios observed in preliminary analyses[3]. **Model A': Catalan** was assessed using Akaike Information Criterion (AIC = 1210.62), corrected AIC (AICc = 1210.83), and Bayesian Information Criterion (BIC = 1289.04). **Model A': Spanish** was evaluated using Akaike Information Criterion (AIC = 924.42), corrected AIC (AICc = 924.62), and Bayesian Information Criterion (BIC = 1003.78).

3.1 Progressive CLI in L3 English

To assess whether L3 English Catalan-Spanish bilinguals show progressive CLI (i.e., RQ1), we compared L3 English Catalan–Spanish bilinguals with their L3 Catalan Spanish-English bilingual

[1] **Model A (English)**: glmer(GlottalizationPresence GROUP * STRESS + (1|Participant) + (1|TargetItem), family = binomial, data = EnglishData, control = glmerControl(optimizer = "bobyqa")).

[2] **Model B: English**:glmer(GlottalizationPresence PC1 + PC2 + PC3 + PC4 + STRESS + (1|Participant) + (1|TargetItem), family = binomial, data = EnglishData).

[3] **Model A' (Catalan and Spanish)**: glmer(GlottalizationPresence AVGENGLISHGLOTTAL * STRESS + PC1 + PC2 + PC3 + PC4 + (1|Participant) + (1|TargetItem), family = binomial, data = CatalanData/SpanishData, control = glmerControl(optimizer = "bobyqa")).

and English monolingual counterparts in **Model A: English**. The marginal R^2, representing the variance explained by fixed effects, was 0.31, while the conditional R^2, which accounts for both fixed and random effects, was 0.71. The odds ratio of the model's intercept was 4.70 (95% *CI* [2.46, 8.99], $p < 0.001$), corresponding to a probability of 82.45%. As shown in **Figure 4**, V2-stressed sequences were more likely to be produced with initial glottal marking. Specifically, the odds of producing vowel-initial glottalization in the UNSTRESSED-STRESSED condition were 6.65 times the odds in the UNSTRESSED-UNSTRESSED condition (95% *CI* [3.06, 14.44], $z = 4.78$, $p < 0.001$). When both syllables were stressed (STRESSED-STRESSED), the odds were 2.48 times higher than in the UNSTRESSED-UNSTRESSED condition (95% *CI* [1.30, 4.71], $z = 2.76$, $p = 0.006$). By contrast, the STRESSED-UNSTRESSED condition did not differ significantly from the UNSTRESSED-UNSTRESSED baseline (*OR* = 0.96, 95% *CI* [0.57, 1.60], $z = –0.17$, $p = 0.863$).

Model A: English also showed simple effects for the GROUP variable. Compared to the L3ENG-CAT-SP-BIL group, the L3CAT-SP-EN-BIL group had 6.94 times higher odds of producing vowel-initial glottalization (95% *CI* [2.01, 23.99], $z = 3.06$, $p = 0.002$), and the L1ENG-MONO group showed 85.58 times higher odds (95% *CI* [19.05, 384.46], $z = 5.80$, $p < 0.001$).

Moreover, the effect of GROUP was moderated by STRESS, as indicated by significant interactions. Compared to the L3ENG-CAT-SP-BIL group, the L1ENG-MONO group had substantially higher odds of producing glottal marking across all STRESS levels: UNSTRESSED-UNSTRESSED (*OR* = 0.0105, $p < 0.001$), STRESSED-UNSTRESSED (*OR* = 0.009, $p < 0.001$), UNSTRESSED-STRESSED (*OR* = 0.007, $p < 0.001$) and STRESSED-STRESSED (*OR* = 0.02, $p < 0.001$). When

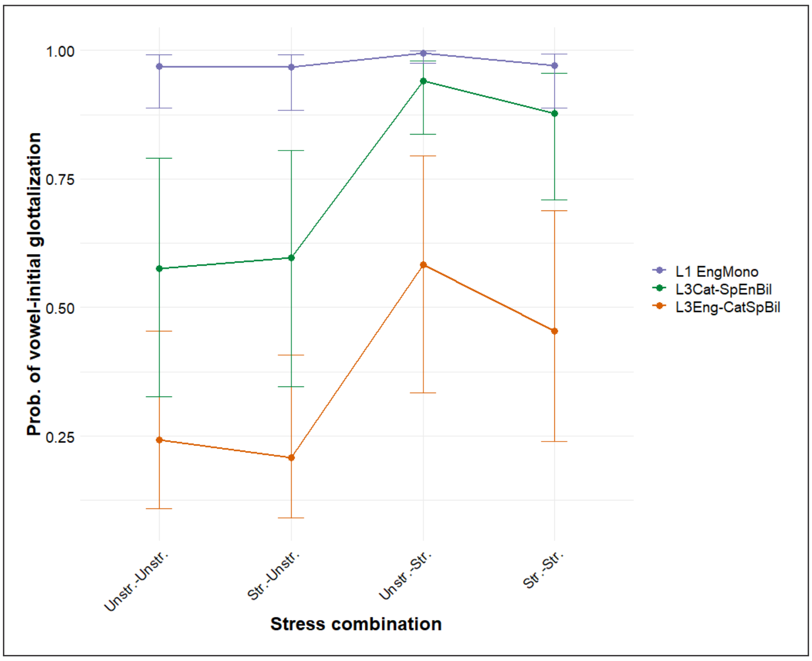


Figure 4: Probability of vowel-initial glottalization in English across stress combinations in L1 English monolinguals, L3Cat-SpEnBil, and L3Eng-CatSpBil.

contrasting the L3Cat-Sp-En-bil group with the L3Eng-Cat-Sp-bil group, pairwise comparisons showed that the latter had a significantly higher likelihood of producing glottal marking in the unstressed-stressed condition ($p = 0.0135$). Finally, the L1Eng-mono group only differed significantly from the L3Cat-Sp-En-bil group in the unstressed-unstressed ($OR = 0.04$, $p = 0.01$) and stressed-unstressed ($OR = 0.05$, $p = 0.006$) conditions.

To examine whether dominance influenced the use of glottal marking in L3 English (i.e., RQ2), we fitted **Model B: English**. The marginal R^2 was 0.11, while the conditional R^2 was 0.67. With unstressed-unstressed as the reference level and the PC components set to 0, the intercept odds ratio was 0.56 (95% *CI* [2.46, 8.99], $p < 0.001$), corresponding to a probability of 36.01%.

Model B showed a simple effect of stress in the V2-stressed levels: the odds of glottalization were 5.13 times higher in the unstressed-stressed level (95% *CI* [2.18, 12.07], $z = 3.75$, $p < 0.001$) and 3.01 times higher in the stressed-stressed level (95% *CI* [1.57, 5.79], $z = 3.30$, $p < 0.001$) compared to the unstressed-unstressed baseline. The stressed-unstressed level did not differ significantly from the baseline ($OR = 0.97$, 95% *CI* [0.53, 1.76], $z = –0.10$, $p = 0.49$). For this model, we were particularly interested in PC1, which captures positive correlations with English dominance scores. However, none of the PCs showed simple effects on vowel-initial glottalization, failing to support the prediction that greater dominance in L3 English would result in increased rates of glottal marking in the English productions of the L3 English Catalan-Spanish bilinguals.

3.2 Regressive CLI in L1 Catalan

To investigate whether English-like glottal marking influences vowel-to-vowel sequences in Catalan as predicted by their rates of glottalization in English (i.e., RQ3 - Catalan), dominance in English (i.e., RQ4 - Catalan), and Catalan-Spanish dominance (i.e., RQ5 - Catalan), we fitted **Model A’: Catalan**. The marginal R^2 was 0.40, while the conditional R^2 was 0.61. The odds ratio of the model’s intercept is estimated to be 0.07 (95% *CI* [0.04, 0.13], $p < 0.001$), corresponding to a probability of 6.9%.

Regarding the effects of individual scores for vowel-initial glottalization in English (as shown in **Figure 5**), the odds of producing glottalization in Catalan were 3.45 times higher for each unit increase in AvgEnglishGlottal (95% *CI* [1.94, 6.15], $z = 4.21$, $p < 0.001$). The model showed significant interactions between AvgEnglishGlottal and stress at the unstressed-stressed ($OR = 1.74$, 95% *CI* [1.08, 2.80], $z = 2.28$, $p = 0.023$) and stressed-stressed levels ($OR = 2.19$, 95% *CI* [1.32, 3.61], $z = 3.06$, $p = 0.002$), indicating a greater effect of AvgEnglishGlottal on vowel-initial glottalization in the V2-stressed sequences compared to the V2-unstressed ones.

With regard to stress, the model showed simple effects for several stress levels. The odds of producing vowel-initial glottalization were 3.34 times higher in the stressed-unstressed level (95% *CI* [1.54, 7.23], $z = 3.06$, $p = 0.002$) and 6.10 times higher in the unstressed-stressed

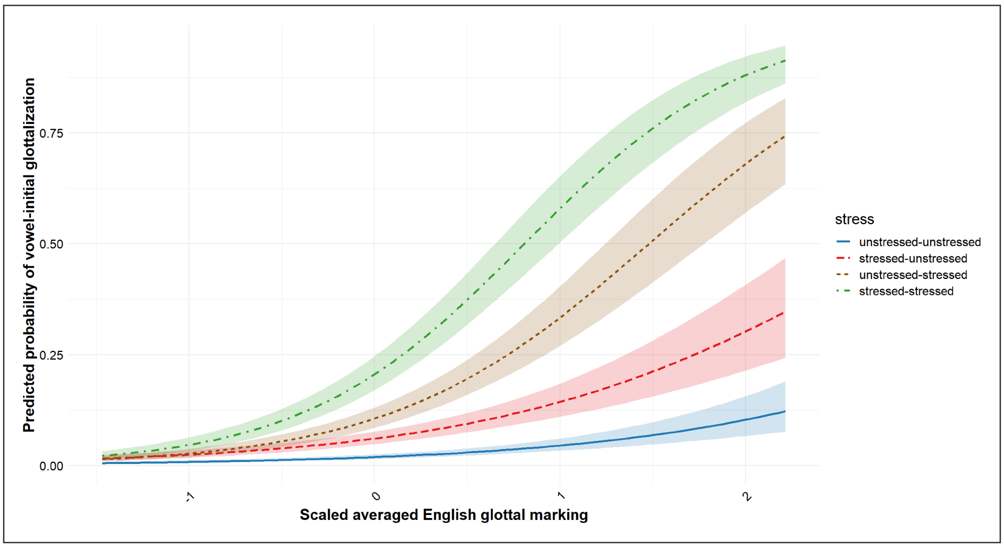


Figure 5: Predicted probability of vowel-initial glottalization across stress conditions and rate of English glottalization in Catalan.

level (95% *CI* [2.84, 13.12], $z = 4.64$, $p < 0.001$) compared to the UNSTRESSED-UNSTRESSED baseline. The effect was even stronger in the STRESSED-STRESSED level, with 13.37 times higher odds (95% *CI* [6.27, 28.52], $z = 6.71$, $p < 0.001$).

Regarding dominance, PC1 showed a significant effect on glottalization rates ($OR = 1.25$, 95% *CI* [1.08, 1.45], $z = 2.98$, $p = 0.003$), indicating a 25% increase in the odds of glottalization with increasing English-to-Catalan/Spanish dominance. PC2 and other components did not reach significance, nor did their interactions with STRESS.

3.3 Regressive CLI in L1 Spanish

To investigate whether English-like glottal marking influences vowel-to-vowel sequences in Spanish as predicted by their rates of glottalization in English (i.e., RQ3 - Spanish), dominance in English (i.e., RQ4 - Spanish), and Catalan-Spanish dominance (i.e., RQ5 - Spanish), we fitted **Model A': Spanish**. The marginal R^2 was 0.56, while the conditional R^2 was 0.69. The odds ratio of the model's intercept, with UNSTRESSED-UNSTRESSED as the reference level and PC values and AVGENGLISHGLOTTAL set to zero, is estimated at 0.05 (95% *CI* [0.03, 0.09], $z = -10.11$, $p < 0.001$), corresponding to a probability of approximately 4.6%.

The effect of STRESS on vowel-initial glottalization in Spanish was not uniform across all levels. Specifically, only the UNSTRESSED-STRESSED ($OR = 3.23$, 95% *CI* [1.31, 7.96], $z = 2.55$, $p = 0.011$) and STRESSED-STRESSED levels ($OR = 4.68$, 95% *CI* [1.98, 11.05], $z = 3.52$, $p < 0.001$) showed significant positive effects compared to the UNSTRESSED-UNSTRESSED baseline, while the STRESSED-UNSTRESSED level did not reach significance ($OR = 1.50$,

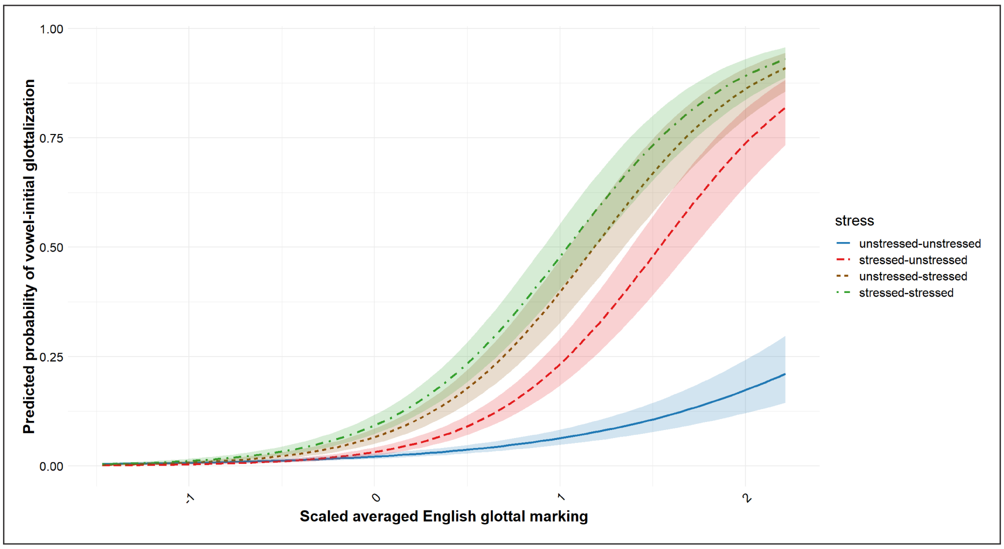


Figure 6: Predicted probability of vowel-initial glottalization across stress conditions and rate of English glottalization in Spanish.

95% *CI* [0.59, 3.83], $z = 0.85$, $p = 0.39$). As shown in **Figure 6**, each unit increase in AvgEnglishGlottal was associated with 7.01 times higher odds of producing vowel-initial glottalization (95% *CI* [4.08, 12.03], $z = 7.07$, $p < 0.001$). This effect was moderated by stress. Relative to the unstressed–unstressed baseline, the model presented significant interactions between AvgEnglishGlottal for all other stress conditions: unstressed-stressed (*OR* = 2.99, 95% *CI* [1.60, 5.56], $z = 3.45$, $p < 0.001$), stressed-unstressed (*OR* = 3.03, 95% *CI* [1.59, 5.75], $z = 3.38$, $p < 0.001$), and stressed-stressed (*OR* = 2.90, 95% *CI* [1.55, 5.44], $z = 3.33$, $p < 0.001$).

Regarding the effects of dominance, each unit increase in Pc1 was associated with 1.19 times higher odds of producing vowel-initial glottalization (95% *CI* [1.04, 1.36], $z = 2.62$, $p = 0.009$). By contrast, each unit increase in Pc2, which correlates positively with Spanish language history, identity, and attitudes, was associated with a 27% decrease in the odds of producing vowel-initial glottalization (95% *CI* [0.62, 0.86], $z = -3.75$, $p < 0.001$).

4 Discussion

In this study, we examined CLI in /V#V/ sequences among L3 English Catalan-Spanish bilinguals by analyzing their rates of vowel-initial glottal marking across all three languages. To establish baseline rates of glottalization in English, we compared the target group to L3 Catalan-Spanish-English bilinguals and English monolinguals. We then applied a PCA to reduce the dimensionality of an adapted BLP for trilingual speakers and investigated whether CLI patterns were influenced by factors such as language use, history, proficiency, and attitudes across the three languages.

4.1 Progressive CLI and language dominance

Before delving into the research questions, we summarize the results for the baseline groups in English. Recall that we expected glottal marking to occur frequently in English /V#V/ sequences, with higher rates in V2-stressed sequences than in V2-unstressed ones. Our results show that, across the baseline groups, glottal marking is the preferred strategy to produce /V#V/ sequences (L1 English monolinguals $M = 88.98\%$, L3 Catalan Spanish-English bilinguals $M = 67.59\%$).

While our findings are consistent with previous research showing a preference for glottal marking in prominent vocalic sequences (Davidson & Erker 2014), they differ in that our L1 English monolinguals exhibited near-ceiling rates of glottalization even in unstressed contexts (unstressed-unstressed: $M = 84.8\%$; stressed-unstressed: $M = 96.79\%$). As a result, significant interactions between stress and speaker groups (L1 English monolinguals and Spanish-English bilinguals) were found in V2-unstressed sequences. These group differences in V2-unstressed vowel sequences were surprising because vowel-initial glottalization has been associated with stressed, or prominent, vowels. That is, the high glottalization rates in V2-unstressed sequences observed among L1 English monolinguals in our results do not align with the prominence-lending function of vowel-initial glottal marking (Shattuck-Hufnagel 1995; Dilley et al. 1996; Garellek 2014; Steffman 2023: among others). One possible explanation for these findings is that the use of vowel-initial glottalization in the L1 English monolinguals of this study has spread to unstressed vowels. However, this interpretation remains tentative, as we cannot rule out the influence of task effects. Recall that, to keep similar vowel quality across experiments, some of our V2 items contained secondary stress (e.g., *inspiration* [ˌɪnspəˈreɪʃən]) and some vowels were unreduced (e.g., *umami* [uːˈmɑ.mi]). These factors may have led speakers to assign some degree of prominence to these sequences, marked by vowel-initial glottalization. In addition, the generally low lexical frequency of our items may have encouraged speakers to use vowel-initial glottalization as a hyperarticulation strategy to highlight the saliency of these low-frequency words (Aylett & Turk 2006; Baker & Bradlow 2009; Zhao & Jurafsky 2009; Scarborough 2012). However, when comparing glottal marking across items in the V2-unstressed sequences, we found no statistically significant correlation between the log word frequency of word 2 and the glottalization rate in these sequences. The absence of comparable effects in the L3 Catalan-Spanish-English bilingual group may stem from CLI from both L3 Catalan and L2 Spanish on their L1 English, exerting a stronger impact on unstressed syllables than on those carrying primary stress. However, without a baseline Spanish-English bilingual group lacking knowledge of L3 Catalan, we cannot disentangle the specific influence of L3 Catalan on L1 English from that of L2 Spanish.

With respect to our research questions, RQ1 investigated whether Catalan-Spanish bilinguals who learn English as an L3 exhibit CLI from L1 Catalan and L1 Spanish (i.e., use of modal phonation in the production of /V#V/ sequences) in their L3 English. Our speakers showed an overall preference for modal phonation in L3 English, with glottal marking occurring at an average rate of 39.01%. Regarding our comparisons between the target and baseline groups, while the L3 English Catalan-Spanish bilinguals differ significantly from the L1 English monolinguals across all four stress levels, they differ from the L3 Catalan-Spanish-English bilinguals only in the unstressed-stressed sequences. This suggests that the experimental group closely aligns with the baseline trilingual group. However, a visual inspection of individual differences in **Figure 7** reveals that three participants (i.e., P08, P02, P12) exhibit negligible rates of L3 English vowel-initial glottalization, which would support an initial L3 stage in which L3 English speakers adopt modal phonation strategies from their L1s. As for the effects of dominance, simple effects for PCs were not observed in the results, which fails to support the prediction that increased dominance in L3 English will result in higher rates of vowel-initial glottal marking. Given the self-reported nature of the BLP (Birdsong et al. 2012), future research should include measures of direct dominance (e.g., relative vocabulary knowledge, grammatical skills, fluency) to assess the possibility that glottal-marking is mediated by increased proficiency in English.

Our results are similar to the findings of Eger et al. (2019), which showed that Italian L1-L2 German learners substantially acquire vowel-initial glottal stops. To explain our rates of learning, we should consider that glottal marking serves as a cue for prosodic prominence (Dilley et al. 1996; Garellek 2014; Steffman 2021), and may, therefore, be a salient cue in the input. In this regard, acoustic saliency has been argued to support the perception, learning, and processing of a sound system (Narayan 2006; Barzilai 2022; Denbaum-Restrepo & Raynor 2023; Barrientos 2024). Furthermore, recall that Eger et al. (2019) explain the acquisition of glottal marking in L2 German as a result of repurposing a sound present in the speakers' L1. In the case of the present study, we could also consider the possibility that L3 English learners repurpose laryngealization from their L1s to their L3, consistent with the hypothesis that learners can redeploy features from their previously acquired languages to their newly acquired ones (Archibald 2005; 2023b; Wu 2024). However, our data do not support the hypothesis that Catalan-Spanish bilinguals rely on glottal marking from L1 Catalan or L1 Spanish to learn L3 English-like glottal marking. First, some Catalan-Spanish bilinguals exhibit negligible rates of vowel-initial glottalization in both Spanish and Catalan (see **Figure 7**), suggesting that these speakers do not have vowel-initial glottal marking available during L3 learning. Second, for those participants who show glottalization in their L1s, we cannot assume that this was present prior to L3 learning, given that the degree of glottal marking in L1 Catalan and L1 Spanish is predicted by the rates of glottalization in L3 English. Our data, however, cannot rule out the possibility that glottal marking is used in Catalan and Spanish for purposes other than strengthening of a stressed vowel (e.g., prosodic boundary marking) and later redeployed in L3 English in /V#V/ sequences. In this regard, articulatory data could help shed light on the uses of laryngealization in Catalan and Spanish.

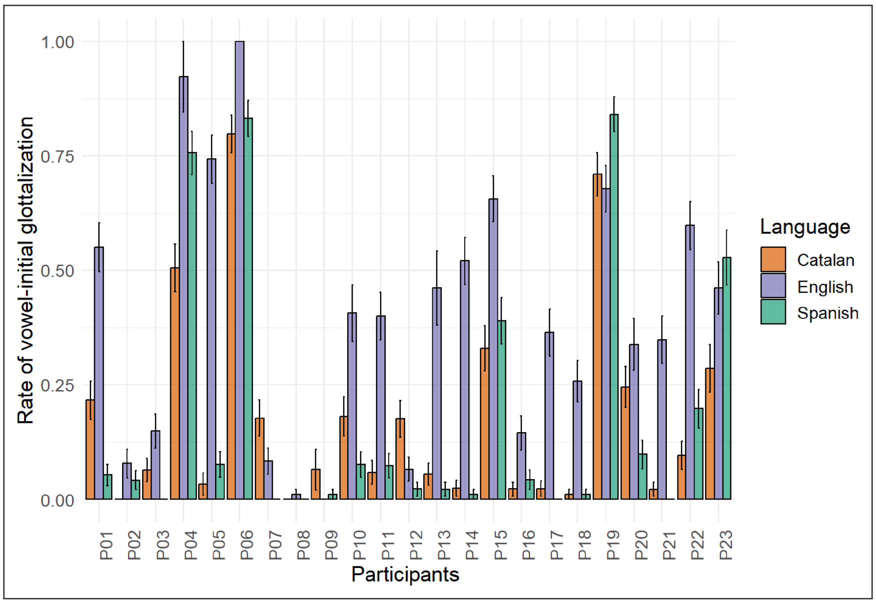


Figure 7: Rate of glottalization across participants with an L3 English language profile, grouped by language.

4.2 Regressive CLI and language dominance

Regarding regressive CLI, we predicted that Catalan-Spanish bilinguals acquiring L3 English would exhibit glottal marking on their L1 Catalan and L1 Spanish, predicted by their rates of glottal marking in L3 English and English dominance. Our results indicate that increased vowel-initial glottalization in English is associated with a greater likelihood of using glottal marking in both L1 Catalan and L1 Spanish. As expected, this suggests that glottal marking must be present in the L3 grammar in order to influence previously acquired languages. Consistent with a prosodic-marking account of vowel-initial glottalization, the interaction between L3 English glottalization rates and stress in L1 Catalan and L1 Spanish reveals that L3 English glottal marking has a stronger effect in /V#V/ sequences with some degree of stress than in unstressed ones.

To investigate the predictions of the Language Communication Model (Fallah et al. 2016; Fallah & Jabbari 2018), we further asked whether L3 English dominance is associated with a higher likelihood of producing vowel-initial glottalization in L1 Catalan and L1 Spanish. Our findings show that, in both Catalan and Spanish, vowel-initial glottalization rates among Catalan-Spanish bilinguals correlate with increases in PC1, reflecting greater dominance in L3 English relative to L1 Catalan and L1 Spanish. Notably, three of the four participants with the highest rates of vowel-initial glottalization (P04, P06, P19, P23) lived outside Catalan- or Spanish-speaking regions at the time of testing, which could have increased their daily use of English. Furthermore, participant P23 reported spending 13 years in an English-speaking country compared to only 8 years in a Catalan/Spanish-speaking environment, reflecting substantial cumulative exposure to English. This indicates that a certain level of cumulative or current exposure to English may be necessary for glottal marking to be transferred from L3 English to L1 Catalan-Spanish. These results align with the Language Communication Model (Fallah et al. 2016; Fallah & Jabbari 2018), which proposes that the language of communication influences the availability of that language for transfer.

Based on the Differential Stability Hypothesis (Cabrelli Amaro 2017) and considering language dominance, we predicted that speakers would show more CLI in their less dominant language. That is, greater dominance in Spanish would predict increased glottalization in Catalan, and greater dominance in Catalan would predict increased glottalization in Spanish. Although our results for Catalan do not show any relationship with the PCs, our Spanish results reveal a negative relationship between PC2 and the rate of vowel-initial glottalization. Recall that PC2 is associated with higher scores in variables related to identity and frequency of use in Spanish relative to Catalan. Therefore, our results indicate that as Spanish dominance relative to Catalan increases (as captured by PC2), the likelihood of vowel-initial glottalization decreases.

Although the rate of vowel-initial glottal marking in Catalan did not show PC2 effects at the group level, we inspected these effects at the individual level (see **Figure 7**). To do so, we conducted a Pearson product-moment correlation to assess the relationship between the Spanish-Catalan glottal marking rate difference and PC2 values. This rate difference was calculated by subtracting the rate of glottalization in Catalan from that in Spanish for each participant. The analysis revealed a moderate negative correlation between the rate difference and PC2 values ($r(21) = -0.59$, $p = 0.003$), indicating that a decrease in PC2 is associated with an increase in the positive difference between Spanish and Catalan rates of vowel-initial glottalization. That is, the lower the scores related to Spanish language use and identity, the more L3 English learners glottalize in L1 Spanish relative to L1 Catalan. This indicates that regressive effects may be more likely to occur in languages that are used less frequently and have weaker associations with the speaker's linguistic identity. These findings also suggest that the vulnerability of early-acquired languages to CLI is dynamic and may be shaped by asymmetries in exposure and use. Nevertheless, this interpretation should be approached with caution, as our results for PC2 do not extend to the Catalan experiment.

Overall, our results showing regressive CLI are consistent with two possible explanations. One is a change in the underlying representations; an integrated multilingual phonetic-phonological system would allow for interaction between earlier and later acquired sound systems, such that sufficient exposure to L3 English may influence and potentially lead to the incorporation of L3-specific properties into the L1 Catalan or L1 Spanish grammars. The other explanation is a processing-based effect under a language coactivation account, where non-target grammars could activate during input evaluation and, if sufficiently active, can influence input evaluation, even when they are not the speaker's intended language. Under the latter account, underlying representations are not necessarily affected by the acquisition of later-learned languages.

Crucially, this study cannot determine whether vowel-initial glottalization in Catalan and Spanish reflects a processing effect during speech production, or a grammatical change in which L3 learners integrate glottalization into their L1 grammars as a prominence-marking strategy. Examining speakers in different bilingual activation modes could help unravel these possibilities. For example, if glottalization is greater in a Catalan-English bilingual mode than in a Catalan monolingual mode, this would suggest a processing-based effect. In this account, CLI arises because the two languages are coactivated, and the /V#V/ sequence is then evaluated by both the target and the non-target grammar. Conversely, similar glottalization rates across bilingual and monolingual contexts would point to a more stable influence of the non-target grammar, indicating a representational change in the L1. Moreover, to better capture shifts in activation thresholds over time, future research should take a longitudinal approach, employing dynamic measures of language dominance to assess multilingual speakers both during the acquisition of their third language and as the dominance of their previously acquired languages evolves. In the context of L3 English acquisition, we predict that increased exposure to English will lead to greater influence on the speakers' L1 Catalan and Spanish, resulting in more English-like patterns of glottal marking. Moreover, longitudinal shifts in Catalan-Spanish dominance are expected to modulate regressive crosslinguistic transfer: as dominance shifts from Catalan to Spanish (or vice versa), the non-dominant language is predicted to exhibit increased rates of glottal marking. Regarding progressive CLI, we anticipate that longitudinal studies could reveal a pattern in Catalan-Spanish bilinguals in which they initially produce modal phonation across vowel-initial sequences, with glottalization increasing over time as dominance in L3 English improves.

5 Conclusions

In this study, we explored the role of dominance on progressive and regressive CLI in the production of word-external vocalic sequences among early Catalan-Spanish bilinguals with English as an L3. To reduce the dimensionality of an adapted version of the BLP (Birdsong et al. 2012), which included an additional set of questions specific to the third language of the participants, we conducted a PCA. This analysis yielded four PCs that together accounted for 57.9% of the variance in the adapted BLP responses from the L3 English Catalan-Spanish bilinguals. By reducing the number of correlated predictors in our models, this approach helps to mitigate the risk of multicollinearity.

Our findings suggest that L3 English speakers who are Catalan-Spanish bilinguals learn to produce vowel-initial glottal marking in English. Although they exhibit lower rates of glottal marking than L1 English speakers across all stress conditions, they show significantly lower rates only in the unstressed-stressed condition when compared to L3 Catalan Spanish-English bilinguals.

In addition, dominance does not have an effect on the glottal marking rates in L3 English. We argue that the prominence-lending function of glottal marking could sustain its learning in a foreign language.

This study investigates trilingual language dominance by applying a PCA to derive uncorrelated scores that explain variance in the dataset, building on its use in Helms (2023). It is important to note that the PCs represent approximations of dominance rather than precise indicators of relative dominance. For example, our PCs revealed distinct patterns: PC1 was positively associated with English scores and negatively associated with Catalan-Spanish scores, while PC2 exhibited a positive association with Catalan scores and a negative association with Spanish scores. However, PC3 and PC4 captured associations that were less clearly interpretable based on the raw variables. Moreover, our PCs did not capture the distinct effects of relative English-Catalan dominance or English-Spanish dominance. In light of these considerations, this study underscores the importance of developing future methods that can capture three-way dominance distinctions through independent uncorrelated predictors.

Data availability

Supplementary materials consisting of supplementary analyses, complete stimuli list, PC loadings, and spreadsheets for analyses are openly available and can be found here: https://osf.io/9xd4c/?view_only=54dba77e255347569f74956522e008e8.

Ethics and consent

Ethical approval was received from the Committee for Protection of Human Subjects at the University of California, Berkeley (2022-08-15555). The approval was issued under the University of California, Berkeley Federalwide Assurance #00006252.

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Competing interests

The author has no competing interests to declare.

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