Native-Language Phonotactic Processing in Bilinguals

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ABSTRACT

Bilinguals are prone to competition from similar sounding words across their two languages (e.g., *strict* activates Spanish *estricto*). In three experiments, we relied on phonotactic constraints (i.e., rules for combining speech sounds) to examine how experience with multiple languages transforms the way in which speech sounds are processed. In Experiment 1, we found that Spanish-English bilinguals accessed the L1 Spanish vowel+s+consonant constraint (Spanish *estricto*) during L2 English processing (English *strict*) when performing a cross modal phonological priming lexical decision task. In Experiments 2 and 3, we found that bilinguals processed L2 auditory and/or visual inputs in line with the L1 constraint (*strict* as *estrict*) in a vowel detection task and a sound recognition task (visual world paradigm). We conclude that bilinguals access L1 phonotactic constraints during L2 processing and that L1 representations for sounds and words influence how L2 input is perceived.

Keywords: bilingualism, phonotactic constraints, phonology, visual world paradigm, speech perception

1. INTRODUCTION

What if we hear a sequence of phonemes that conflicts with how sounds are typically combined within our language? For example, a rule for combining speech sounds in Spanish is that a vowel must precede word-initial s+consonant clusters (s+c), as in *estricto* (English: "strict"). In English, however, s+c onsets with and without an initial vowel are abundant. For a native Spanish speaker learning English, s/he may experience competition from the Spanish vowel+s+consonant cluster (v+s+c) rule when speaking English. Herein lies the reason native Spanish speakers often produce English s+c words with a vowel at the onset, such as *estudy* and *espring* [26]. And, while prothesis (i.e., the addition of a vowel at a word's onset) is commonly observed in Spanish-English bilinguals' accented English speech, the current investigation examines whether bilinguals implement rules of their native language (L1) when processing their second language (L2). Do non-native speakers perceive speech differently than L1 speakers of a given language?

Bilingualism provides a unique tool to examine perception of non-native sounds that conflict with L1 rules. Interestingly, when monolinguals hear nonsense sounds that contrast with the rules of their language, they repair the sound sequences to conform to the rules [8,11,12,14]. For example, Spanish monolinguals repair the Spanish-like non-word *special* (/spesjal/) to *especial*, the latter conforming to Spanish's v+s+c rule [8,14]. Spanish-dominant bilinguals also repair sounds that do not align with their L1 when they are in an L1 testing environment [5,6]. Here, we examine how bilinguals process L2 sound sequences that conflict with L1 rules. Bilinguals have demonstrated parallel activation of the L1 when comprehending in the L2, across phonotactic-constraint [13], phonological-word [2,3,9,20], lexical [1,18], semantic [21], and syntactic levels [16,18]. The current experiments provide further evidence for parallel processing in bilinguals, with perception of L1 phonotactics during L2 processing.

Moreover, this investigation provides insight into the structure of acoustic space and the phonological system within the bilingual mind by characterizing new cross-linguistic interactions at the sub-lexical level. If bilinguals process L2 input (e.g., English s+c word or non-word: *strict*/*spelg*) in accordance with L1 phonotactic constraints (e.g., Spanish-like v+s+c word or non-word: *estrict*/*espelg*), then bilinguals might perceive an illusory vowel onset due to L1 constraints on how phonetic categories are represented.

The purpose of this investigation is twofold. First, we examine *whether* bilinguals access L1 phonotactic constraints during L2 comprehension. When examining between-language co-activation in bilinguals, previous studies have identified that bilinguals process auditory and visual input through a combination of bottom-up (e.g., *plum* activates Spanish *pluma* (English: *pen*) and top-down pathways (e.g., inhibitory control of the irrelevant language allows for lexical selection) [2,3,20]. As speech unfolds through time, for example, hearing the word *strict*, neighbors that share phonology become activated (e.g., within-language neighbor: *string*, between-language Spanish neighbor *estudio*). Second, we investigate *the extent to which* bilinguals process L1 phonotactic constraints while listening to and/or reading the L2. For example, a Spanish-English bilingual hearing and/or reading *strict* may process it as *estrict*, since their L1 (Spanish) contains the v+s+c rule. We tested the following two hypotheses: (1) Bilinguals experience L1 cross-linguistic influences during L2 sub-lexical processing, and (2) Bilinguals access L1 sounds during L2 audio-visual and visual-only (orthographic) processing.

2. EXPERIMENT 1

Learning a new set of phonotactic constraints is challenging for L2 learners, especially when an L2 phonological structure is not present in the L1 [4]. For example, in Spanish, s+cs cannot exist at word onsets and a vowel, usually 'e' must be added (e.g., English *strict,* Spanish *estricto*). In language production, native-Spanish speakers may at times produce English words such as *estudy* ("study"), adding an 'e' onset [26], which suggests that bilinguals access and apply Spanish constraints when speaking English. During receptive language processing, Spanish monolinguals report hearing the 'e' onset when primed with a Spanish word that has the 'e' removed (e.g., *stricto*) [14]. For bilinguals, when hearing *strict,* they may activate phonological cohorts that overlap with Spanish through phonotactic constraints and phonological form (e.g., *estándar*/standard) and potentially even cohorts that overlap with Spanish through phonotactic constraints only (e.g., *edad*/age) through cross-linguistic activation. Therefore, it was hypothesized that Spanish-English bilinguals accessed Spanish (L1) phonotactic constraints during English (L2) comprehension.

2.1. Method

In Experiment 1, bilingual Spanish-English (n=22) adult participants were tested. Proficiency was measured with *Language Experience and Proficiency Questionnaire* [19]. Bilinguals acquired English at age 6 or later and were exposed to Spanish a minimum 30% daily. In a cross-modal phonological priming lexical decision task, English primes included words with 'st' and 'sp' onsets, and fillers, controlled on lexical characteristics (e.g., frequency). Lexical decision targets included English words, or English-like non-words with 'es' and 'e' onsets, control non-words, and fillers. Participants heard English primes with initial s+c (*strict*) and controls without initial s+c (*workers*). Immediately after hearing the prime, participants performed a lexical decision on visual targets: English-like 'es' non-words (*estomb*), 'e' non-words (*entaty*), non-word controls (*atters*), and English word controls (*rising*). If English primes containing s+c onsets activated Spanish phonological rules, then faster responses to 'e' onset target non-words were expected.

2.2. Results

A 2(prime: s+c, control) x 4(target: 'es' non-word, 'e' non-word, non-word control, word control) repeated-measures ANOVA was conducted on lexical decision targets. There was a main effect of target condition, $F(3,129)=16.02$, $p<.001$, $\eta_p^2=.27$. Bonferroni-corrected pairwise post hoc comparisons indicated that bilinguals were faster to respond to 'es' overlap non-word targets (*estomb*) *and* 'e' non-word targets (*entaty*) preceded by s+c primes (*strict*; M = 876.33ms, SE = 61.85; M = 881.14ms, SE = 62.67, respectively) than to non-word controls preceded by s+c (M = 944.39ms, SE = 72.11), $t(21) = -4.63$, $p <$ 0.001; $t(21) = -3.56$, $p < 0.01$, respectively. The results demonstrate significant effects of Spanish phonotactic constraint activation during English comprehension. Bilinguals demonstrated faster reaction times, relative to control conditions, to 'es' overlap non-words and 'e' overlap non-words when primed with s+c onset words.

2.3. Discussion

Experiment 1's findings demonstrate that during single-language comprehension, bilinguals access phonotactic constraints of the other language (Spanish) to comprehend words in the relevant language (English). Bilinguals were faster to respond to 'e' onset non-words than to controls without 'e' onsets when primed with s+c words, suggesting that bilinguals co-activated English and Spanish lexica containing words with 'e' onsets. We extend previous findings examining cross-linguistic phonological access in bilinguals [2,3] to suggest that phonotactic constraints of the non-target language, in addition to phonological representations, are accessed during comprehension. Experiment 1 established that bilinguals access L1 phonotactic constraints during L2 processing. Experiments 2 and 3 examine the extent to which parallel processing of phonotactic constraints occurs.

3. EXPERIMENT 2

To follow up on the findings of Experiment 1, as well as on the findings of Carlson et al. [6], Freeman et al. [13], Lentz and Kager [17], and Weber and Cutler [25], we examined the extent to which bilinguals engaged parallel processing of L1 phonotactic constraints during L2 comprehension. Our objective was to determine whether bilinguals *perceived* L1 phonotactics when hearing L2 sound sequences (auditory input). Previous evidence demonstrates that bilinguals perceptually repair L2 syllable sequences that are illicit in the L1 to conform to the L1 [25]. The hypothesis was that Spanish-English bilinguals relied on parallel processing to perceive English and English-like sounds as Spanish-like, assimilating English (L2) sound sequences to Spanish (L1) phonotactic constraints.

3.1. Method

Participants included a new group of 26 Spanish-English bilinguals (native Spanish speakers), ages 18-34. The vowel detection task measured perception of the 'e' onset in s+c words and non-words. Perception of this phonotactic constraint was examined in the presence of s+c that conflicted with the Spanish 'e' onset vowel rule. Accuracy and reaction times to identifying whether a vowel was present were measured. We used a mix of words and non-words that conflicted with the 'e' onset constraint. With a non-word, participants may have been more likely to report hearing a vowel, as lexical status, and therefore the language to which the non-word could belong, were unclear.

In the vowel detection task, we asked participants if they heard a vowel at the onset of English s+c words (*strict*) and English-like s+c non-words (*spelg*), as well as word and non-word controls (*can, nulse*). Bilinguals were expected to demonstrate differences in reaction times to s+c words and non-words relative to control words and English-like non-words.

3.2. Results

Two 2(onset type: s+c onset, control) by 2(lexical status: word, non-word) mixed effects logistic regression models were used to analyze accuracy and reaction time data. The accuracy model failed to converge due to ceiling effects; therefore, we only report reaction time data. There was a main effect of Onset Type, $\beta = -0.04$, $SE = 0.02$, $t = -2.00$, $p < 0.01$; and a marginal interaction between Lexical Status and Onset Type, $\beta = 0.06$, $SE = 0.02$, $t = 1.50$, $p = 0.07$. Bilinguals responded more slowly to non- words ($M = 1133.11$ms, $SE = 30.76$) than to words ($M = 1076.03$ms, $SE = 22.88$), $\beta = 0.05$, $SE = 0.02$, $t = 2.40$, $p = 0.02$. Bilinguals showed slower response times to s+c words ($M = 1112.85$ms, $SE = 30.29$) than to control words ($M = 1039.09$ms, $SE = 28.98$), $\beta = -0.07$, $SE = 0.03$, $t = -2.4$, $p = 0.03$. Bilinguals' response times to s+c non-words ($M = 1136.03$ms, $SE = 35.45$) relative to control non-words ($M = 1130.17$ms, $SE = 47.47$) were similar, $\beta = -0.01$, $SE = 0.03$, $t = -0.42$, $p = 0.10$. Therefore, bilinguals demonstrated slower response times to Spanish-conflicting words relative to control words, suggesting L1 cross-linguistic influence on L2 s+c words. This pattern did not hold true for Spanish-conflicting non-words relative to control non-words.

3.3. Discussion

In vowel detection, which is an explicit measure of vowel perception, Spanish-English bilinguals perceived an illusory 'e' onset when listening to L2 words that conflicted with the L1 v+s+c rule. An explanation as to why there were differential effects for words versus non-words on vowel detection is that with words, bilinguals recruited top-down perceptual knowledge of phonotactic constraints, as well as top-down lexical knowledge. This finding slightly contrasts with the stronger phonotactic effects for non-words in Experiment 1. Only non-words were used as visual targets in Experiment 1, and it appears that when the onset sound of a stimulus is the explicit focus (Experiment 2), a stronger perceptual representation exists for words than for non-words, likely due to differential recruitment of top-down processes. Interestingly, the result for words but not non-words suggests that Spanish-like phonotactic processing affected word learning in earlier stages of acquiring English, but it may no longer affect the learning of new s+c words in English for this population [10]. Experiments 1 and 2 established that bilinguals process L2 input in line with L1 phonotactics through audio-visual and auditory-only input. Experiment 3 further examines the extent to which bilinguals experience parallel processing of the L1 during L2 comprehension in the visual-only modality.

4. EXPERIMENT 3

When comprehending words in one language, words from the other, irrelevant language may be simultaneously accessed through parallel activation [18,20]. This cross-language interactivity within bilinguals is surprising given that individuals can only speak in one language at a time. In Experiment 3, we again examined whether bilinguals were influenced by L1 phonotactic constraints when processing the L2, but this time we further investigated the role of input modality. In Experiments 1 and 2, bilinguals processed the L2 according to L1 phonotactics audio-visually (Experiment 1) or auditorily (Experiment 2). In Experiment 3, the Spanish phonotactic violation occurred in the visual domain with eye-tracking to different words on a visual display (visual world paradigm). The visual target word was identified by hearing only the word onset (e.g., "Click on /s/" for *spa*), while viewing three other words as well (an e-onset competitor: *egg*, and two fillers: *work* and *can*).

It was hypothesized that activation of the Spanish (L1) phonotactic constraint could occur independently of auditory input, as parallel activation does not always rely on hearing words [7,15,24]. In addition, because bilinguals were tested in English, their L2, it was predicted that those with lower L2 proficiency would experience increased L1 phonotactic interference during L2 processing than bilinguals with higher L2 proficiency.

4.2. Method

Participants included 33 Spanish–English bilingual adults, ages 18-34. In the sound recognition task, Spanish-English bilinguals saw four words on a visual display while eye movements were tracked. Participants identified the target word by hearing its onset (i.e., "Click on /s/", target = *spa*). On critical trials, items included an English target word that conflicted with the Spanish phonotactic constraint of a vowel onset at the beginning of s+c words (*spa*) and a competitor word containing the presumably activated vowel onset (*egg*). Two filler words were also present that did not conflict or overlap with the Spanish constraint (*work* and *can*). If bilinguals accessed Spanish phonotactics during English comprehension, then more looks to 'e' onset competitors (*egg*) than fillers (*work*/*can*) were expected when presented with s+c onset targets.

4.2. Results

Growth-curve analyses (GCA; [22]) of fixation proportions were employed to examine the time course of phonotactic-constraint activation during visual word processing. A composite score was created for L2 proficiency comprising of objective (PPVT-3 standard score) and self-report measures (LEAP-Q averaged speaking, understanding, and reading proficiency ratings) and entered into the model. Visual fixations were analyzed from the auditory prompt onset until the point at which fixations to the target peaked, indicating final target selection, which was around 1100ms post-sound onset. The model revealed main effects of proficiency on the intercept term, $\beta = 0.69$, $SE = 0.37$, $t = -2.48$, $p = 0.01$ and on the quadratic term (i.e., the rise and fall rate of fixation proportions in the model curve), $\beta = 0.51$, $SE = 0.28$, $t = 2.53$, $p = 0.01$. There were also significant interactions of word type by proficiency on the intercept, $\beta = 0.32$, $SE = 0.12$, $t = 2.67$, $p < 0.0$, and on the quadratic terms, $\beta = 0.62$, $SE = 0.28$, $t = -2.51$, $p = 0.01$. The model demonstrated that bilinguals with lower L2 (English) proficiency produced a greater proportion of fixations to the "e"-onset word relative to filler words than did higher L2 proficiency bilinguals.

4.3. Discussion

Experiment 3 results suggest the Spanish phonotactic constraints influence bilinguals relatively early on during English comprehension, without hearing the conflicting word (in the visual modality). In addition, bilinguals with lower L2 proficiency were more likely to activate the L1 phonotactic constraint when viewing L2 words. In other words, decreased L2 proficiency results in increased L1 interference. Experiment 3 was unique in that, for the first time, evidence was found for phonotactic-constraint activation of the unintended language during visual word processing without auditory input of the constraint-conflicting structure (i.e., s+c; *spa*).

5. GENERAL DISCUSSION

The current investigation demonstrates that native-language phonotactic constraints influence how bilinguals processe their second language. The purpose of these experiments was to further characterize and understand the involvement of the L1 during L2 comprehension. Typically, as auditory input unfolds through the acoustic stream, bilinguals activate neighboring words within and between their languages [23]. As each phone is heard, neighboring words are eliminated that do not coincide with the input until the target representation is reached. This process of elimination explains how phonologically competing words are activated and suppressed. However, the findings of the current investigation suggest that when the L2 acoustic stream conflicts with L1 phonotactic constraints, or rules, then words that conform to this rule are activated as well.

Moreover, the findings that bilinguals access phonotactic constraints from the unintended language when receiving auditory and visual input (Experiments 1 and 2) and only visual input (Experiment 3) suggest that models of bilingual language activation should include phonotactic constraints as further evidence for the extent to which cross-linguistic structures can be activated. These results underscore the dynamic connections within the bilingual language system[27]. Bilinguals activate and perceive L1 sub-lexical structures, such as phonotactic constraints, during L2 processing. These results also contribute to understanding how the language system is organized in the bilingual brain.

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