Studies in Second Language Acquisition, **44** (2022), 759–787
doi:10.1017/S027226312100053X

Research Article

VISUAL WORD RECOGNITION IN BILINGUALS

EYE-TRACKING EVIDENCE THAT L2 PROFICIENCY IMPACTS ACCESS OF L1 PHONOTACTICS

Max R. Freeman *

St. John's University

Viorica Marian

Northwestern University

Abstract
A bilingual's language system is highly interactive. When hearing a second language (L2), bilinguals access native-language (L1) words that share sounds across languages. In the present study, we examine whether input modality and L2 proficiency moderate the extent to which bilinguals activate L1 phonotactic constraints (i.e., rules for combining speech sounds) during L2 processing. Eye movements of English monolinguals and Spanish–English bilinguals were tracked as they searched for a target English word in a visual display. On critical trials, displays included a target that conflicted with the Spanish vowel-onset rule (e.g., *spa*), as well as a competitor containing the potentially activated "e" onset (e.g., *egg*). The rule violation was processed either in the visual modality (Experiment 1) or audio-visually (Experiment 2). In both experiments, bilinguals with lower L2 proficiency made more eye movements to competitors than fillers. Findings suggest that bilinguals who have lower L2 proficiency access L1 phonotactic constraints during L2 visual word processing with and without auditory input of the constraint-conflicting structure (e.g., *spa*). We conclude that the interactivity between a bilingual's two languages is not limited to words that share form across languages, but also extends to sublexical, rule-based structures.

INTRODUCTION

Bilinguals access their two languages in parallel even when the input is only in one language (Blumenfeld & Marian 2007, 2013; Giezen et al., 2015; Kroll et al., 2008; Marian & Spivey, 2003a, 2003b; Sunderman & Kroll, 2006). The extent of coactivation

* Correspondence concerning this article should be addressed to Max R. Freeman, Department of Communication Sciences and Disorders, St. John's University, 8000 Utopia Parkway, St. John Hall, Room 344, Jamaica, NY 11439. E-mail: freemanm@stjohns.edu

across the two languages is influenced by proficiency, with lower levels of second language (L2) proficiency resulting in increased native-language (L1) coactivation (e.g., Blumenfeld & Marian, 2007; Grainger et al., 2010; Marian & Spivey, 2003a, 2003b; van Hell & Tanner, 2012; Weber & Cutler, 2004). Recent evidence suggests that parallel activation also occurs at the sublexical level, with bilinguals accessing L1 phonotactic constraints (i.e., rules for combining speech sounds) during L2 comprehension (Freeman et al., 2016, 2021; Lentz & Kager, 2015; Parlato-Oliveira et al., 2010; Weber & Cutler, 2006). For example, when a Spanish–English bilingual hears the English word *spa*, they may also access the Spanish translation equivalent, *balneario*, and the Spanish "e"-onset vowel rule, which requires that word onsets with an s+consonant cluster (s+c) contain a vowel (e.g., es+c rather than s+c; Freeman et al., 2016, 2021). In the current study, we use eye tracking to examine the extent to which input modality (auditory and visual) and bilinguals' language proficiency influence parallel activation of L1 phonotactics during L2 visual word recognition.

THEORETICAL MODELS FOR BILINGUAL SPEECH PROCESSING

Several theoretical accounts have been proposed to explain language coactivation and phonotactic access during bilingual comprehension. A connectionist computational model, the Bilingual Language Interaction Network for Comprehension of Speech (BLINCS; Shook & Marian, 2013), suggests that bilinguals access phonological neighbors during spoken word comprehension. For example, the Spanish word *tenedor* ("fork") activates the Spanish word *tiburón* ("shark") and the English words *tunnel* and *tent* through phonological overlap within and between languages. Support for phonological neighbor activation, including access to phonotactic constraints, also comes from the Activation Threshold Hypothesis (ATH; Paradis, 2004). Activation of a word and its neighbors occurs as a threshold is approached. Selection of a target word requires that its activation exceeds the threshold of its alternatives. Thus, bottom-up activation of neighbors within the ATH occurs during initial stages of auditory word comprehension.

In addition to bottom-up activation of cross-linguistic structures, top-down information may influence how and which words are accessed as auditory input unfolds. The Perceptual Assimilation Model (PAM; Best, 1994) explains that rules specific to each language influence how individuals process speech. Conflict occurs when a bilingual hears a nonnative (L2) speech sound that does not exist in the L1 inventory. The model suggests that if the phonetic characteristics of the sound resemble those of an existing phoneme in the L1, the sound will be assimilated to the L1 category. Thus, bilinguals may apply knowledge of L1 rules when processing L2 auditory input. This top-down manner of processing speech sounds provides a potential explanation as to why a rule, such as a phonotactic constraint, may impact bilingual speech processing.

The BLINCS, ATH, and PAM shed light on the potential mechanisms used by bilinguals when processing L2 words that conflict with L1 rules. In addition to the bottom-up influences on activation of within- and between-language neighbors and phonotactic constraints, bilinguals are also likely influenced by L1 phonotactic constraints when processing L2 input in a top-down manner (e.g., Carlson et al., 2016; Parlato-Oliveira et al., 2010). However, it is unclear how auditory and visual inputs affect bottom-up and top-down mechanisms. Based on these models, when no L2 auditory input is present, visual (orthographic) input may mediate cross-linguistic access to L1 phonological representations and phonotactic constraints.

LANGUAGE COACTIVATION IN BILINGUALS

Theoretical models of language coactivation are supported by empirical evidence from unimodal tasks with bilinguals in the auditory (Fitzpatrick & Indefrey, 2010; Weber & Cutler, 2006), visual (Chabal & Marian, 2015; Finkbeiner et al., 2004; Kaushanskaya & Marian, 2007; Martín et al., 2010; Schoonbaert et al., 2009; Sunderman & Kroll, 2006; Thierry & Wu, 2007), and audio-visual modalities (Blumenfeld & Marian, 2013; Giezen et al., 2015; Ju & Luce, 2004; Marian & Spivey, 2003a, 2003b; Shook & Marian, 2019), suggesting that phonological overlap between words across languages leads to parallel activation (e.g., Blumenfeld & Marian, 2007, 2013; Marian & Spivey, 2003a, 2003b; Shook & Marian, 2013).

LANGUAGE COACTIVATION AND PROFICIENCY

The extent and time course of parallel activation at the phonological level are moderated by language proficiency (Blumenfeld & Marian, 2013; Mercier et al., 2014; Mishra & Singh, 2016; Veivo et al., 2018). Blumenfeld and Marian (2013) tracked English-Spanish bilinguals' eye movements to pictures of targets cued by an English word (e.g., *comb*), as well as to cross-linguistic competitors (e.g., a rabbit; Spanish: *conejo*) and unrelated fillers. Looks to competitor versus filler pictures revealed that both the initial onset and subsequent resolution of L2 parallel activation was earlier for bilinguals with higher L2 proficiency. This pattern of early-then-reduced parallel activation was also associated with a smaller nonlinguistic Stroop effect, or better competition resolution abilities, suggesting that greater L2 proficiency and cognitive control skills resulted in more efficient L2 activation and resolution during L1 auditory/visual comprehension.

Participants in Mishra and Singh (2016) listened to a word while they saw on a visual display a translation phonological-cohort competitor of the spoken word amongst three unrelated words. Results demonstrated that Hindi bilinguals with high and low proficiency in their L2 English accessed the translation equivalent through the phonological cohort competitor when performing the task in the L1 and L2. The higher L2 proficiency bilinguals looked at the competitor earlier on than the lower L2 proficiency bilinguals, irrespective of language direction. These findings suggest that bilinguals of varying proficiency access both languages simultaneously; however, bilinguals with higher levels of proficiency experience parallel language activation earlier on than bilinguals with lower proficiency, similar to Blumenfeld and Marian (2013).

Veivo et al. (2018) examined how orthographic and phonological information influenced bilinguals' matching of spoken and written L2 word forms in a printed-word visual world paradigm. Results suggested that when hearing L2 words, bilinguals activated L1 orthographically and phonologically similar word forms. For bilinguals with lower L2 proficiency, there was delay in L2 target word identification due to orthographically similar L1 competitors, while the authors attribute more efficient performance amongst bilinguals with higher L2 proficiency to their ability to suppress the irrelevant language (i.e., orthographic between-language information), also in line with Blumenfeld and

https://doi.org/10.1017/S027226312100053X Published online by Cambridge University Press

Marian (2013). Across these studies, bilinguals with higher levels of L2 proficiency suppress or inhibit activation of the unintended language more efficiently than bilinguals with lower levels of L2 proficiency during auditory and/or visual word processing.

LANGUAGE COACTIVATION AND INPUT MODALITY

In addition to proficiency, the current study examines the contributions of auditory (phonological) and visual (orthographic) input to bilingual language processing. Though Blumenfeld and Marian (2013) found evidence of parallel language activation using auditory and visual stimuli, cross-linguistic access has also been observed during visual/orthographic word comprehension without auditory input (e.g., Kaushanskaya & Marian, 2007; Thierry & Wu, 2007). For instance, Thierry and Wu (2007) found that bilinguals performing a semantic relatedness judgment task were influenced by L1 translations when reading L2 words. Chinese–English bilinguals were visually presented with L2-English word pairs and decided if they overlapped in meaning while event-related potentials were recorded. Some of the L2 pairs contained a character that overlapped (character repetition) in L1-Chinese translation equivalents. ERP results revealed a significant character repetition effect (and semantic relatedness effect), suggesting that bilinguals in this study accessed, and experienced interference from, L1 phonology when processing L2 orthography. These findings were replicated in the auditory modality as well. Of interest to the current investigation are the contributions of auditory (phonological) versus visual (orthographic) input in bilinguals' activation of L1 phonotactic constraints during L2 processing.

LANGUAGE COACTIVATION AND PHONOTACTIC CONSTRAINTS

Previous investigations have examined whether bilinguals access L1 constraints when processing L1-conflicting L2 words (e.g., Freeman et al., 2021 Parlato-Oliveira et al., 2010; Weber & Cutler, 2006); however, input was presented auditorily. Moreover, bilinguals and monolinguals may even perceptually repair these conflicting sound sequences to make them more L1-like (Carlson, 2018; Carlson et al., 2016; Dupoux et al., 2008; Hallé et al., 2008; Parlato-Oliveira et al., 2010). For example, findings from Freeman et al. (2016, 2021) suggest that bilinguals activate L1 phonotactic constraints during L2 processing. When hearing L2-English auditory speech segments that conflicted with the L1-Spanish vowel+s+consonant (v+s+c) onset rule (e.g., *spa*), Spanish–English bilinguals were slower to respond to these stimuli in lexical decision and vowel detection tasks than to nonconflicting stimuli (e.g., *work*) (Freeman et al., 2016, 2021). Slower response times to L1-conflicting L2 words, relative to controls, suggested that bilinguals experienced L1 interference from the v+s+c constraint during L2 processing. However, these previous investigations do not dissociate the relative contributions of auditory and visual input of conflicting sound sequences, or proficiency, to parallel language activation. Specifically, cross-linguistic phonotactic access using orthographic representations has not been demonstrated in previous research. Therefore, the current investigation aimed to provide support for parallel processing of L1 phonotactic constraints when bilinguals of varying L2 proficiency *read* L2 words.

https://doi.org/10.1017/S027226312100053X Published online by Cambridge University Press

THE PRESENT STUDY

The present study examined whether bilinguals of varying L2 proficiency activated L1 phonotactic constraints during L2 visual processing with different amounts of speech input. Across Experiments 1 and 2, participants viewed words on a display while eye movements were tracked. Using eye tracking enabled inferences about participants' behavior before the decision level was reached, and cross-linguistic activation of phonotactic constraints could be examined over time (time course).

The overarching prediction across both experiments was that if bilinguals accessed the L1 Spanish "e" phonotactic constraint during L2 English comprehension, then there would be more looks to an "e"-onset competitor than to fillers when an s+c target word was present. Furthermore, we predicted that the degree of L1 activation would be moderated by L2 proficiency and input modality. We examined how L2 proficiency influenced parallel activation in both Experiments 1 and 2, and investigated the role of input modality by manipulating whether the Spanish phonotactic violation was processed in the visual modality alone (Experiment 1) or audio-visually (Experiment 2). Across both experiments, the same participants read an L2 target word that conflicted with Spanish phonotactics (e.g., *spa*), an e-onset competitor (e.g., *egg*), and two fillers (e.g., *work* and *can*). The critical manipulation in Experiment 1 was that participants processed the L1 violation visually, as the visual target was identified by hearing only the word onset (e.g., "Click on /s/" for *spa*). In Experiment 2, the L1 violation was processed in both audio-visual modalities, as participants heard the entire target word presented as the auditory cue (e.g., "spa") while viewing it on the visual display.

EXPERIMENT 1: SOUND RECOGNITION AND ACTIVATION OF L1 PHONOTACTIC CONSTRAINTS IN BILINGUALS

Experiment 1's goal was to determine whether bilinguals of varying L2 proficiencies accessed the L1 constraint when viewing L2 words. Participants heard only the onset sound of the target (e.g., "Click on /s/") in a visual display of four items (e.g., target: *spa*, competitor: *egg*, two fillers: *work* and *can*). It was hypothesized that activation of the Spanish phonotactic constraint could occur independently of auditory input, as parallel activation does not always rely on hearing words (Chabal & Marian, 2015; Kaushanskaya & Marian, 2007; Thierry & Wu, 2007). Specifically, it was predicted that while bilinguals read words (orthography), phonological encoding would occur, which would activate phonological neighbors, translation equivalents, and phonotactic constraints of the irrelevant language in a bottom-up manner (Freeman et al., 2016). Therefore, orthography would indirectly provide access to phonological, and eventually phonotactic, representations. In addition, top-down processes, such as L1 phonotactic knowledge, would influence the phonological neighbors that are accessed (Best, 1994). We also examined the role of proficiency as previous studies have demonstrated differences in the extent and time course of parallel language access across bilinguals with lower and higher L2 proficiency (Blumenfeld & Marian, 2007, 2013; Mishra & Singh, 2016; Veivo et al., 2018). Because bilinguals in the current study were tested in 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 (e.g., Grainger et al., 2010; van Hell & Tanner, 2012). Monolinguals were not expected to demonstrate any differences in looks to the different words in the visual display because the stimuli were designed without any phonological overlap within English.

EXPERIMENT 1 METHODS

PARTICIPANTS

Participants were 28 English monolingual (8 males) and 33 Spanish–English bilingual (7 males) adults, with normal or corrected-to-normal vision, and no history of a neurological impairment. Bilinguals were native Spanish speakers. Monolinguals were excluded if they had a reported Spanish or another foreign language speaking proficiency of or greater than 3 (1–10 scale) on the Language Experience and Proficiency Questionnaire (LEAP-Q; Marian et al., 2007). See Table 1 for additional participant information.

MATERIALS

Stimulus pairings of interest for Experiment 1 included (a) s+c onset target (e.g., *spa*), (b) "e"-onset competitor (e.g., *egg*), and (c) two filler words (e.g., *work* and *can*), with a

TABLE 1. Linguistic and cognitive background of Spanish–English bilingual (n = 33) and English monolingual (n = 28) participants

	Bilinguals Mean (SE)	Monolinguals Mean (SE)	
	Range	*Range*	*P*-value
Age	23.09 (0.91)	22.10 (0.62)	0.39
	18–34	*18–30*	
Age of Spanish acquisition	0	–	
Age of English acquisition	6.21 (0.52)	0	<0.001
	5–10	–	
Current exposure to Spanish	31.90% (2.51)	–	
	10–69%	–	
Current exposure to English	66.88% (3.60)	99.57% (0.21)	<0.001
	40–88%	*95–100%*	
Self-reported Spanish proficiency (1–10 scale)	9.04 (0.11)	–	
	6.33–10%	–	
Self-reported English proficiency (1–10 scale)	8.88 (0.15)	9.67 (0.08)	<0.001
	6.77–10%	*8–10%*	
Spanish receptive vocabulary (TVIP) standard score	111.48 (1.73)	–	
	79–124	–	
English receptive vocabulary (PPVT) standard score	104.72 (3.47)	108.43 (2.38)	0.40
	91–125	*63–141*	
WASI matrix reasoning	27.51 (0.69)	29.17 (0.5)	0.06
	23–33	*25–32*	
WJ-III Backward digit span (numbers reversed)	9.78 (0.70)	10.57 (0.78)	0.46
	3–16	*3–18*	

TABLE 2. Lexical characteristics for target, competitor, and filler (control) items and Spanish translations (CLEARPOND: Marian et al., 2012). Means (Standard Deviations). All ps > 0.05.

	Target ($n = 24$)		Competitor ($n = 24$)		Filler ($n = 72$)	
	English	Spanish	English	Spanish	English	Spanish
Log Frequency	3.95	3.77	3.78	4.01	3.96	4.03
	(0.71)	(1.61)	(0.81)	(0.83)	(0.86)	(0.86)
Orthographic	2.08	1.33	1.83	2.79	2.58	2.30
Neighborhood	(2.15)	(1.43)	(1.86)	(3.39)	(2.40)	(2.29)
Length	6.21	7.58	6.25	7.58	6.11	6.90
	(1.18)	(1.61)	(1.70)	(2.54)	(1.72)	(2.71)

total of four words displayed in the visual world paradigm (see Appendix A for stimulus pairings of interest).[1] Other pairings included the s+c onset replaced with a filler (control) word, the "e" onset replaced with a filler, and both s+c and "e" onsets replaced with a filler. All words (s+c onset, "e" onset, and filler) and their Spanish translation equivalents were matched on lexical characteristics as shown in Table 2 (CLEARPOND; Marian et al., 2012). The stimuli were recorded in a soundproof room (44,100 Hz, 16 bits) by a male native speaker of English. The audio recording was split into individual audio files. All files were normalized (using audio compression) in Praat (Boersma & Weenink, 2013) and exported into MatLab.

Experiment 1 contained a total of 156 trials (12 practice, 144 experimental). The task consisted of 48 trials in which cross-linguistic phonotactic competitors were present (i.e., s+c *spa* and "e" onset *egg*) where 24 trials included the s+c onset word as the target and 24 trials with the "e" onset word as the target.[2] The task also included 96 additional trials where no phonotactic competition was present to obscure the purpose of the experiment. Task order was pseudorandomized so that no more than two consecutive trials contained s+c onsets. Trial order was counterbalanced across participants by reversing the order of presentation.

PROCEDURE

Participants were administered the following tasks in the order listed in Table 3.

After consent was obtained and the LEAP-Q was completed, participants were seated in a quiet room, 80 cm from the visual display, and the eye-tracker was calibrated. The sound recognition task was controlled by an iMac 3.3 GHz Intel Core i5 running MatLab 2011a (Brainard, 1997; Kleiner et al., 2007; Pelli, 1997), and stimuli were displayed on a 27-inch monitor with a screen resolution of 5120 × 2880. Eye movements were recorded using a desk-mounted eye-tracker (EyeLink 1000 Version 1.5.2, SR Research Ltd.) at a sampling rate of 1,000 Hz. Mouse clicks to identify the target served for collection of accuracy and reaction time data.

Participants were instructed to identify the visual target word by hearing its onset sound (e.g., "Click on /s/"). The four word stimuli were presented orthographically in four quadrants (top-left, bottom-left, top-right, bottom-right) in a 3 × 3 square grid (1,440 ×

https://doi.org/10.1017/S027226312100053X Published online by Cambridge University Press

TABLE 3. Order of tasks

Task	Purpose
LEAP-Q (Marian et al., 2007)	Linguistic background information, inclusionary criteria
Sound recognition task (Experiment 1)	L1 phonotactic constraint activation during L2 processing without auditory input
Word recognition task (Experiment 2)	L1 phonotactic constraint activation during L2 processing with auditory input (replication of Experiment 1)
Wechsler Abbreviated Scale of Intelligence (WASI; PsychCorp, 1999)	Nonverbal cognitive reasoning
Backward digit span task (numbers reversed, Woodcock et al., 2001, 2007)	Working memory
Peabody Picture Vocabulary Test-3 (PPVT-3) (Dunn & Dunn, 1997)	English vocabulary
Vocabulario en Imágenes Peabody (TVIP) (Dunn et al., 1997)	Spanish vocabulary (bilinguals only)

1,440 pixels), on a white screen in black font. After 1,000 ms of viewing the words, participants heard the carrier phrase, "Click on…" (830 ms duration), with the onset sound immediately following. Participants therefore processed the words on the visual display and then selected the target word that contained the auditory-onset sound they heard. During experimental trials of interest, an s+c target word was presented with an "e"-onset competitor, as well as two unrelated filler words. In the noncritical trials, the s+c and/or "e" onset words were replaced with fillers. Response times were measured at the start of the visual display, until the participant responded. See Figure 1 for task procedure.

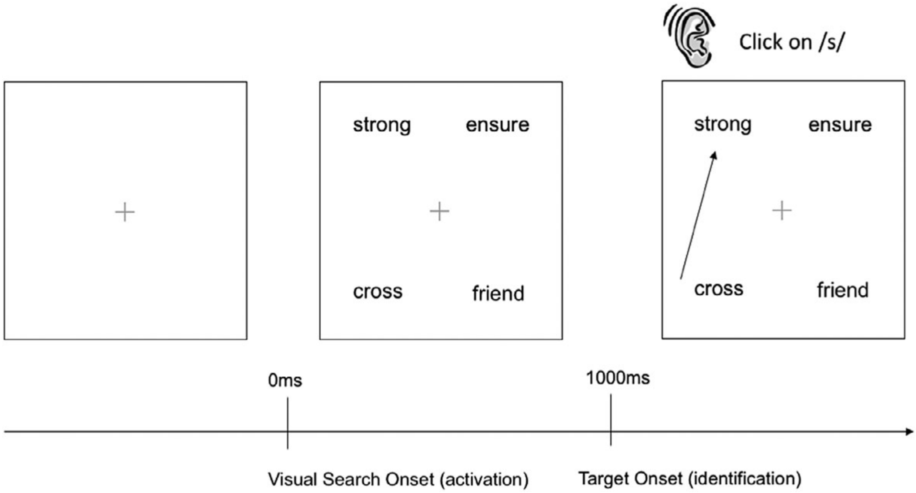

FIGURE 1. Example trial from the sound recognition task. Participants viewed four words on the screen while eye movements were tracked. The words included a target that conflicted with the Spanish "e" onset constraint (*strong*), a competitor that contained an "e" onset (*ensure*), and two filler words (*cross* and *friend*). Participants then heard, "Click on /s/," where /s/ was the onset of the target word (*strong*).

https://doi.org/10.1017/S027226312100053X Published online by Cambridge University Press

CODING AND ANALYSIS

Accuracy and Reaction Times

Accuracy and reaction times to identify the target word in the visual display were analyzed. Linear mixed-effects models (*lme4* package in R software) were employed to investigate potential group differences between monolinguals and bilinguals on trials of interest containing an s+c onset target and "e"-onset competitor. Incorrect trials and trials 2.5 standard deviations above and below the mean reaction time were not included in the analyses (approximately 1.5% of the data). Models contained the same structure for accuracy and reaction time (log transformed): fixed effect of language group, random intercept of language group, and a random slope of participants. The accuracy model failed to converge, suggesting participants' performance was at ceiling. In addition, no main effects or interactions were found in reaction times across monolinguals and bilinguals (ps > 0.1). Therefore, we focus on the time course of fixation proportion data.

Time Course of Fixations

For fixation proportions, the two between-subjects variables included language group (monolinguals and bilinguals) and L2 (English) proficiency as a continuous variable, analyzed separately. For L2 proficiency, a composite score comprising of objective (PPVT-3 standard score) and self-report measures (LEAP-Q averaged speaking, understanding, and reading proficiency ratings) was calculated for each participant. The two factors had high internal reliability (Cronbach's $\alpha = 0.72$). Z-scores were created for each factor and then added together for the composite score (Song et al., 2013). The composite score was entered into the bilingual model (see growth-curve analysis models in the following text) as a continuous variable to examine the extent to which L2 proficiency influenced fixation proportions. A median-split procedure was then applied within the bilingual group for graphical depiction of the fixation proportion data (see Appendix B for information on participants' linguistic and cognitive measures). The within-subjects independent variables were word type ("e"-onset competitor and unrelated filler words) and cognate status (s+c cognate and s+c noncognate). The dependent variable was fixation proportions.

Growth-curve analyses (GCA; Mirman et al., 2008) of fixation proportions were employed to examine the time course of phonotactic-constraint activation during visual word processing. Eye-fixations were counted when participants maintained a consistent gaze duration on one of the four quadrants in the visual display for greater than 70 ms; fixations below this time were not included. Fixation interest areas were built within each quadrant, measuring 350 × 350 pixels surrounding the center of each word. The time-course analyses included fixations that were collapsed into 25 ms bins and participants' average fixation to each word at the 25 ms bin was recorded.

Two separate models were constructed using GCAs: one with language group as a factor comparing monolinguals and bilinguals, the other with L2 proficiency within the bilingual group only. For both models, 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 1100 ms postsound onset. This calculation also factors in 830 ms for the carrier phrase (i.e., "Click on…") and 200 ms to account for the time required to plan and execute an eye movement (Viviani, 1990). The fixation proportion analyses included comparisons of looks to the “e” onset word (competitor) relative to the unrelated filler words in the visual display. The fixations to the two filler words were averaged together.

A base fourth-order orthogonal polynomial was implemented to capture the rise and fall of visual fixations to the visual competitor and the average of both filler words. Time courses included fixed effects of the polynomial time terms, word type (competitors and fillers), language group (monolinguals and bilinguals), cognate status (cognate and noncognate), along with interactions of word type-by-language group, word type-by-cognate status, language group-by-cognate status, and word type-by-language group-by-cognate status. The L2 proficiency model had the same structure, with L2 proficiency replacing language group on the fixed effects and interactions. Orthogonal polynomial time terms were treated as random slopes in the models. Random effects of participants, items, and polynomial time terms were also included. The best-fitting orthogonal polynomial time terms were determined by constructing models with linear, quadratic, cubic, and quartic time terms, and comparing them using chi-square model comparisons. The maximally converging model for language group contained random slopes of the linear, quadratic, cubic, and quartic orthogonal terms on the random-effects structure of participant and item, and random slopes of the four time terms on the interacting word type-by-language group-by-cognate structure ($\chi^2(9) = 194.90$, $p < 0.01$). The maximally converging model for L2 proficiency included the same random slopes of the linear, quadratic, cubic, and quartic terms, and random slopes of the four terms on the interacting word type-by-L2 proficiency-by-cognate structure ($\chi^2(9) = 176.29$, $p < 0.01$). In addition, previous research has demonstrated that cross-linguistic competition occurs early on within the first 600 ms posttarget onset (Blumenfeld & Marian, 2013; Shook & Marian, 2019). We thus used a narrower time window (300–600 ms postsound onset) for follow-up analyses to confirm initial results based on visual inspection of the data. The maximally converging models contained the same random slopes and four time terms for language group ($\chi^2(9) = 159.68$, $p < 0.01$) and word type-by-L2 proficiency-by-cognate status ($\chi^2(9) = 226.95$, $p < 0.01$). *P*-values from all GCA models were calculated assuming that the *t*-values converged to a normal distribution given the large number of observations present in time course data (Mirman, 2014).

EXPERIMENT 1 RESULTS

ACCURACY AND REACTION TIMES

Accuracy on trials of interest was at ceiling in both bilinguals ($M = 99.20\%$, $SE = 0.17$) and monolinguals ($M = 99.38\%$, $SE = 0.14$) and did not differ ($p > 0.1$). Reaction times for bilinguals ($M = 3284.79$ms, $SE = 25.71$) and monolinguals ($M = 3228.87$ms, $SE = 31.67$) were also similar ($p > 0.1$).

TIME COURSE ANALYSES: MONOLINGUALS AND BILINGUALS

See Appendix C for the results within a table. To uncover if bilinguals activated L1 phonotactics during L2 processing, fixation proportions were analyzed to the competitors (e.g., *egg*) relative to fillers (e.g., *work* and *can*) when a conflicting target (e.g., *spa*) was

https://doi.org/10.1017/S027226312100053X Published online by Cambridge University Press

present in the visual display. There was a main effect of language group on the intercept term (i.e., differences in average overall fixation proportions with monolinguals and bilinguals in the model curve), $\beta = 0.71$, $SE = 0.19$, $t = 3.72$, $p < 0.01$, with monolinguals producing a greater proportion of fixations than bilinguals during the initial 0–1,100 ms time window posttarget sound onset. No main effects or interactions of cognate status emerged ($ps > 0.1$).

Visual inspection of the time course data suggested that monolinguals produced more looks to competitors and fillers overall early on. To further uncover whether this trend held for monolinguals and bilinguals in a narrower time window when cross-linguistic effects are typically present (Blumenfeld & Marian, 2013; Shook & Marian, 2019), we selected 300–600 ms postsound onset. These follow-up analyses revealed no main effects or interactions within the narrower time window. Within the longer time window, monolinguals and bilinguals differed in their overall fixation proportions, but no phonotactic-constraint activation (greater proportion of fixations to competitors than fillers) was observed within the bilingual group. See Figure 2 for monolingual/bilingual differences in the time course of fixations to "e"-onset competitor words, relative to filler words.

TIME COURSE ANALYSES: L2 PROFICIENCY

Our next step was to assess the extent to which L2 (English) proficiency influenced bilinguals' L2 visual word recognition.[3] 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. There were no cognate status main effects or interactions ($ps > 0.1$).

Using the same procedure of a narrower time window across monolinguals and bilinguals, also consistent with the significant interactions on the quadratic and cubic terms, we followed up to confirm the result 300–600 ms postsound onset. There was a main effect of proficiency on the quadratic term, $\beta = 0.06$, $SE = 0.01$, $t = 5.42$, $p < 0.01$. There were significant interactions of word type by proficiency on the intercept, $\beta = 0.20$, $SE = 0.05$, $t = 3.75$, $p < 0.01$, and quadratic terms, $\beta = -0.14$, $SE = 0.06$, $t = -2.02$, $p =$ 0.04. No additional main effects or interactions emerged. The main effect and interactions suggest that decreased L2 proficiency resulted in more looks to competitors than fillers. See Figure 3 for differences among lower and higher proficiency bilinguals in the time course of fixations to "e"-onset competitor words, relative to filler words.[4]

EXPERIMENT 1 DISCUSSION

The goal of Experiment 1 was to examine whether bilinguals activated L1 phonotactic constraints during L2 processing with minimal auditory input of an L1-conflicting L2 word (i.e., "Click on /s/" for *spa*). Time course data suggest that monolinguals produced more fixations in the early time window (300–600 ms postsound onset); however, when collapsed across language groups, participants looked at "e"-onset competitor and filler

https://doi.org/10.1017/S027226312100053X Published online by Cambridge University Press

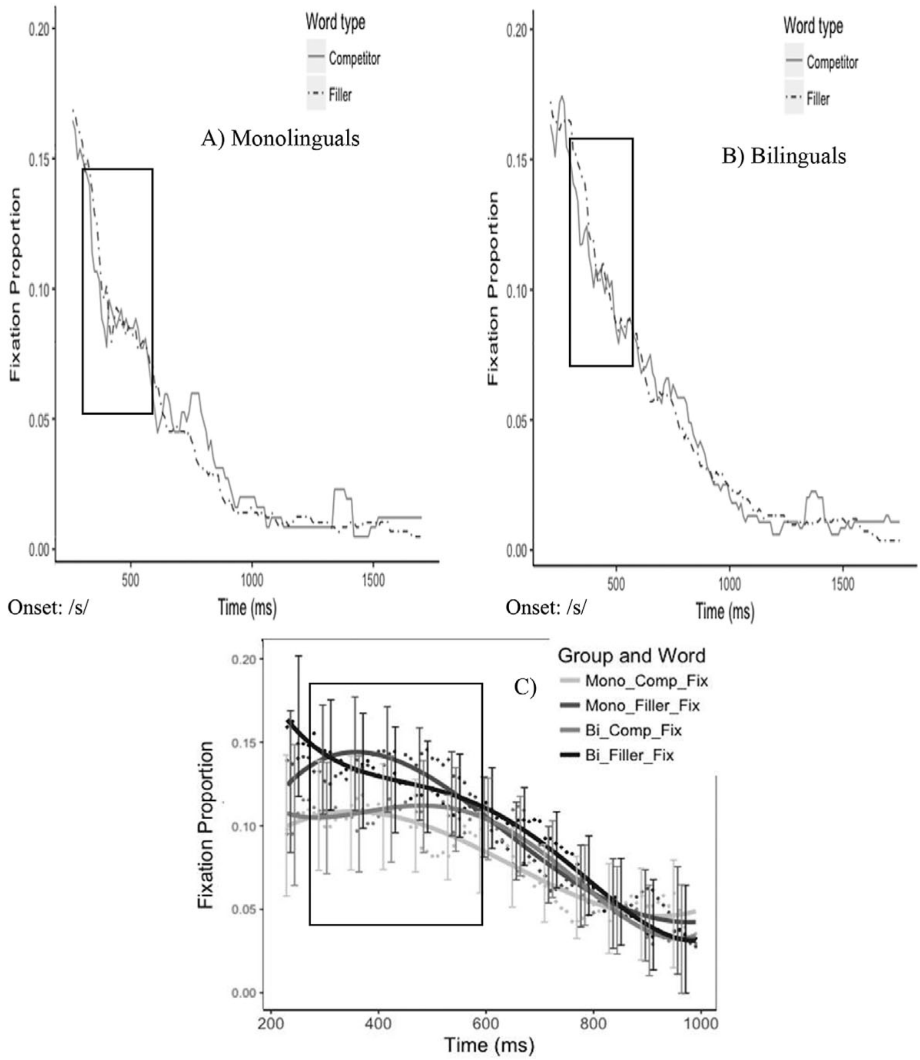

FIGURE 2. Time course analyses for (a) monolinguals and (b) bilinguals in Experiment 1. Y axis represents mean proportion of fixations to competitor (*egg*) versus filler words (*work* and *can*). X axis represents the time course starting at the onset sound of the target (*spa*). (C) Dots represent mean fixations and lines represent GCA model fits for fixation proportions (competitor to filler words) for monolinguals and bilinguals. Error bars represent 95% confidence interval of GCA model fits.

items equally. Bilinguals with lower L2 (English) proficiency fixated on the competitor more than the filler words, while bilinguals with higher L2 proficiency did not. These findings suggest that decreased L2 (English) proficiency resulted in activation of the L1 (Spanish) v+s+c phonotactic constraint when viewing L1-conflicting L2 s+c words and only hearing their onset sound (e.g., /s/). Therefore, bilinguals with lower L2 proficiency are more likely to be influenced by the L1 phonotactic constraint when reading L2

https://doi.org/10.1017/S027226312100053X Published online by Cambridge University Press

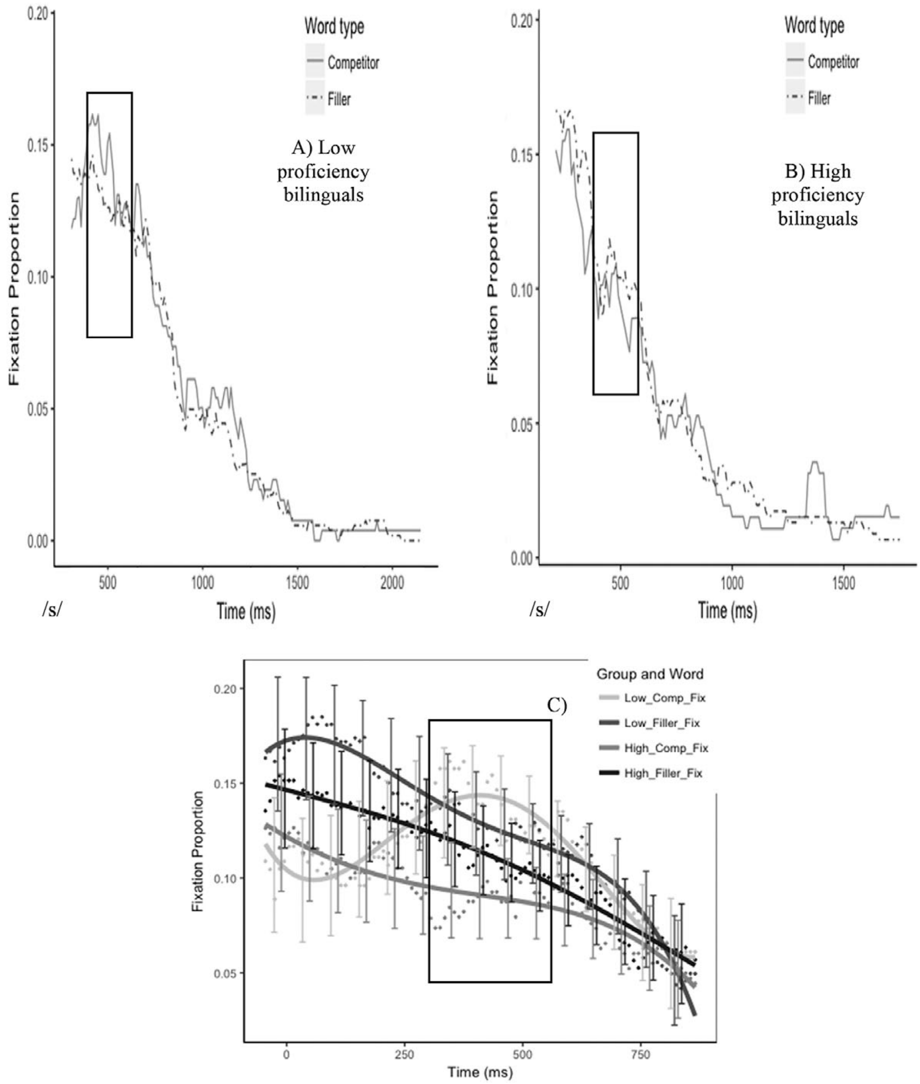

FIGURE 3. Time course analyses for (a) lower proficiency in English bilinguals and (b) higher proficiency in English bilinguals. Y axis represents mean proportion of fixations to competitor (*egg*) versus filler words (*work* and *can*). X axis represents the time course starting at the onset sound of the target (*spa*). (C) Dots represent mean fixations and lines represent GCA model fits for fixation proportions for competitor and filler words for lower and higher proficiency bilinguals. Error bars represent 95% confidence interval of GCA model fits.

words. At the same time, increased L2 proficiency yields more efficient processing of L1-conflicting L2 input, as evidenced by no differences in looks to competitors versus fillers in bilinguals with higher L2 proficiency, and as suggested by previous studies (e.g., Blumenfeld & Marian, 2013).

Experiment 1 demonstrated for the first time that bilinguals accessed the L1 phonotactic constraint upon reading a conflicting L2 word with minimal auditory/phonological input,

https://doi.org/10.1017/S027226312100053X Published online by Cambridge University Press

suggesting that orthography mediated access to phonotactic representations. The constraint-conflicting structure (e.g., s+c, *spa*) was not heard, just the onset of the word (e.g., /s/). In Experiment 2, we examined whether bilinguals would access the L1 constraint when viewing *and hearing* L2 words.

EXPERIMENT 2: WORD RECOGNITION AND ACTIVATION OF L1 PHONOTACTIC CONSTRAINTS IN BILINGUALS

The purpose of Experiment 2 was to identify if bilinguals of varying proficiencies accessed L1 constraints during L2 whole-word auditory and visual processing, similar to previous findings of language coactivation with audio-visual input (Blumenfeld & Marian, 2013; Giezen et al., 2015; Ju & Luce, 2004; Marian & Spivey, 2003a, 2003b; Shook & Marian, 2019). Experiment 2 was also designed to replicate the results from Experiment 1. As in Experiment 1, participants viewed four words on the screen while eye movements were tracked. Participants identified the target by hearing the word in its entirety (e.g., "spa"), as opposed to hearing the onset only (e.g., "Click on /s/") in Experiment 1. Importantly, new stimulus pairings were created to minimize cross-experimental effects. Activation of the L1 constraint during L2 processing was expected in bilinguals. However, given the findings from Experiment 1, it was also anticipated that proficiency would impact bilinguals' access of the L1 constraint during L2 processing.

Moreover, it was predicted that auditory input would be processed in a bottom-up way because within- and between-language phonological neighbors would be accessed (e.g., Shook & Marian, 2013), and eventually phonotactic constraints (Freeman et al., 2016). However, due to the auditory input of the whole word, the phonological representation of the L1-conflicting L2 word could be directly accessed instead of mediated through the orthographic representation, as in Experiment 1, which is the primary difference between Experiments 1 and 2. Top-down information, specifically the L1 (Spanish) phonotactic constraint, would also influence how the input was processed. Bilinguals might initially access knowledge of the L1 (Spanish) phonotactic constraint upon hearing the conflicting word (e.g., *spa*/*e̲spa*) (Best, 1994), demonstrating parallel language access. Activation may thus rely on a combination of bottom-up and top-down processes when whole-word auditory and visual input is present. If bilinguals accessed the L1 phonotactic constraint directly through the phonological representation of the conflicting s+c L2 word, then more looks were expected to the competitor than filler items.

EXPERIMENT 2 METHODS

PARTICIPANTS

Participants from Experiment 2 were the same from Experiment 1 (see Table 1).

MATERIALS

Experimental software, sampling rate, and audio recordings were the same as in Experiment 1. Stimuli for Experiment 2 were the same as in Experiment 1, but with new trial

https://doi.org/10.1017/S027226312100053X Published online by Cambridge University Press

pairings (see Appendix D for stimulus pairings of interest). See Experiment 1 Materials for stimulus lexical characteristics.

PROCEDURE

The word recognition task examined cross-linguistic activation between Spanish and English by tracking eye-movements to English "e" onset words (e.g., *egg*) when English s+c onset words (e.g., *spa*) were present. The eye tracker was recalibrated for Experiment 2. Instructions were to select the target by clicking on the word heard. As in Experiment 1, four words appeared on the screen, then a 1,000 ms delay occurred before the target word (e.g., *spa*) was played. The rest of the procedure was the same as Experiment 1, including practice and experimental trials, presentation of the visual display, and the collection of accuracy, reaction time, and eye fixation data. See Figure 4 for task procedure.

CODING AND ANALYSIS

For Experiment 2, the within- and between-subjects independent variables and dependent variables were the same as in Experiment 1. The same response time and accuracy analyses were performed as in Experiment 1. The accuracy model failed to converge and there were no main effects or interactions for reaction times ($ps > 0.1$). The procedure for constructing the GCA models from Experiment 1 was adapted to Experiment 2. For language group, the maximally converging model in the initial time window (0–1,100 ms, including 200 ms for fixation planning, and no carrier phrase) contained random slopes of the linear, quadratic, cubic, and quartic orthogonal time terms on the random-effects

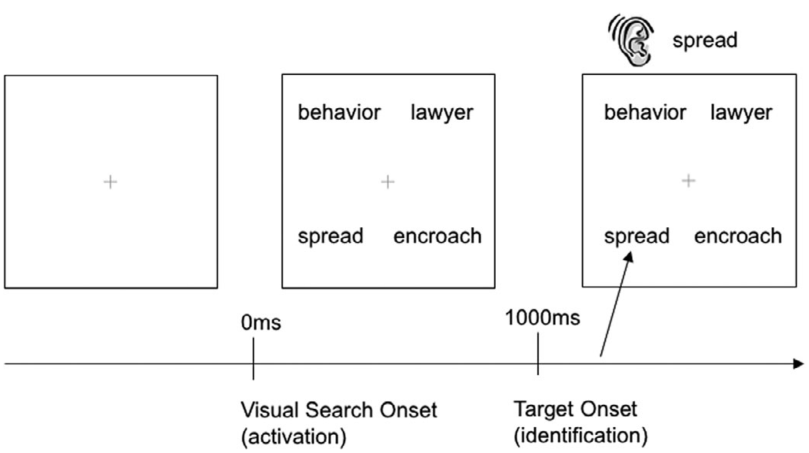

FIGURE 4. Example trial from the word recognition task. In this example, participants viewed four words on the screen while eye movements were tracked. The words included a target that conflicted with the Spanish "e" onset constraint (*spread*), a competitor that contained an "e" onset (*encroach*), and two filler words (*behavior* and *lawyer*). Participants then heard the target word (*spread*) and made their response.

https://doi.org/10.1017/S027226312100053X Published online by Cambridge University Press

structure of participant and item, and random slopes of the four time terms on the word type-by-language group-by-cognate status structure ($\chi^2(9) = 296.92$, $p < 0.01$). The maximally converging model for L2 proficiency included the same random slopes of time terms and the four terms on the word type-by-L2 proficiency-by-cognate status structure ($\chi^2(9) = 169.23$, $p < 0.01$). Within the narrower time window (300–600 ms postword onset), the maximally converging model included the same random slopes and four time terms for word type-by-L2 proficiency-by-cognate status ($\chi^2(9) = 199.23$, $p < 0.01$).

EXPERIMENT 2 RESULTS

ACCURACY AND REACTION TIMES

Bilingual ($M = 99.08\%$, $SE = 0.30$) and monolingual ($M = 100.00\%$, $SE = 0$) participants' accuracy was at ceiling ($p > 0.1$). Bilinguals' mean reaction time[5] was 2298.92ms ($SE = 0.27$) and monolinguals' was 2243.77ms ($SE = 0.27$), $p > 0.1$.

TIME COURSE ANALYSES: MONOLINGUALS AND BILINGUALS

See Appendix E for the results within a table. The language group model revealed no main effects or interactions, (ps > 0.1). Monolinguals and bilinguals produced similar looking patterns throughout the 0–1,100 ms time window to competitors and filler items. See Figure 5 for the time course of fixations to "e"-onset competitor words relative to filler words.

TIME COURSE ANALYSES: L2 PROFICIENCY

Within the bilingual group,[6] GCAs revealed a main effect of L2 proficiency on the intercept term, $\beta = 0.60$, $SE = 0.21$, $t = 2.80$, $p < 0.01$. There were also significant interactions of word type by proficiency on the intercept, $\beta = 0.34$, $SE = 0.01$, $t = -7.98$, $p < 0.01$, and quadratic terms, $\beta = -0.33$, $SE = 0.04$ $t = -8.00$, $p < 0.01$, indicating that bilinguals with lower L2 proficiency produced a greater proportion of fixations to the competitors than filler words than did the higher L2 proficiency bilinguals. There were no main effects or interactions for cognate status ($ps > 0.1$).

We followed up on the main effect and interactions within the shorter, 300–600 ms postword onset, time window. There was a main effect of proficiency on the intercept term, $\beta = 0.09$, $SE = 0.04$, $t = 2.26$, $p = 0.04$. The model also revealed interactions of word type by proficiency on the intercept term, $\beta = -0.17$, $SE = 0.06$, $t = -2.71$, $p < 0.01$. No additional main effects or interactions emerged. The findings within the narrower time window confirm the significant effects observed for lower L2 proficiency bilinguals, with more looks to competitors than fillers. See Figure 6 for monolingual/bilingual differences in the time course of fixations to "e"-onset competitor words, relative to filler words.[7]

Time course results indicated no overall differences between monolinguals and bilinguals in looks to fillers versus competitors. However, and as in Experiment 1, bilinguals with lower L2 proficiency made more looks to competitor versus filler words, relative to bilinguals with higher L2 proficiency.

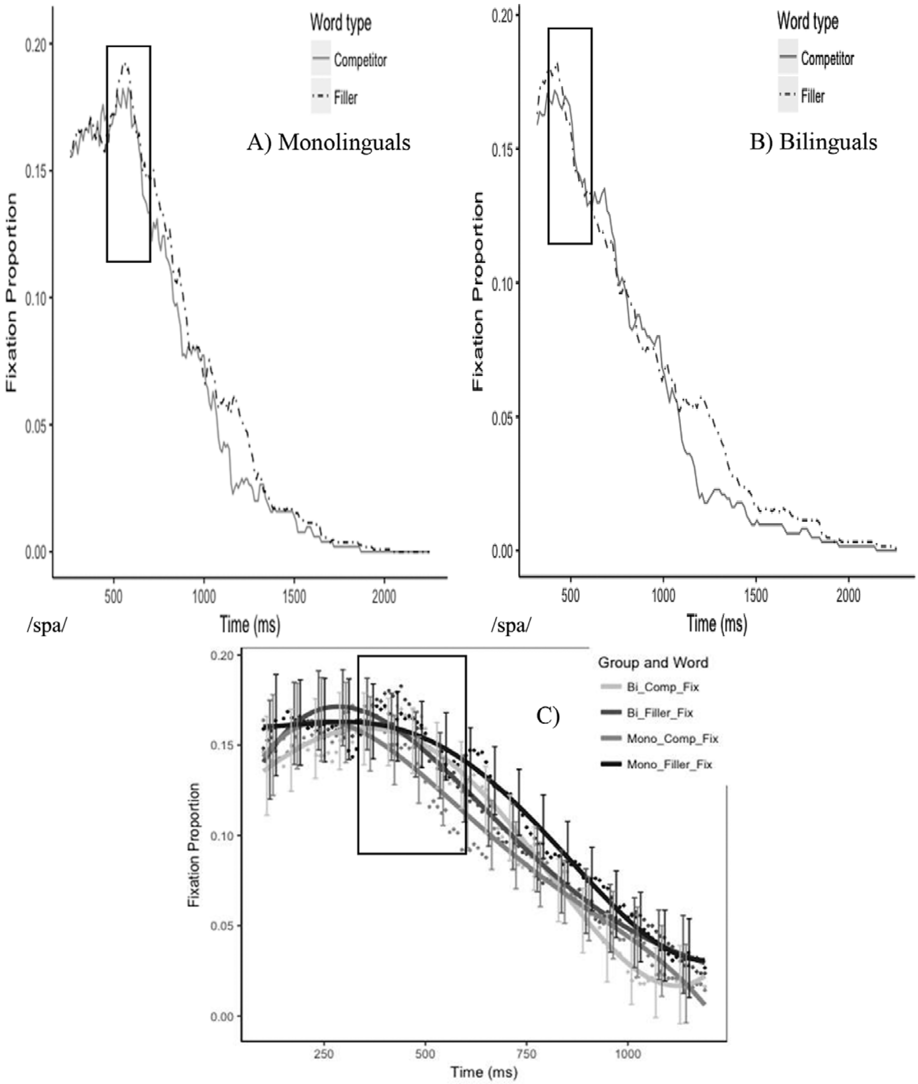

FIGURE 5. Time course analyses for (a) monolinguals and (b) bilinguals. Y axis represents mean proportion of fixations to competitor (*egg*) versus filler words (*work* and *can*). X axis represents the time course starting at the onset of the target (*spa*). (C) Dots represent mean fixations and lines represent GCA model fits for fixation proportions to competitor and filler words for monolinguals and bilinguals. Error bars represent 95% confidence interval of GCA model fits.

EXPERIMENT 2 DISCUSSION

The focus of Experiment 2 was twofold: (a) to examine the extent to which audio-visual input and L2 proficiency influenced language coactivation of the L1 Spanish phonotactic constraint during L2 English comprehension and (b) to replicate the findings from Experiment 1. Results suggest that decreased L2 (English) proficiency resulted in an

https://doi.org/10.1017/S027226312100053X Published online by Cambridge University Press

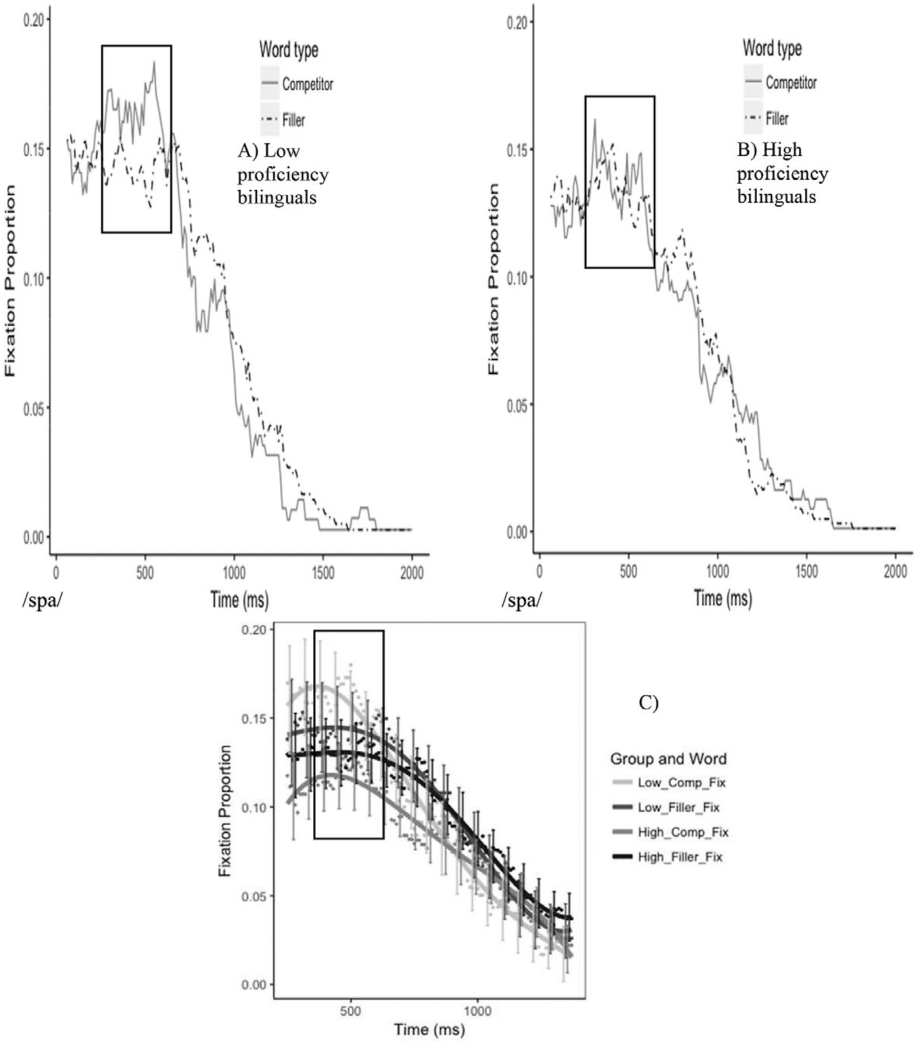

FIGURE 6. Time course analyses for bilinguals with (a) lower proficiency and (b) higher proficiency in English. Y axis represents mean proportion of fixations to competitor (*egg*) versus filler words (*work* and *can*). X axis represents the time course starting at the onset of the target (*spa*). (C) Dots represent mean fixations and lines represent GCA model fits for fixation proportions to competitor and filler words for lower proficiency and higher proficiency bilinguals. Error bars represent 95% confidence interval of GCA model fits.

increase in looks to competitors, relative to fillers, early on (300–600 ms postword onset) during the time course. Bilinguals with lower L2 English proficiency activated the L1 Spanish phonotactic constraint when viewing *and hearing* L1-conflicting L2 words, highlighting interference from the L1 during L2 processing (Grainger et al., 2010; van Hell & Tanner, 2012). The findings from Experiment 2 are in line with previous studies that suggest L1 phonotactic constraints are activated during L2 visual and spoken word

https://doi.org/10.1017/S027226312100053X Published online by Cambridge University Press

comprehension (Freeman et al., 2016, 2021; Lentz & Kager, 2015; Parlato-Oliveira et al., 2010; Weber & Cutler, 2006) and replicate the results from Experiment 1.

GENERAL DISCUSSION

The goal of the current investigation was to identify the extent to which bilinguals of different L2 proficiency levels activated L1 phonotactic constraints (i.e., rules for combining speech sounds) during visual word processing. Results across both experiments demonstrated that bilinguals with decreased L2 proficiency produced more looks to the "e"-onset competitor (e.g., *egg*) than to filler words (e.g., *work* and *can*). Experiment 1 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*). Experiment 2 replicated those results and also showed cross-linguistic effects in the auditory *and* visual modalities. Combined, the results from Experiments 1 and 2 suggest that visual orthographic input is sufficient to access phonotactic constraints across languages.

Interestingly, there were no performance differences between bilinguals and monolinguals to suggest that bilinguals overall as a group were experiencing L1 interference during L2 processing. However, when examining the role of L2 proficiency within the bilingual group, bilinguals with lower L2 proficiency accessed the L1, while bilinguals with higher L2 proficiency did not. Additional analyses revealed that there were no differences in time courses across language groups or L2 proficiency preinitial phoneme (Experiment 1) or preword onset (Experiment 2). This suggests that lower L2 proficiency bilinguals' attention needed to be drawn to the target word to engender cross-linguistic interference from the phonotactic constraint. While we initially expected that bilinguals might produce more fixations to competitors than fillers, we also predicted that L2 proficiency could modulate fixation patterns indicative of activation of L1 phonotactic constraints. Because we controlled for item and participant variability in all GCA models, it was unlikely that the stimuli or participant sample caused an absence of an overall group difference in looking patterns between monolinguals and bilinguals.

LANGUAGE COACTIVATION AND PROFICIENCY

Across Experiments 1 and 2, we found evidence that bilinguals activated both languages simultaneously when in a single-language context. These results contribute to the body of work investigating between-language phonological processing in bilinguals of varying proficiencies (e.g., Blumenfeld & Marian, 2007, 2013; Ju & Luce, 2004; Linck et al., 2008; Mercier et al., 2014) and confirms findings that bilinguals experience cross-linguistic activation at the lexical (Finkbeiner et al., 2004; Fitzpatrick & Indefrey, 2010; Hartsuiker et al., 2004; Ju & Luce, 2004; Kaushanskaya & Marian, 2007; Loebell & Bock, 2003; Marian & Spivey, 2003a, 2003b; Martín et al., 2010; Schoonbaert et al., 2009; Sunderman & Kroll, 2006; Thierry & Wu, 2007) and sublexical levels (Freeman et al., 2016, 2021; Lentz & Kager, 2015; Weber & Cutler, 2006). For example, in Blumenfeld and Marian (2013), participants were tested in their *L1* and experienced greater L2 activation as L2 proficiency increased. In the current study, bilinguals were tested in an *L2* environment, and those with lower L2 proficiency experienced increased

https://doi.org/10.1017/S027226312100053X Published online by Cambridge University Press

L1 phonotactic interference (also see Grainger et al., 2010; van Hell & Tanner, 2012 for review). These results suggest that bilinguals with higher L2 proficiency may resolve cross-language competition at an earlier stage than bilinguals with lower L2 proficiency during L2 auditory and/or visual word recognition. Therefore, bilinguals with higher proficiency levels may process language input with greater automaticity and are able to inhibit activation of the nontarget language more efficiently (Blumenfeld & Marian, 2013; Mercier et al., 2014; Mishra & Singh, 2016; van Hell & Tanner, 2012; Veivo et al., 2018).

THE ROLES OF AUDITORY INPUT AND METALINGUISTIC DEMANDS IN LANGUAGE COACTIVATION

In addition to L2 proficiency, target stimulus presentation (auditory vs. visual) and task difficulty (metalinguistic demands) may have influenced participants' performance in the current study. Experiment 2's results bolster previous research on cross-linguistic access through the combination of auditory (phonological) *and* visual (orthographic) stimulus presentation (Mishra & Singh, 2016; Veivo et al., 2018). However, the findings from Experiment 1, along with others (Chabal & Marian, 2015; Kaushanskaya & Marian, 2007; Thierry & Wu, 2007), suggest that bilinguals activate their languages in parallel when viewing words (orthography) and/or pictures *with no to minimal auditory input.*

In one such study, Chabal and Marian (2015) investigated English monolinguals' and Spanish–English bilinguals' eye movements to pictures containing target and competitor items overlapping in phonology within or between languages. Critically, a target picture was visually presented in the center of the screen (no auditory input) and participants matched the target amongst four pictures. For example, when the target item was *clock*, English monolinguals and Spanish–English bilinguals also looked at a picture of *cloud.* However, even though the experiment was conducted in an L2 "English" mode (i.e., participants were instructed in English and tested in an English environment), bilinguals additionally looked at *gift* (Spanish: "regalo") because it phonologically overlapped with the Spanish translation of *clock* ("reloj"). This finding highlights cross-language interactivity with no auditory input. In addition, Kaushanskaya and Marian (2007), along with Thierry and Wu (2007), found cross-linguistic activation with only orthographic input in bilinguals. In line with these studies, findings from Experiment 1 demonstrated for the first time that bilinguals with lower levels of L2 proficiency activated the L1 "e"-onset constraint during L2 processing without whole-word auditory input.

In addition to input modality, metalinguistic demands of a task may also influence the extent to which parallel language activation occurs in bilinguals. Previous studies demonstrate that as a task's metalinguistic demands increase, so do effects of parallel processing in bilinguals, especially at the sublexical level (Freeman et al., 2021; Parlato-Oliveira et al., 2010). In the current investigation, participants simply identified a word in a visual display after hearing its onset sound or the word in its entirety. Therefore, the metalinguistic demands were lower compared to a lexical decision task in which participants search the lexicon for an entry, or a vowel detection task in which they attend to aspects of the stimulus (e.g., onset or rime, consonant or vowel) to detect if a vowel is present (e.g., Freeman et al., 2021). The sound and word recognition tasks might not have been sensitive enough to capture differences across monolinguals and bilinguals due to

https://doi.org/10.1017/S027226312100053X Published online by Cambridge University Press

their relative facility. However, despite low metalinguistic demands, bilinguals with lower L2 proficiency were still susceptible to L1 interference during L2 comprehension, highlighting the potential relation between proficiency and metalinguistic demands. A task with increased metalinguistic demands might result in bilinguals with higher L2 proficiency demonstrating effects of language coactivation with phonotactic constraints.

THEORETICAL IMPLICATIONS FOR LANGUAGE ACTIVATION

The results of Experiments 1 and 2 have implications for bilingual language processing models. Current findings directly support and potentially extend BLINCS (Shook & Marian, 2013) to include phonotactic constraints. Moreover, empirical and theoretical evidence suggests that linguistic input is processed in a bottom-up way and supports activation of within-language (monolinguals and bilinguals) and between-language (bilinguals only) neighbors (e.g., Marian & Spivey, 2003a, 2003b; Shook & Marian, 2013). Constraints may influence which words are accessed in the bilingual lexicon in a top-down manner, in line with PAM (Best, 1994). Across Experiments 1 and 2, bilinguals with lower L2 proficiency relied on an interplay between bottom-up and top-down mechanisms during visual and spoken word comprehension. Bottom-up processing began with visual or auditory input, which then activated phonological representations, lexical items, and constraints. Top-down processing also occurred, starting with knowledge of the L1 constraint, flowing down to phono-ortho representations.

Though similar trajectories of activation were expected, the key difference across studies was that the phonological representations were accessed indirectly (Experiment 1) or directly (Experiment 2). In contrast to Experiment 2, which provided whole-word auditory input, access to phonotactic constraints in Experiment 1 was mediated by orthographic representations. The combination of the two experiments therefore sheds light on the individual contributions of auditory (phonological) versus visual (orthographic) input during bilingual comprehension. We find that orthography alone is sufficient to access cross-linguistic phonological structures (also see Kaushanskaya & Marian, 2007; Thierry & Wu, 2007), and subsequently, to activate phonotactic (constraint-based) representations.

LIMITATIONS AND FUTURE DIRECTIONS

A potential limitation of Experiments 1 and 2 is the assumption that bilinguals are not accessing stored representations for sound sequences. For example, when visually presented with an English word that conflicts with the Spanish v+s+c rule (e.g., *spa*), it is unclear whether the L1 Spanish speaker's orthographic and phonological representation of English *spa* is *spa* or *espa*, which would then account for eye movements to phonologically/orthographically overlapping targets like *egg*. Hallé et al. (2008) showed Spanish monolinguals Spanish-like s+c nonwords (orthography), which conflicted with the Spanish v+s+c rule. Monolinguals appeared to perceptually or phototactically repair the visual input to conform to the v+s+c rule by reporting a vowel was present. However, an alternative explanation for this pattern of results is that orthographic input permitted access to phonological representations, and then eventually activated the Spanish phonotactic constraint.

Our research sets the stage for future work examining more carefully the bottom-up and top-down mechanisms that come online as bilinguals process auditory input. Understanding how these mechanisms interact depending on the nature of the task is essential, for example, based on type of linguistic interference created (e.g., semantic vs. phonological/orthographic) or the metalinguistic demands. Perhaps in a more explicit and metalinguistically challenging task combined with word recognition, such as asking whether a vowel is present at the target word's onset (vowel detection: Carlson et al., 2016; Freeman et al., 2021), bilinguals of varying proficiency levels would demonstrate enhanced access to L1 sublexical structures during L2 processing.

Future research should also further examine the role of cognates on L1 phonotactic access. In this investigation, we observed no effect of cognate status across monolinguals and bilinguals, as well as bilinguals with lower and higher L2 proficiency. We speculate that the absence of a significant cognate effect on eye gaze patterns, especially amongst the lower L2 proficiency bilinguals, could be due to the limited number of cognate and noncognate stimuli in the experiment (12 of each type; 24 total). In addition, we included the same stimulus set in a previous investigation (see Freeman et al., 2021) and did not observe any cognate effects across three tasks investigating L1 phonotactic-constraint access during L2 processing. Including more cognate and noncognate s+c stimuli in future investigations would yield more power to examine this critical manipulation.

The results of the current study suggest that bilinguals activate sublexical phonotactic constraints across both languages when reading words with minimal auditory cues. Language proficiency and task demands modulated the extent to which L1 influenced L2 processing at the sublexical level. We conclude that the interactivity between a bilingual's two languages is not limited to words that share form across languages, but also extends to sublexical, rule-based structures and thus permeates the language system throughout.

NOTES

[1]Half the s+c stimuli were cognates, while the other half were noncognates. No significant effects of cognate status on fixation proportions to competitors versus fillers were observed.

[2]In our analyses, the condition in which the s+c onset word was the competitor and "e"-onset word was the target did not result in any patterns suggestive of cross-linguistic activation (greater fixation proportions to competitors than fillers) across language groups and by L2 proficiency, $ps > 0.1$. This control condition served to distract participants from thinking that the s+c onset word was the target every time they saw it and to verify that the auditory input of the s+c onset or s+c word drove the observed effects in Experiments 1 and 2.

[3]There were no bilingual differences in proportions of fixations to competitor versus filler words by language dominance and age of acquisition. An additional model was created to ensure that lower L2 proficiency bilinguals and monolinguals demonstrated different fixation proportions to competitors than fillers. Using the median-split procedure outlined in the "Coding and Analysis" section, lower L2 proficiency bilinguals fixated more on competitors than fillers than monolinguals did ($ps < 0.05$). We therefore decided to keep proficiency as a continuous variable in all models.

[4]Follow-up GCA models for language group and proficiency time-course data were constructed to examine whether there were any competitor versus filler effects in the absence of the Spanish-conflicting target (e.g., *spa*), which was replaced by a nonconflicting control/filler word (target-absent condition: e.g., *demand*). For bilinguals and monolinguals, there were no main effects of language group on any of the time terms, $ps >$ 0.2, and fixation patterns did not diverge from the target-present condition. Within the bilingual group, the main

https://doi.org/10.1017/S027226312100053X Published online by Cambridge University Press

effects of proficiency on the time terms disappeared in the target-absent condition, *p*s > 0.1, suggesting that in the target-present condition, greater fixation proportions to competitors (e.g., *egg*) versus fillers (e.g., *work/can*) occurred because of the presence of a Spanish-conflicting target.

[5]Reaction times were overall shorter for Experiment 2 than Experiment 1 because in Experiment 1, there was a carrier phrase ("click on") that preceded the onset sound (e.g., /s/) indicating the target in the visual display. Reaction times were measured from the onset of the visual display.

[6]There were no effects of age of acquisition or language dominance (*p*s > 0.05). Similar to Experiment 1, lower L2 proficiency bilinguals made more fixations to the competitors versus fillers than monolinguals (*p*s < 0.05).

[7]Follow-up GCA models completed for the target-absent condition. Between monolinguals and bilinguals, there were no effects on any of the time terms, *p*s > 0.1, and fixation patterns did not differ from the target-present condition. Within the bilingual group, the main effects of proficiency on the time terms once again disappeared in the target-absent condition, *p*s > 0.1.

REFERENCES

Best, C. T. (1994). The emergence of native-language phonological influences in infants: A perceptual assimilation model. *The Development of Speech Perception: The Transition From Speech Sounds to Spoken Words*, *167*, 233–277.

Blumenfeld, H. K., & Marian, V. (2007). Constraints on parallel activation in bilingual spoken language processing: Examining proficiency and lexical status using eye-tracking. *Language and Cognitive Processes*, *2*, 633–660. https://doi.org/10.1080/01690960601000746

Blumenfeld, H. K., & Marian, V. (2013) Parallel language activation and cognitive control during spoken word recognition in bilinguals. *Journal of Cognitive Psychology*, *25*, 547–567.

Boersma, P., & Weenink, D. (2013). Praat: doing phonetics by computer [Computer program]. Version 5.3.47. http://www.praat.org/

Brainard, D. H. (1997). The Psychophysics Toolbox. *Spatial Vision*, *10*, 433–436.

Carlson, M. T. (2018). Making room for second language phonotactics: Effects of L2 learning and environment on first language speech perception. *Language and Speech*, *61*, 598–614. https://doi.org/10.1177/0023830918767208.

Carlson, M. T., Goldrick, M., Blasingame, M., & Fink, A. (2016). Navigating conflicting phonotactic constraints in bilingual speech perception. *Bilingualism: Language and Cognition*, *19*, 939–954. https://doi.org10.1017/S1366728915000334.

Chabal, S., & Marian, V. (2015). Speakers of different languages process the visual world differently. *Journal of Experimental Psychology: General*, *144*, 539.

Dunn, L. M., & Dunn, L. M. (1997). *PPVT-III: Peabody picture vocabulary test*. American Guidance Service.

Dunn, L. M., Lugo, P., & Dunn, L. M. (1997). *Vocabulario en imágenes Peabody (TVIP)*. American Guidance Service.

Dupoux, E., Sebastián-Gallés, N., Navarrete, E., & Peperkamp, S. (2008). Persistent stress "deafness": The case of French learners of Spanish. *Cognition*, *106*, 682–706.

Finkbeiner, M., Forster, K., Nicol, J., & Nakamura, K. (2004). The role of polysemy in masked semantic and translation priming. *Journal of Memory and Language*, *51*, 1–22.

Fitzpatrick, I., & Indefrey, P. (2010). Lexical competition in nonnative speech comprehension. *Journal of Cognitive Neuroscience*, *22*, 1165–1178.

Freeman, M. R., Blumenfeld, H. K., & Marian, V. (2016). Phonotactic constraints are activated across languages in bilinguals. *Frontiers in Psychology*, *7*, 702. https://doi.org/10.3389/fpsyg.2016.00702.

Freeman, M. R., Blumenfeld, H. K., & Marian, V. (2021). First-language influence on second language speech perception depends on task demands. *Journal of Language and Speech.* Advance online publication. https://doi.org/10.1177/0023830920983368.

Giezen, M. R., Blumenfeld, H. K., Shook, A., Marian, V., & Emmorey, K. (2015). Parallel language activation and inhibitory control in bimodal bilinguals. *Cognition*, *141*, 9–25.

Grainger, J., Midgley, K., & Holcomb, P. J. (2010). Re-thinking the bilingual interactive activation model from a developmental perspective (BIA-d). In M. Kail & M. Hickmann (Eds.), *Language acquisition across linguistic and cognitive systems* (pp. 267–284). John Benjamins.
Hallé, P. A., Dominguez, A., Cuetos, F., & Segui, J. (2008). Phonological mediation in visual masked priming: Evidence from phonotactic repair. *Journal of Experimental Psychology: Human Perception and Performance*, *34*, 177–192.
Hartsuiker, R. J., Pickering, M. J., & Veltkamp, E. (2004). Is syntax separate or shared between languages? Cross-linguistic syntactic priming in Spanish-English bilinguals. *Psychological Science*, *15*, 409–414.
Ju, M., & Luce, P. A. (2004). Falling on sensitive ears. *Psychological Science*, *15*, 314–318.
Kaushanskaya, M., & Marian, V. (2007). Non-target language recognition and interference: Evidence from eye-tracking and picture naming. *Language Learning*, *57*, 119–163.
Kleiner M., Brainard D., and Pelli D. (2007). What's new in Psychtoolbox-3? Perception 36 ECVP Abstract Supplement.
Kroll, J. F., Bobb, S. C., Misra, M., & Guo, T. (2008). Language selection in bilingual speech: Evidence for inhibitory processes. *Acta Psychologica*, *128*, 416–430. https://doi.org/10.1016/j.actpsy.2008.02.001
Lentz, T. O., & Kager, R. W. (2015). Categorical phonotactic knowledge filters second language input, but probabilistic phonotactic knowledge can still be acquired. *Language and Speech*, *58*, 387–413.
Linck, J. A., Hoshino, N., & Kroll, J. F. (2008). Cross-language lexical processes and inhibitory control. *Mental Lexicon*, *3*, 349–374. https://doi.org/10.1075/ml.3.3.06lin
Loebell, H., & Bock, K. (2003). Structural priming across languages. *Linguistics*, *41*, 791–824.
Marian, V., Bartolotti, J., Chabal, S., and Shook, A. (2012). CLEARPOND: Cross-Linguistic Easy Access Resource for Phonological and Orthographic Neighborhood Densities. *PLoS ONE*, *7*, e43230. https://doi.org/10.1371/journal.pone.0043230
Marian, V., Blumenfeld, H. K., Kaushanskaya, M. (2007). The Language Experience and Proficiency Questionnaire (LEAP-Q): Assessing language profiles in bilinguals and multilinguals. *Journal of Speech Language and Hearing Research*, *50*, 940–967.
Marian V, & Spivey M. (2003a). Bilingual and monolingual processing of competing lexical items. *Applied Psycholinguistics*, *24*, 173–193.
Marian V, & Spivey M. (2003b). Competing activation in bilingual language processing: Within-and between-language competition. *Bilingualism: Language and Cognition*, *6*, 97–115.
Martín, M. C., Macizo, P., & Bajo, T. (2010). Time course of inhibitory processes in bilingual language processing. *British Journal of Psychology*, *101*, 679–693. https://doi.org/10.1348/000712609X480571
Mercier, J., Pivneva, I., & Titone, D. (2014). Individual differences in inhibitory control relate to bilingual spoken word processing. *Bilingualism: Language and Cognition*, *17*, 89–117.
Mirman, D. (2014). *Growth curve analysis and visualization using R*. CRC Press.
Mirman, D., Dixon, J. A., & Magnuson, J. S. (2008). Statistical and computational models of the visual world paradigm: Growth curves and individual differences. *Journal of Memory and Language*, *59*, 475–494.
Mishra, R. K., & Singh, N. (2016). The influence of second language proficiency on bilingual parallel language activation in Hindi–English bilinguals. *Journal of Cognitive Psychology*, *28*, 396–411.
Paradis, M. (2004). *A neurolinguistic theory of bilingualism* (Vol. *18*). John Benjamins Publishing.
Parlato-Oliveira, E., Christophe, A., Hirose, Y., & Dupoux, E. (2010). Plasticity of illusory vowel perception in Brazilian-Japanese bilinguals. *The Journal of the Acoustical Society of America*, *127*, 3738–3748. http://doi.org/10.1121/1.3327792
Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision*, *10*, 437–442.
PsychCorp. (1999). *Wechsler Abbreviated Scale of Intelligence (WASI)*. Harcourt Assessment.
Schoonbaert, S., Duyck, W., Brysbaert, M., & Hartsuiker, R. J. (2009). Semantic and translation priming from a first language to a second and back: Making sense of the findings. *Memory and Cognition*, *37*, 569–586.
Shook, A., & Marian, V. (2013). The bilingual language interaction network for comprehension of speech. *Bilingualism: Language and Cognition*, *16*, 304–324.
Shook, A., & Marian, V. (2019). Covert co-activation of bilinguals' non-target language: Phonological competition from translations. *Linguistic Approaches to Bilingualism*, *9*, 228–252.

Song, M. K., Lin, F. C., Ward, S. E., & Fine, J. P. (2013). Composite variables: When and how. *Nursing Research*, *62*, 45–49. https://doi.org/10.1097/NNR.0b013e3182741948

Sunderman, G., & Kroll, J. F. (2006). First language activation during second language lexical processing: An investigation of lexical form, meaning, and grammatical class. *Studies in Second Language Acquisition*, *28*, 387–422.

Thierry, G., & Wu, Y. J. (2007). Brain potentials reveal unconscious translation during foreign language comprehension. *Proceedings of the National Academy of Sciences*, *104*, 12530–12535.

van Hell, J. G., & Tanner, D. (2012). Second language proficiency and cross-language lexical activation. *Language Learning*, *62*, 148–171.

Veivo, O., Porretta, V., Hyönä, J., & Järvikivi, J. (2018). Spoken second language words activate native language orthographic information in late second language learners. *Applied Psycholinguistics*, *39*, 1011–1032.

Viviani, P. (1990). Eye movements in visual search: Cognitive, perceptual and motor control aspects. *Reviews of Oculomotor Research*, *4*, 353.

Weber, A., & Cutler, A. (2004). Lexical competition in non-native spoken-word recognition. *Journal of Memory and Language*, *50*, 1–25.

Weber, A., & Cutler, A. (2006). First-language phonotactics in second-language listening. *The Journal of the Acoustical Society of America*, *119*, 597–607.

Woodcock, R. W., McGrew, K. S., and Mather, N. (2001). *Woodcock Johnson III Tests of Cognitive Abilities*. Riverside Publishing.

Woodcock, R. W., McGrew, K. S., and Mather, N. (2007). *Woodcock Johnson III Tests of Cognitive Abilities*. Riverside Publishing.

APPENDIX A

Target, competitor, and control/filler stimuli (Spanish translations) for the s+c target, "e"-onset competitor condition in Experiment 1.

Target	Competitor	Filler 1	Filler 2
spiral	ember	acorn	lazy
(*espiral*)	(*brasa*)	(*bellota*)	(*perezoso*)
stable	encroach	afford	leisure
(*estable*)	(*invadir*)	(*permitirse*)	(ocio)
starch	engine	aisle	outfit
(*almidón*)	(*motor*)	(*pasillo*)	(*traje*)
spider	elevator	alley	nickname
(*araña*)	(*ascensor*)	(*callejón*)	(*apodo*)
spread	enact	annoy	onward
(*difundir*)	(*promulgar*)	(*molestar*)	(*adelante*)
special	elbow	apology	owner
(*especial*)	(*codo*)	(*disculpa*)	(*dueño*)
spirit	enable	argue	flavor
(*espíritu*)	(*permitir*)	(*discutir*)	(*sabor*)
speaker	effort	arise	hammer
(*altavoz*)	(*esfuerzo*)	(*surgir*)	(*martillo*)
specific	elder	ashes	imprison
(*específico*)	(*mayor*)	(*cenizas*)	(*encarcelar*)
spotless	enforcement	assignment	nightmare
(*inmaculado*)	(*aplicación*)	(*tarea*)	(*pesadilla*)
stumble	exchange	award	overcome
(*trastabillar*)	(*intercambiar*)	(*premio*)	(*vencer*)
space	edge	beginning	issue
(*espacio*)	(*borde*)	(*principio*)	(*asunto*)
stocking	endeavor	behavior	little
(*media*)	(*esfuerzo*)	(*comportamiento*)	(*pequño*)
split	empty	blessing	narrow
(*dividido*)	(*vacío*)	(*bendición*)	(*escaso*)
strict	essay	blind	old
(*estricto*)	(*ensayo*)	(*ciego*)	(*viejo*)
stricken	endless	breadth	flatten
(*afligido*)	(*interminable*)	(*ancho*)	(*aplastar*)
stench	enroll	injure	outline
(*hedor*)	(*inscribir*)	(*herir*)	(*contorno*)
station	ending	clearance	improve
(*estación*)	(*finalizando*)	(*liquidación*)	(*mejorar*)
study	envelope	clingy	open
(*estudiar*)	(*sobre*)	(*dependiente*)	(*abierto*)
strong	ensure	cross	friend
(*fuerte*)	(*asegurar*)	(*cruzar*)	(*amigo*)
stereo	engaged	crumble	furnish
(*estéreo*)	(*comprometido*)	(*desmoronarse*)	(*amueblar*)
sponge	embrace	demand	lawyer
(*esponja*)	(*abrazo*)	(*exigir*)	(*abogado*)
spa	egg	desk	itch
(*balneario*)	(*huevo*)	(*mesa*)	(*picazón*)
stoic	enjoy	frozen	intrude
(*estoico*)	(*disfrutar*)	(*congelado*)	(*meterse*)

https://doi.org/10.1017/S027226312100053X Published online by Cambridge University Press

APPENDIX B

Linguistic and cognitive background of lower-English proficiency (n = 15) and higher-English proficiency bilinguals (n = 18) participants.

	Lower-English Proficiency Bilinguals Mean (SE) *Range* *n* =15	Higher-English Proficiency Bilinguals Mean (SE) *Range* *n* =18	*P*-value
Age	24.13 (1.62) *18–34*	22.22 (0.96) *18–30*	0.30
Age of English acquisition	6.53 (0.62) *6–10*	5.16 (0.61) *5–10*	0.13
Current exposure to Spanish	38.26% (3.87) *10–69%*	28.77% (3.20) *10–50%*	0.18
Current exposure to English	61.93% (3.97) *40–80%*	69.50% (3.01) *49–88%*	0.06
Self-reported Spanish proficiency (1–10 scale)	9.00 (0.19) *6.77–10%*	9.07 (0.14) *6.33–10%*	0.75
Self-reported English proficiency (1–10 scale)	8.44 (0.25) *6.77–10%*	9.61 (0.15) *7.77–10%*	<0.001
Spanish receptive vocabulary (TVIP) standard score	111.47 (1.82) *95–124*	115.11 (0.85) *108–120*	0.14
English receptive vocabulary (PPVT) standard score	92.53 (6.17) *91–107*	114.89 (1.49) *102–125*	<0.001
English proficiency composite (z-score)	–1.25 (0.38) *–4.92–0.21*	1.04 (0.17) *–1.30–1.93*	<0.001
WASI, matrix reasoning	27.73 (1.17) *16–32*	27.33 (0.86) *22–33*	0.78
Backward digit span	8.93 (0.58) *4–12*	11.33 (1.02) *3–16*	0.21

*p < .001.

APPENDIX C

Parameter estimates for growth curve analysis of word fixations in Experiment 1: Sound Recognition.

Monolinguals and Bilinguals

	Time window	*β*	*SE*	*t*	*p*
Group: Intercept	0–1100ms	0.71	0.19	3.72	<0.01

https://doi.org/10.1017/S027226312100053X Published online by Cambridge University Press

Low and High L2 Proficiency Bilinguals

	Time window	*β*	*SE*	*t*	*p*
Proficiency: Intercept	0–1,100 ms	–0.69	0.37	–2.48	0.01
Proficiency: Quadratic	0–1,100 ms	0.51	0.28	2.53	0.01
Word Type*Proficiency: Intercept	0–1,100 ms	0.32	0.12	2.67	<0.01
Word Type*Proficiency: Quadratic	0–1,100 ms	–0.62	0.28	–2.51	0.01
Proficiency: Quadratic	300–600ms	0.06	0.01	5.42	<0.01
Word Type*Proficiency: Intercept	300–600ms	0.20	0.05	3.75	<0.01
Word Type*Proficiency: Quadratic	300–600ms	–0.14	0.06	–2.02	0.04

APPENDIX D

Target, competitor, and control/filler stimuli (Spanish translations) for the s+c target, "e"-onset competitor condition in Experiment 2.

Target	Competitor	Filler 1	Filler 2
spa	edge	acorn	flatten
(*balneario*)	(*borde*)	(*bellota*)	(*aplastar*)
space	egg	afford	flavor
(*espacio*)	(*huevo*)	(*permitirse*)	(*sabor*)
speaker	elder	aisle	furnish
(*altavoz*)	(*mayor*)	(*pasillo*)	(*amueblar*)
special	elevator	alley	friend
(*especial*)	(*ascensor*)	(*callejón*)	(*amigo*)
specific	effort	annoy	hammer
(*específico*)	(*esfuerzo*)	(*molestar*)	(*martillo*)
spider	ember	apology	imprison
(*araña*)	(*braza*)	(*disculpa*)	(*encarcelar*)
spiral	embrace	argue	itch
(*espiral*)	(*abrazo*)	(*discutir*)	(*picazón*)
spirit	empty	arise	injure
(*espíritu*)	(*vacío*)	(*surgir*)	(*herir*)
split	enable	ashes	intrude
(*dividido*)	(*permitir*)	(*cenizas*)	(*meterse*)
sponge	enact	assignment	issue
(*esponja*)	(*promulgar*)	(*tarea*)	(*asunto*)
spotless	elbow	award	improve
(*inmaculado*)	(*codo*)	(*premio*)	(*mejorar*)
spread	encroach	behavior	lawyer
(*difundir*)	(*invadir*)	(*comportamiento*)	(*abogado*)
stable	endeavor	beginning	lazy
(*estable*)	(*esfuerzo*)	(*principio*)	(*perezoso*)
starch	ending	blind	leisure
(*almidón*)	(*finalizando*)	(*ciego*)	(*ocio*)

(Continued)

https://doi.org/10.1017/S027226312100053X Published online by Cambridge University Press

(Continued)

Target	Competitor	Filler 1	Filler 2
station	endless	blessing	little
(*estación*)	(*interminable*)	(*bendición*)	(*pequeño*)
stench	enforcement	breadth	narrow
(*hedor*)	(*aplicación*)	(*ancho*)	(*escaso*)
stereo	engaged	owner	nickname
(*estéreo*)	(*comprometido*)	(*dueño*)	(*apodo*)
stocking	engine	clearance	nightmare
(*media*)	(*motor*)	(*liquidación*)	(*pesadilla*)
stoic	enjoy	clingy	old
(*estoico*)	(*disfrutar*)	(*dependiente*)	(*viejo*)
stricken	essay	crumble	onward
(*afligido*)	(*ensayo*)	(*desmoronarse*)	(*adelante*)
strict	enroll	cross	open
(*estricto*)	(*inscribir*)	(*cruzar*)	(*abierto*)
strong	ensure	desk	outfit
(*fuerte*)	(*asegurar*)	(*mesa*)	(*traje*)
study	envelope	demand	outline
(*estudiar*)	(*sobre*)	(*exigir*)	(*contorno*)
stumble	exchange	frozen	overcome
(*trastabillar*)	(*intercambio*)	(*congelado*)	(*vencer*)

APPENDIX E

Parameter estimates for growth curve analysis of word fixations in Experiment 2: Word Recognition.

Low and High L2 Proficiency Bilinguals

	Time window	β	*SE*	*t*	*p*
Proficiency: Intercept	0–1,100 ms	0.60	0.21	2.80	<0.01
Word Type*Proficiency: Intercept	0–1,100 ms	–0.34	0.01	–7.98	<0.01
Word Type*Proficiency: Quadratic	0–1,100 ms	–0.33	0.04	–8.00	<0.01
Proficiency: Intercept	300–600 ms	0.09	0.04	2.26	0.04
Word Type*Proficiency: Intercept	300–600 ms	–0.17	0.06	–2.71	<0.01
Word Type*Proficiency: Quadratic	300–600 ms	–0.45	0.02	–2.10	0.03

https://doi.org/10.1017/S027226312100053X Published online by Cambridge University Press