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How bilinguals perceive speech depends on which language they think they're hearing

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Abstract

Bilinguals understand when the communication context calls for speaking a particular language and can switch from speaking one language to the other based on such conceptual knowledge. There is disagreement regarding whether conceptually-based language switching is also possible in the listening modality. For example, can bilingual listeners perceptually adjust to changes in pronunciation across languages based on their conceptual understanding of which language they're currently hearing? We asked French- and Spanish-English bilinguals to identify nonsense monosyllables as beginning with /b/ or /p/, speech categories that French and Spanish speakers pronounce differently than English speakers. We conceptually cued each bilingual group to one of their two languages or the other by explicitly instructing them that the speech items were word onsets in that language, uttered by a native speaker thereof. Both groups adjusted their /b–p/ identification boundary in accordance with this conceptual cue to the language context. These results support a bilingual model permitting conceptually-based language selection on both the speaking and listening end of a communicative exchange.

Keywords: language switching, speech perception, top-down processing, neural network models, rational listener

1. Introduction

A fundamental challenge of communicating in more than one language is that the speech signal often calls for different interpretations depending on which language is being spoken. For example, the English word *sea* (/si/) comprises two speech categories (/s/ and /i/) that not only occur in the same order, but are each pronounced very similarly, in the Spanish word *sí* (/si/; “yes”). In other words, these lexical items are nearly the same in form despite meaning very different things. For a Spanish-English bilingual, then, hearing each word may trigger unwanted activation of the other word’s meaning. In this descriptive analysis, of course, the two languages share incongruent overlap only at the lexical level. They do not do so at the sublexical level, as the beginning of each word corresponds phonetically to English and Spanish counterpart sounds (i.e., English /s/ and Spanish /s/), as does the end of each word (i.e., English /i/ and Spanish /i/). It is not the case, for example, that the beginning of English *sea* corresponds phonetically to English /s/ but to Spanish /f/. However, languages do additionally exhibit such sublexical-level incongruence. For example, Spanish /p/ actually corresponds phonetically to English /b/, as discussed in more depth below. When units of speech overlap incongruently across languages, how might bilingual listeners avoid confusing them?

1.1. Conceptual cueing hypothesis

Much previous research has focused on the idea that bilingual listeners disambiguate cross-language overlap by looking to other aspects of their perceptual input for cues to which language is being spoken (e.g., Grosjean, 1988; Hazan & Boulakia, 1993; Ju & Luce, 2004;

Lagrou, Hartsuiker, & Duyck, 2013; Molnar, Ibáñez-Molina, & Carreiras, 2015; Quam & Creel, 2017; Schulpen, Dijkstra, Herbert, Schriefers, & Hasper, 2003; Singh, Poh, & Fu, 2016; Singh & Quam, 2016). These cues may include potentially any aspect of perceptual input associated more strongly with the target language than with the other language in long-term memory. Examples range from linguistic aspects like language-specific vowels and consonants (e.g., the /r/ in Spanish *frío*; Gonzales & Lotto, 2013), to nonlinguistic aspects like facial and vocal features distinguishing an acquaintance who speaks only the target language (Molnar et al., 2015). Expanding this focus, the present study tested the hypothesis that bilingual listeners might additionally look beyond their perceptual input to their own conceptual understanding of which language is actually being spoken. It is already well established that bilinguals can use such conceptual knowledge of the communication context at least to produce, as opposed to perceive, the target language (e.g., Grosjean, 2008; Tare & Gelman, 2010). Thus, a Spanish-English bilingual addressing a stranger in English might readily switch to speaking Spanish upon being informed by a third party that the stranger knows only the latter language. This type of language switching cannot be attributed to a mere association in long-term memory between the unfamiliar person's identifying features and the target language. Rather, it implicates conceptual knowledge of the language context. Under the hypothesis investigated here, bilinguals might use such knowledge not only to produce the relevant language when they themselves are speaking, but also to perceive that language when the other person begins to speak. For example, a bilingual might use his or her conceptual knowledge that the interlocutor knows only Spanish to avoid mistaking that speaker's Spanish *sí* for English *sea*, or Spanish /p/ for English /b/.

1.2. Mixed support from bilingual models

Conceptually-cued language selection in the listening modality would imply that bilinguals' interpretation of the speech signal is modulated by abstract representations of their two languages (e.g., "I'm hearing Language X"). This accords with a few prominent models of bilingual language processing (Dijkstra & Van Heuven, 2002; Green, 1998; Grosjean, 2008). Léwy and Grosjean's BIMOLA (Bilingual Model of Lexical Access) implements the theory that bilinguals can operate in different "monolingual modes" (Grosjean, 1988; Grosjean, 2008). Specifically, bilinguals may choose one language (typically unconsciously) as the most active and thus most influential on processing, while simultaneously minimizing activation of the other language. Inspired by TRACE (McClelland & Elman, 1986), BIMOLA has three ascending layers of nodes, one each for feature, phoneme, and word units. Of these layers, only the feature layer is shared between languages; the phoneme and word layers are language-specific. A monolingual mode is simulated by pre-activating the target language's word and phoneme sublayers, on the assumption that these are selectively activated by external sources pertaining to language mode, including conceptual knowledge of which language the interlocutor is speaking. Another model that permits conceptually-cued language selection is Green's (1998) Inhibitory Control (IC) model, which is derived from a model of action by Norman and Shallice (1986). The IC model posits that bilinguals construct mental schemas that allow them to perform various communicative "actions", including producing and comprehending speech. A separate schema is constructed for each language. These schemas compete to control the output of a lexico-semantic system, wherein linguistic representations are tagged for language membership. The schemas can be

differentially activated by a supervisory attentional system. This system monitors language processing with respect to the bilingual's communicative goals, like using a particular language in accordance with conceptual knowledge about the current context. Finally, Dijkstra and Van Heuven's (2002) BIA+ model likewise assumes that bilinguals construct language schemas sensitive to conceptual knowledge about the language context. In the BIA+, however, these schemas do not change the activation levels of the two languages, consistent with the view that both languages are always activated. Instead, these schemas use decision criteria to select forms belonging to one versus the other of the two activated languages.

Research to date does not, however, rule out a model of listeners' language selection capacity that is simpler than any of the above—a model without mechanisms to harness conceptual knowledge about the language context (e.g., language tags and language schemas). An example would be Macnamara's classic two-switch model (Macnamara, 1967; see also Macnamara & Kushnir, 1971). This model assumes that high-level cognitive states, such as a conceptual understanding of the language context, can guide language selection only in an output modality like speaking. In an input modality like listening, language selection is a strict function of the perceptual input. Other examples, which highlight the potential power of strictly perceptually-based language selection, include recent self-organizing models of bilingual learning (French, 1998; Li & Farkas, 2002; Shook & Marian, 2013). When these models are trained on a corpus of bilingual input, they divide elements from the two languages into separate clusters. The models do this by exploiting the tendency for elements within the same language to occur closer in time. A subset of these models additionally exploit the tendency for same-language elements to share greater phonological similarity (Li

& Farkas, 2002; Shook & Marian, 2013). Once the two language clusters emerge, presentation of a language-specific pattern (e.g., Spanish /r/ vs. English /ɹ/) activates a representation of that pattern within the corresponding language cluster. Activation then spreads to other, interconnected, representations within the same cluster (Shook & Marian, 2013). In theory, this perceptual “priming” of a particular language aids in subsequently mapping additional patterns from the same language, including patterns whose language membership is more ambiguous (e.g., Spanish /p/ rather than English /b/). In Shook and Marian’s (2013) BLINCS model, each language cluster incorporates not only phonemes and words but also various other perceptual patterns co-occurring with these elements, including visible articulatory gestures and orthographic characters. On a miniature scale, this elaborate self-organizing network captures the general idea that each language comes to be internalized as a rich multimodal constellation of linguistic and nonlinguistic patterns typifying the context wherein it is experienced (Hernandez, Li, & MacWhinney, 2005; Kandhadai, Danielson, & Werker, 2014). In principle, each language can then be primed, and language ambiguous forms hence disambiguated, by any linguistic or nonlinguistic patterns uniquely represented in the corresponding language cluster, without the need for conceptual knowledge about the language context.

1.3. Debating the utility of conceptual cueing to bilingual listeners

One way to theorize about whether bilinguals might select between languages based on their own conceptual understanding of which language is being spoken is to consider the extent to which such an approach might be helpful. A number of investigators have suggested that this approach may not be very helpful, but we will argue to the contrary. One assumption

underlying some of these suggestions is that conceptually-based language selection is cognitively demanding (Caramazza, Yeni-Komshian, & Zurif, 1974; Macnamara & Kushnir, 1971). Perceptually-based selection, in contrast, may rely on preattentive processes, like those recently postulated by Bosker, Reinisch, and Sjerps (2017) to underpin auditory contrast effects in research outside of bilingualism (e.g., Liang, Liu, Lotto, & Holt, 2012). A second assumption is that listeners find little need for conceptually-based selection (Hartsuiker, Van Assche, Lagrou, & Duyck, 2011; Grainger, Midgley, & Holcomb, 2010; Vitevitch, 2012). Seeking quantitative support, Vitevitch (2012) employed corpus analyses to assess the degree of phonological overlap between Spanish and English word forms. He found that less than 5% of words in each language were similar enough to any words in the other language to constitute their “phonological neighbors”. Two words are said to be phonological neighbors if they bear a common phoneme sequence after a single phoneme in either word is deleted, added, or substituted. An example of phonological neighbors across English and Spanish would be English *pan* (/pæn/) and Spanish *pan* (“bread”; /pan/), words that share a common phoneme sequence when the vowel in one is replaced by that in the other. Vitevitch suggested that this minimal overlap across languages mitigates the need for a language selection mechanism based other than on the perceptual elements of the input itself. Therefore, the cognitive costs incurred from developing or using any such mechanism may outweigh the benefits.

There is, however, an important limitation of Vitevitch’s (2012) analyses, as well as of other investigators’ less formal observations of minimal cross-language overlap (Grainger et al., 2010; Hartsuiker et al., 2011). These estimates of amount of cross-language overlap

only took into account overlap existing between whole word forms, such as between English *pan* and Spanish *pan*. They did not take into account overlap between other linguistic forms, such as word onsets. Proponents of the language modes theory assume that this latter type of cross-language overlap has the potential to elicit strong parallel language activation (Grosjean, 2008; Marian & Spivey, 2003). Consider English *floor* (/flɔr/) and Spanish *flauta* (/flaʊta/; “flute”). Overall, these word forms are quite distinct. Nevertheless, they have highly overlapping word onsets. Research indicates that, for a Spanish-English bilingual, hearing each word unfold in time may consequently result in momentary competition from the other word for recognition (e.g., Marian & Spivey, 2003). To the extent that conceptual knowledge of the target language can constrain this competition, it could in theory greatly offset any cognitive costs incurred from such an approach. Cross-language overlap in word onsets poses another challenge for bilingual listeners. An assumption of many models, including of both monolingual and bilingual processing (e.g., Dijkstra and Van Heuven, 2002; Grosjean, 2008; McClelland & Elman, 1986; Shook & Marian, 2013), is that accurate lexical identification is facilitated by accurate detection of the word’s sublexical elements, including its onset sound. In the case of Spanish *pan*, accurate identification would be facilitated by accurate detection of the onset /p/. Recall, however, that Spanish /p/ overlaps incongruently with English /b/, raising the possibility that a Spanish-English bilingual mishears this word as starting with /b/ rather than with /p/.

In fact, this type of incongruent overlap, concerning the sublexical rather than lexical level, is but one example of how linguistic systems commonly distinguish the same vowel and consonant categories in different ways (e.g., E. S. Levy, 2009; Lisker & Abramson, 1970;

Niedzielski, 1999). Regarding /b/ and /p/, languages do not always distinguish voiced from voiceless stops (e.g., /g–k/, /d–t/, and /b–p/) the same way along the dimension VOT (Voice Onset Time). VOT is the duration between when a stop is released at the lips and when the vocal folds begin vibrating (Lisker & Abramson, 1970). When vocal fold vibration precedes consonantal release (“leads”), the timing difference is conventionally assigned a negative value; when it follows (“lags”), a positive value. In some languages, including Spanish and French, voiced stops like /b/ are distinguished from voiceless stops like /p/ by vibrating the vocal folds long before releasing the consonant rather than shortly thereafter. That is, voiced stops differ from voiceless stops in that they are long-lead stops with large negative VOT values rather than short-lag stops with small positive VOT values (Hay, 2005; Hazan & Boulakia, 1993; Lisker & Abramson, 1970; Macleod & Stoel-Gammon, 2009; Schertz, 2014; Sundara, Polka, & Baum, 2006; Williams, 1977). In some other languages like English and German, however, voiced stops are actually produced like French and Spanish voiceless stops, as short-lag stops. Voiceless stops are instead produced with relatively longer voicing lag, as long-lag stops (Hay, 2005; Hazan & Boulakia, 1993; Kehoe, Lleó, & Rakow, 2004; Lisker & Abramson, 1970; Macleod & Stoel-Gammon, 2009; Schertz, 2014; Sundara et al., 2006; Williams, 1977). It is thus in this sense that Spanish /p/ overlaps with English /b/.

1.4. Empirical gap

In the present study, we asked whether bilingual listeners are capable of harnessing their conceptual knowledge of the language context to negotiate a cross-language difference in how utterance-initial voiced and voiceless stops are pronounced. Dating back to the early 70’s, previous research investigating bilingual listeners’ ability to negotiate this type of

cross-language difference has been strongly motivated by studies on the relationship between monolinguals' production and perception (e.g., Caramazza, Yeni-Komshian, Zurif, & Carbone, 1973; Hay, 2005; Lisker & Abramson, 1970; Schertz, 2014; Williams, 1977). These motivational studies indicate that when monolingual speakers of different languages diverge on how they pronounce voiced and voiceless stops, they correspondingly diverge on how they identify these stops. For example, Hay (2005) recorded Spanish and English monolinguals' productions of /b/- and /p/-initial words in these speakers' respective languages. She then had each group identify as /ba/ or /pa/ tokens from a synthetic VOT continuum with these two syllables at its endpoints. Not surprisingly, results from the production task showed that Spanish monolinguals' productions of long-lead /b/ and short-lag /p/ were optimally separated at a lower value on the VOT dimension than were English monolinguals' productions of short-lag /b/ and long-lag /p/ (−12 vs. +33.4 ms, respectively). More interestingly, results from the perception task revealed that Spanish monolinguals correspondingly shifted from labeling tokens /ba/ to labeling them /pa/ at a lower value on the VOT continuum as compared to English monolinguals (+.86 vs. +16.63 ms, respectively)—this despite hearing the exact same continuum (see also Lisker & Abramson, 1970; Schertz, 2014; Williams, 1977). Other investigators have found similar production–perception parallels comparing English and French monolinguals (Caramazza et al., 1973). Such findings have thus raised an interesting question concerning bilinguals who speak two languages that implement voiced–voiceless stop contrasts differently: Do these bilinguals adjust their voiced–voiceless identification boundary according to which language they are currently hearing?

In seminal work by Caramazza and colleagues (Caramazza et al., 1973), French-English bilinguals completed production and perception tasks in both French and English contexts. The contexts differed in location (French-speaking high school versus English-speaking university), the language of task instructions, and the language bilinguals spoke during the production task. The production task entailed reading aloud stop-initial words in the relevant language and the perception task identifying as voiced or voiceless monosyllabic tokens drawn from synthetic /ga-ka/, /da-ta/, and /ba-pa/ VOT continua. With respect to distinguishing between these voicing contrasts, results indicated that bilinguals performed in a more French-like manner in the French than English context, but only on the speaking task. On the listening task, bilinguals performed the same way in both contexts. More specifically, their voicing identification boundary remained fixed across contexts, lying intermediate between French and English monolinguals' identification boundaries. Caramazza and colleagues later replicated this failure on the part of bilinguals to adjust their identification boundary across language contexts (Caramazza et al., 1974). The authors took this finding as support for Macnamara's two-switch model (Caramazza et al., 1974). Their reasoning was that bilinguals' identification boundary should indeed remain fixed across contexts if language-switching in the listening modality is stimulus controlled as posited by the two-switch model, since bilinguals heard the same continuum tokens in both contexts.

To this day, this conclusion has not been subject to empirical scrutiny. To be sure, numerous studies have since found that bilingual listeners actually *can* adjust their identification boundary across language contexts, perhaps because these subsequent studies

have provided more proximal contextual information continually cueing the target language (for a review, see Simonet, 2016). For example, some studies prepended target-language phrases to continuum tokens and/or interspersed them with continuum tokens (Elman, Diehl, & Buchwald, 1977; Flege & Eefting, 1987; García-Sierra, Diehl, & Champlin, 2009; Hazan & Boulakia, 1993). Some embedded target-language phonetic cues directly in the continuum tokens (Gonzales & Lotto, 2013; Hazan & Boulakia, 1993; Zampini & Green, 2001). Some attached target-language orthography to response buttons (Antoniou, Tyler, & Best, 2012). And one study even had participants silently read a target-language magazine while their ERP responses to continuum tokens were recorded (García-Sierra, Ramirez-Esparza, Silva-Pereyra, Siard, & Champlin, 2012). Precisely because of such perceptual cues, however, one cannot exclude the possibility that bilinguals' perception was a rigid function of these cues alone—unaffected by any conceptual knowledge of the language context. That is, none of these studies manipulated conceptual knowledge of the communication context independently of perceptual cues, as is necessary to determine whether such knowledge influences bilingual listeners' spoken language processing. Notably, the same empirical gap exists in bilingual research focusing on other aspects of listening, including lexical access (e.g., Blanco-Elorrieta & Pylkkänen 2016; Grosjean, 1988; Ju & Luce, 2004; Lagrou et al., 2013; Marian & Spivey, 2003; Pellikka, Helenius, Mäkelä, & Lehtonen, 2015) and suprasegmental interpretations (Quam & Creel, 2017; Singh et al., 2016; Singh & Quam, 2016). It is for this reason that whether such conceptual knowledge influences any aspect of bilingual listeners' language selection whatsoever remains an open question.

Arguably, then, the strongest indication that bilingual listeners might use conceptual

knowledge to select between languages comes not from research testing bilinguals but rather from that testing monolinguals. Specifically, several studies testing monolinguals demonstrate that high-level cognitive processes can drive perceptual accommodation to cross-dialect and cross-gender variation (Johnson, Strand & D'Imperio, 1999; Niedzielski, 1999). For example, Johnson and colleagues instructed monolinguals to imagine that a gender-neutral voice was male or female while identifying words in that voice. Results revealed that listeners identified the words in a manner consistent with perceptually accounting for gender differences in the phonetic implementation of the vowels distinguishing *hood* and *hud*. Still, languages are arguably much less similar in form than either dialects or male and female voices. While one may conceivably find two languages that diverge on acoustic-phonetic dimensions to a similar extent as two dialects or two opposite-gender voices, only languages typically diverge at higher levels of linguistic structure (e.g., words and syntax) to such an extent as to all but guarantee mutual unintelligibility. From a cognitive efficiency standpoint, listeners may therefore find less need to go beyond the linguistic signal for cues distinguishing languages.

1.5. The present study

To investigate whether bilingual listeners develop a language selection system that is sensitive to the communication context at a conceptual level, we extended a previous study of ours testing Spanish-English bilinguals (Gonzales & Lotto, 2013). In that study, bilinguals adjusted their identification boundary on a VOT continuum (*bafri*–*pafri*) when afforded joint conceptual and perceptual cues to the language context. Bilinguals were conceptually cued by whether English instructions explicitly referred to the response alternatives (*bafri* and *pafri*)

as rare Spanish or English words. They were perceptually cued by whether continuum token endings were phonetically consistent with Spanish (/bafri–pafri/) or English (/baf^ɹi–paf^ɹi/). The present study differed from this previous work—and indeed from all previous work investigating bilinguals’ ability to adjust perception across language contexts—in that we conceptually cued the target language independently of any perceptual cues. As in our previous study, bilinguals received English instructions that a native speaker of the target language would, on each trial, begin but not finish saying one of two rare words in that language. Contrasting /b/ and /p/ in word initial position, these “rare words” were in fact pseudowords (e.g., *bafri* and *pafri*). Critically, however, the language contexts in the present study were distinguished solely by the conceptual content of the instructions; the pseudowords were realized the same way in both contexts. During the instructions, bilinguals never heard these items; they only saw their orthographic forms, which were the same in both contexts. During the identification task, bilinguals heard the same VOT continuum in both contexts. This continuum varied between two monosyllables (e.g., /ba/ and /pa/), endpoints corresponding to the beginnings of the two pseudowords.

If cognitive efficiency constraints preclude bilinguals from developing a system for perceptually adjusting to their two languages based on conceptual knowledge of the language context, then bilinguals should not adjust their voicing identification boundary across our language contexts distinguished solely by conceptual information. Only if bilinguals can in fact develop such a system might they be expected to adjust their boundary across these contexts. Of course, not all bilinguals whose two languages exhibit incongruent overlap between voiced and voiceless stops may be capable of developing such a system. Here we

sought to establish the generality of our results across two highly proficient groups of such bilinguals recruitable at our testing sites—Spanish-English bilinguals and French-English bilinguals.

2. Method

2.1. Participants

2.1.1. Spanish-English bilinguals

Thirty Spanish-English bilinguals were each randomly assigned to either a Spanish or English language context. Participating for course credit, these bilinguals were undergraduate students enrolled in an introductory psychology course at the University of Arizona, in Tucson (USA). This university's principle language of instruction is English, and Tucson is a predominantly English-speaking city. Nevertheless, Tucson has a relatively large Spanish-speaking community (Beaudrie, 2011). Participants completed a questionnaire in which they rated their own proficiency in each language using separate 1–5 scales of how well they spoke and comprehended the language (where 1 denotes “very poorly” and 5 “almost perfectly”). They then indicated how early they began learning each language and from whom. Participants were included in the Spanish-English group according to the same inclusion criteria as in our previous work (Gonzales & Lotto, 2013). One criterion was that the participant's average self-rating in each language was at least 3.5 across the speaking and comprehension scales ($M_{Spa} = 4.5$; $M_{Eng} = 4.75$). Another was that the participant reported no more than 1 year of experience learning a language other than Spanish and English, with this experience being limited to formal classroom instruction. The final criterion was that the participant reported receiving regular exposure to both Spanish and English from one or more

native speakers before age 8 ($M_{age} = 2.33$ yrs). This age-of-acquisition cut-off was based on studies showing distinct neural and behavioral outcomes between second-language learners divided at or around this cut-off (see Silverberg & Samuel, 2004).

2.1.2. French-English bilinguals

Thirty French-English bilinguals were randomly assigned to either a French or English context.¹ These participants consisted of undergraduate students at Concordia University, in Montreal (Canada). Montreal is located in the province of Quebec, where the official language is French. However, Montreal has a large population of French-English bilinguals (Boberg, 2012) and Concordia's courses are principally conducted in English. Due to time limitations, participants at this testing site completed a briefer questionnaire than those at the University of Arizona—namely, a modified version of the LEAP-Q (Language Experience and Proficiency Questionnaire; Marian, Blumenfeld & Kaushanskya, 2007). Participants included in the French-English bilingual group were individuals who reported beginning to learn both languages before age 8 ($M_{age} = 3.88$ yrs), and whose average self-rating in each language was at least 7 across separate 0–10 scales of speaking and understanding (where 0 denotes “none” and 10 “perfect”; $M_{Eng} = 9.75$; $M_{Fre} = 8.77$). Unlike our inclusion criteria for Spanish-English bilinguals in Tucson, no restrictions were placed on experience learning a third language other than that the language was indeed learned as such (i.e., after French and English). This was to accommodate the much larger proportion of participants proficient in a third language in Montreal. Additionally, no restrictions were set on how often or from whom participants received early exposure to French and English, since

¹ One additional participant who met our French-English bilingual criteria was nevertheless excluded for responding uniformly across all trials, precluding calculation of a voicing boundary.

the LEAP-Q does not directly inquire into these details. However, all but four bilinguals indicated growing up in a Canadian city where both languages are spoken, and the remaining four still reported attaining fluency in both languages before age 8. In summary, then, one can say that our Spanish- and French-English bilingual groups were both highly proficient in their two respective languages and that both groups likely received regular exposure to both languages before age 8.

2.2. Stimuli

2.2.1. Instructions

For both bilingual groups, the instructions that conceptually cued the target language differed across contexts in two ways. First, they differed in whether they introduced the identification-task speaker as a native speaker of English or of the group's other language (Spanish or French). Second, they differed in whether they introduced the pseudowords, which they stated that this speaker would begin but not finish saying aloud, as rare words in English or in the other language. Thus, for example, Spanish-English bilinguals in the English context were told that this speaker was a native English speaker and the pseudowords rare English words. Those in the Spanish context, in contrast, were told that she was a native Spanish speaker and the pseudowords rare Spanish words. In order to avoid distinguishing contexts by perceptual cues, instructions were always administered in English regardless of the context.

The English instructions for each context were conveyed orally by the experimenter in general terms, and then via computer in greater detail. The computer-based instructions consisted of pre-recorded sentences matched word-for-word by on-screen text. As an

exception, the pseudowords, described below, appeared only in the text. This is because these items were spelled identically across language contexts. When spoken, in contrast, they would have had phonetic characteristics unique to Spanish in the Spanish context and to English in the English context. In other words, they would have constituted a reliable perceptual cue to the target language. For the same reason, the experimenter never pronounced these items aloud. For each bilingual group, we first created the computer-based instructions for the English context. We then transformed a copy of these instructions for the other language context. We did so simply by replacing every occurrence of the word *English* (e.g., ...a native **English** speaker will begin to say...) with the English word for the group's other language (e.g., ...a native **Spanish** speaker will begin to say...). We followed this procedure for transforming both the pre-recorded sentences and the accompanying text.

2.2.2. Pseudoword stimuli

Spanish/English contexts – The ostensible words for Spanish-English bilinguals were adopted from our previous work (Gonzales & Lotto, 2013). Spelled *bafri* and *pafri* in both language contexts, these pseudowords were devised to satisfy a number of constraints. One was that they could be spelled identically across language contexts per each language's phoneme-to-grapheme conversion rules. A second was that that neither pseudoword would be easily mistaken for a real word or co-articulated sequence thereof in either language. A third was that, in each context, the two pseudowords differed phonologically from one another only in whether they began with a voiced or voiceless stop consonant. A fourth was that the two pseudowords had no saliently language-specific phonetic characteristics when produced

in either language, save for their ending portion. For *bafri* and *pafri*, this was ‘ri’.² Finally, the pseudowords needed to contain an internal fricative or other sound onto which the Spanish- and English-specific endings could be interchangeably spliced across contexts. For *bafri* and *pafri*, this fricative was ‘f’.

For the main task, in which Spanish-English bilinguals indicated whether the speaker was beginning to say *bafri* and *pafri*, we created a single /ba-/pa/ continuum for both contexts in which these participants took part. Earlier we alluded to why we created such a context-general continuum of “truncated” tokens. This was so that any shift in bilinguals’ identification boundary across contexts could not be explained in terms of tokens changing across contexts to phonetically match, and thereby perceptually cue, each context. An alternative approach to controlling for such a perceptual cueing effect would have been to likewise present a single continuum in both contexts, only one varying between two whole pseudowords with relatively language-neutral phonetics from beginning to end (e.g., *bafa* and *pafa*). However, the present stimuli were designed to be broadly useful for a larger program of research, incorporating additional studies probing for a perceptual cueing effect with whole pseudoword tokens.

The /ba-/pa/ continuum comprised 14 tokens across which only the initial stop consonant’s VOT value varied, starting at –35 ms and increasing in equal 5 ms steps to +30 ms. Using Praat (Boersma & Weenink, 2010), these tokens were created from natural speech

² Spanish and English pronunciations of these co-articulated segments are saliently language-specific primarily because the Spanish rhotic is a tap (/r/) whereas the English rhotic is an approximant (/ɹ/). The Spanish /r/ is thus phonetically more similar to the English flap, though English speakers do not closely associate it with any English consonant (Rose, 2012). Similarly, the English /ɹ/ is perceived as foreign-sounding to Spanish speakers (Dalbor, 1980).

recorded by an early Spanish-English bilingual. One clearly pronounced Spanish *paʔri* token (/paʔri/) was stripped both of its final three segments, 'ʔri', and of the voiceless interval of its initial segment, 'p', not including the release burst. This Spanish 'pa' token was designated the continuum's 0 ms VOT token. It was transformed into 7 voicing lead tokens ranging from -35 ms to -5 ms VOT. It was also transformed into 6 voicing lag tokens ranging from +5 ms to +30 ms VOT. The lead tokens were created by adding to the beginning of the stripped token (before its release burst) successive prevoicing intervals excised from multiple different Spanish *baʔri* tokens (/baʔri/). The lag tokens were created by inserting between the stripped token's release burst and its voicing onset successive voiceless intervals from multiple different Spanish *paʔri* tokens. All prevoicing and voiceless intervals were approximately 5 ms long. Some had been slightly trimmed down to this duration via hand-editing, with care taken not to introduce any perceptible clicks into the stimulus. The resulting /ba-pa/ continuum was relatively language neutral. The bilabial stop's VOT range fell within both Spanish and English /b-p/ ranges (Hay, 2005; Lisker & Abramson, 1970; Williams, 1977) and the following Spanish /a/ segment had an English phonetic counterpart in English /ɑ/. Spanish /a/ and English /ɑ/ differ in backness (being central and back vowels, respectively) but nevertheless overlap in F1-F2 space. Moreover, these vowels are rated as perceptually very similar by Spanish-English bilinguals (Flege, Munro, & Fox, 1994).

French/English contexts – The pseudoword stimuli for French-English bilinguals were devised to satisfy the same five constraints as those for Spanish-English bilinguals, except with respect to French-English bilinguals' own two languages. This meant that French-English bilinguals did not receive a minimal pair whose spellings in both contexts

were, as for Spanish-English bilinguals, *bafri* and *pafri*. For our multi-study investigation, one issue with using these same pseudowords for French-English bilinguals was that the French pronunciation of *pafri* would have potentially violated the constraint that no variant should be easily mistaken for a co-articulated sequence of real words. The reason is that this variant might have been easily mistaken for French *pas frit* (“not fried”), though this was not an issue specifically in the present study where tokens were truncated. The pseudowords that we devised to satisfy all five constraints were, in both contexts, instead spelled *befru* and *pefru*. In their spoken forms, their saliently language-specific ending was ‘ru’,³ which was not present in the truncated tokens. In both contexts, these tokens were drawn from a single continuum ranging from /bef/ to /pef/. This continuum was created analogously to that for Spanish-English bilinguals, thus comprising 14 tokens across which only the VOT value of the onset stop varied (in equal 5 ms steps from –35 ms to +30 ms). Tokens were derived from an early French-English bilingual’s French productions of *befru* and *pefru*. The continuum was relatively language neutral, with the onset stop spanning a VOT range falling within both

³ French and English pronunciations of the ‘ru’ ending differ markedly due to both the consonant and the vowel. French ‘r’ (/ʁ/) is a voiced dorsal fricative described as a novel sound for naïve English listeners. It is distinct from English ‘r’ (/ɹ/), which is an alveolar approximate, but also from English voiced fricatives, none of which are dorsal (Colantoni & Steele, 2008). English ‘r’ likewise lacks a perceptual equivalent in French, with French listeners perceiving it as somewhat /w/-like (Hallé, Best, & Levitt, 1999). French and English pronunciations of the ‘ru’ ending also differ with respect to the vowel segment, though the French vowel (/y/) may cue French more than the English vowel (/u/) English. French /y/, which combines lip rounding with a forward tongue body, is said to be a novel sound for naïve English listeners (Flege & Hillenbrand, 1984; Flege, 1987). English has rounded vowel categories, but none defined by tongue-fronting (E. S. Levy, 2009). English-French bilinguals perceive French /y/ as closest to English /u/ when palatalized (/ʏu/, as in *beauty*) but nevertheless as quite foreign to English (E. S. Levy, 2009). English /u/, on the other hand, may pass perceptually as French, since although it is quite distinct from French /y/, it has a phonetic counterpart in French /u/ (Flege & Hillenbrand, 1984; Flege, 1987).

French and English /b–p/ ranges (Caramazza et al., 1973), and the following French /ɛ/ and /f/ segments having English phonetic counterparts in English /ɛ/ and /f/.

2.3. Procedure

All participants provided informed consent to participate in the experiment. After completing our language background questionnaire, they received general instructions from the experimenter. They were then seated individually facing a computer monitor, where they first received the computer-based instructions and then completed the identification task. Each identification trial began with the appearance of a centrally located black cross, which participants were instructed to fixate. Approximately 710 ms later, this cross was automatically replaced by the two pseudowords on either side of the screen. Side order was randomized across participants. For Spanish-English bilinguals, the pseudowords were *bafri* and *pafrri*; for French-English bilinguals, *befru* and *pefru*. The pseudowords stayed on the screen for the remainder of the trial. Approximately 710 ms after their onset, a continuum token was delivered via headphones at a comfortable listening level (Spanish-English bilinguals), or via loudspeakers at an intensity of 70 dB SPL (French-English bilinguals). Participants were instructed to use the left or right shift key to indicate whether the speaker was beginning to say the left or right “rare word”, respectively. The trial terminated on the participant’s key press, or else automatically after 4.1 s elapsed. The 14 continuum tokens were presented in 3 random orders for a total of 42 trials. The computer-based instructions and identification task were both controlled by DMDX software (Forster & Forster, 2003).

3. Results

Research reviewed earlier indicates that Spanish, French, and English all contain

contrasting /b/ and /p/ stops that are separable on the VOT dimension. At the same time, however, this research also indicates that the Spanish and French variants of these contrasting stops are optimally separable at a comparatively lower VOT boundary value than the English variants (e.g., Hay, 2005; Kehoe et al., 2004; Lisker & Abramson, 1970; Macleod & Stoel-Gammon, 2009; Sundara et al., 2006; Williams, 1977). Given this research, a clear prediction follows from the hypothesis that bilingual listeners can develop a system for selecting between their respective languages based on conceptual knowledge of the language context. The highly proficient Spanish- and French-English bilinguals tested here should adopt a different pseudoword identification boundary depending on which of their two languages they are instructed they are hearing. More specifically, they should place their boundary at a lower VOT value when told they are hearing their Romance language (Spanish or French) than when told they are hearing English.

3.1. Probability functions

Using logistic regression (see Morrison, 2007), we fitted each participant's identification responses to a binary logistic regression model. The model was then used to predict, at each step along the VOT continuum, the probability of the participant responding that the speaker began saying the ostensible /p/- rather than /b/-initial word. Fig. 1 shows each bilingual group's probability of a /p/-initial response as a joint function of the language context and continuum token's VOT value. Within each group and context, we plot median rather than average probabilities because probabilities at multiple VOT steps were non-normally distributed across individuals ($p < .05$ to $< .01$; Anderson-Darling test).

Figure 1. Spanish- and French-English bilinguals' response probability functions, derived from logistic regression. The left panel displays Spanish-English bilinguals' median probability of responding that they heard the beginning of the ostensible word *pafri* (rather than *bafri*), plotted as a function of the language context and /ba-/pa/ continuum. The right panel displays French-English bilinguals' median probability of responding that they heard the beginning of *pefru* (rather than *befru*), plotted as a function of the language context and /bɛf-/pɛf/ continuum (all error bars denote SEM).

3.2. VOT boundary values

Each participant's voicing identification boundary was computed using the logistic regression model fitted to his or her data. Specifically, the model's intercept and slope coefficients were used to compute the VOT value where the participant's /b/- and /p/- initial responses were equally probable. Fig. 2 displays each bilingual group's individual boundary values within the two language contexts. Consistent with our hypothesis, Spanish-English bilinguals' median boundary value in the Spanish context (+9.97 ms, $SD = 6.25$) was lower than in the English context (+7.94 ms, $SD = 60.13$) by 6.97 ms. Also consistent with our

hypothesis, French-English bilinguals' median boundary value in the French context (-11.34 ms, $SD = 12.5$) was lower than in the English context ($+5.94$ ms, $SD = 42.08$) by 17.28 ms. However, neither bilingual group's cross-context boundary difference was amenable to a regular two-sample (Student's) t -test. For each group, this test requires assuming that individual boundary values are normally distributed within both language contexts and that the two distributions do not differ from one another in variance. As Fig. 2 shows, each bilingual group's distribution of English boundary values contains three outliers. The outliers in the Spanish-English bilingual group's distribution of English boundary values cause this distribution to be skewed significantly rightward ($p < .01$; skewness test⁴) and to hence deviate significantly from normality ($p < .01$; Anderson-Darling test). They also cause it to differ significantly in variance from this group's distribution of Spanish boundary values ($p < .05$; Levene's test). Likewise, the outliers in the French-English bilingual group's distribution of English boundary values cause it to deviate significantly from normality ($p < .01$), though it is not significantly skewed ($p > .90$) and does not differ significantly in variance from these bilinguals' distribution of French boundary values ($p > .20$).

⁴ We used the Z-test approach (see, e.g., Corder and Foreman, 2009)

Figure 2. Each bilingual group's VOT boundary values within the two language contexts, derived from logistic regression. Individual boundary values are represented by the gray circles and within-context medians by the black circles (error bars denote SEM). Each participant's individual boundary value is the point on the VOT dimension where he or she is predicted to become as likely to make a /p/-initial as a /b/-initial response. Some boundary values fall outside the continuum tokens' VOT range (i.e., -35 to $+30$ ms). They were not computationally constrained to fall within this range for lack of any *a priori* basis for such a constraint on the boundary values of individual listeners.

3.3. WMW test and rank-transformation

A widespread approach to analyzing data unfit for the two-sample Student's *t*-test is to perform the Wilcoxon-Mann-Whitney (WMW) test. When used to compare unpaired samples, the WMW test is indeed said to be the former test's nonparametric counterpart. The reason is that it analyzes the ranks of observations rather than the raw values themselves

(Zimmerman, 2011). More specifically, each raw observation in the combined sample is ranked according to its magnitude relative to all the other observations, so as to determine whether the ranks in one sample are systematically higher or lower than those in the other. The fact that the WMW test invariably transforms each sample into a set of ranks with a rectangular-shaped distribution means that it makes no assumption about whether either sample comes from a normal parent distribution. Further, rank-based variance estimates are less sensitive to outliers (Fagerland & Sandvik, 2009; Hettmansperger & McKean, 1978), which can create skewness and variance heterogeneity, as our raw data described above illustrate. Nevertheless, the WMW test is sensitive to these properties whenever they are retained in, or even created by, the rank transformation (Fagerland & Sandvik, 2009; Zimmerman & Zumbo, 1993). Therefore, this test is a suitable nonparametric alternative only insofar as these properties are absent from the rank transformation. Fig. 3 displays each bilingual groups' data after being rank-transformed as when deriving the WMW test statistic (Conover & Iman, 1985). Specifically, each group's individual boundary values across the two language contexts were pooled to form a single series of values ($n_{\text{English}} + n_{\text{Romance}} = 30$) sorted in numerically ascending order. Each boundary value in this series was then replaced by its ordinal position number, or "boundary rank". That is, the lowest of the 30 boundary values was replaced by a boundary rank of 1, the second lowest by a boundary rank of 2, and so on up to the highest value, replaced by a boundary rank of 30. Tied values were each replaced by their average position number. As Fig. 3 shows, neither bilingual group's rank-transformed data exhibits significant variance heterogeneity across the two language contexts ($p > .30$ to $p > .60$) or skewness within either context ($p > .10$ to $p > .90$), indicating

that the WMW test is a suitable nonparametric alternative for both groups' data.⁵

Figure 3. Each bilingual group's boundary ranks within the two language contexts. Gray circles represent individual boundary ranks and black circles within-context medians (error bars denote SEM). Each participant's individual boundary rank represents the magnitude of his or her boundary value relative to the boundary values of all other participants in the same bilingual group across both contexts. Thus, the lowest boundary rank represents the lowest boundary value, the second lowest boundary rank the second lowest boundary value, and so on (equal ranks equal tied values).

⁵ This reduction in variance heterogeneity and skewness can be understood as follows. When the raw data are rank-transformed, each sample with values falling extremely far from its mean in either direction no longer contains such extreme values, as each value ends up falling just one unit (one rank) away from the next farthest value in the same direction (whether the next farthest is in the same sample or in the group's other sample). A similar effect might likewise be obtained by winzorizing, downweighting, or otherwise truncating the data, but this latter type of approach typically requires making assumptions about what value should count as an outlier and what value should replace it.

3.4. WMW test results

If bilinguals tend to adopt a lower identification boundary in the context cueing their Romance language than in that cueing English, their mean boundary rank should be systematically lower in the former context. To test this prediction, we submitted each bilingual group's data to a two-tailed WMW test with context as the between-subjects factor (alpha set at .05). Fig. 3 shows each bilingual group's mean boundary rank within the two language contexts. Consistent with our prediction, Spanish-English bilinguals' cross-context difference in mean boundary rank was significant ($W = 280.50$, $p = .0488$, $r = .36$), reflecting a reliable tendency for these bilinguals' individual boundary ranks to be lower in the Spanish context ($M = 12.30$; $SD = 7.94$) than in the English context ($M = 18.70$; $SD = 8.69$). French-English bilinguals' cross-context difference in mean boundary rank was analogously significant ($W = 290.00$, $p = .0183$, $r = .44$). Moreover, their cross-context difference likewise reflected a reliable tendency for their individual boundary ranks to be lower in the context cueing their Romance language ($M = 11.67$; $SD = 6.72$) than in that cueing English ($M = 19.33$; $SD = 9.15$). Together, then, these results indicate that both bilingual groups tended to adopt a lower identification boundary in the context cueing their Romance language.⁶

4. General Discussion

Previous research has showcased bilinguals' ability to switch from speaking one language to speaking the other based on conceptual knowledge of the communication context (e.g., Grosjean, 2008; Tare & Gelman, 2010). The present study investigated whether

⁶ For supplementary analyses, see the Appendix

conceptually-based language selection is also possible in the *listening* modality. We conceptually cued French- and Spanish-English bilinguals either to English or to their Romance language (French or Spanish). We did so by explicitly instructing bilinguals that they were going to perform a word identification task wherein a speaker of the language in question would begin, but not finish, saying one of two rare words in that language. The two “rare words” were actually pseudowords, contrasting voiced /b/ and voiceless /p/ onsets (e.g., *bafri* and *pafri*). Identification tokens varied from the first syllable of one pseudoword (e.g., /ba/) to that of the other (e.g., /pa/) along the VOT dimension. We predicted that both bilingual groups would apply different voicing identification criteria depending on which language they were instructed they were hearing. We made this prediction because both of these bilingual groups’ Romance languages contrast voiced and voiceless stops differently than English. More specifically, both Spanish and French variants of these contrasting stops are optimally separated at a lower VOT boundary value than English variants (e.g., Hay, 2005; Kehoe et al., 2004; Lisker & Abramson, 1970; Macleod & Stoel-Gammon, 2009; Sundara et al., 2006; Williams, 1977), with Spanish and French voiceless stops consequently overlapping incongruently with English voiced stops the VOT dimension.

Consistent with both bilingual groups accounting for this incongruent cross-language overlap, both groups placed their voicing identification boundary at a lower VOT value when cued to their Romance language than when cued to English. Critically, these results cannot be explained in terms of bilinguals being perceptually, rather than conceptually, cued to the target language. Unlike in previous studies, we did not vary any auditory or visual stimuli to perceptually match each conceptually-cued language context. For

example, we did not vary the language of instructions (always in English) or of a more local linguistic environment surrounding continuum tokens (e.g., carrier phrases) to match each context. Nor did we perceptually cue each context by varying the phonetic makeup of the continuum tokens themselves, which were held constant across contexts. Put simply, all that distinguished contexts was the conceptual content of the verbal instructions, thus implicating this conceptual information in bilinguals' context-specific voicing identifications.

4.1. Conceptual knowledge of the target language facilitates language selection for the listener, too

These results thus provide the first clear evidence favoring a bilingual model of language selection in which conceptual knowledge about the language context can be exploited in the listening modality just as in the speaking modality (Dijkstra & Van Heuven, 2002; Green, 1998; Grosjean, 2008). In the language of Green's IC model, bilingual participants may have achieved such language selection with the aid of a supervisory attentional system. Based on our explicit instructions cueing the target language, this system may have activated a target-language schema biasing perception toward target-language representations, as of a Spanish-tagged /p/ rather than of English-tagged /b/ when the target language was Spanish. The system may have then maintained strong activation of this schema by inhibiting a competing nontarget-language schema, activated automatically (albeit perhaps minimally) by VOT values equally compatible with both speech categories. As alluded to above, the two language contexts were not reliably distinguished by any perceptual information associated in long-term memory with the target language (e.g., real Spanish vs. English words, or a familiar Spanish vs. English monolingual). Therefore, one might suppose

further that bilinguals perceived speech differently in the two contexts because the supervisory attentional system directed the target-language schema to make do with make-shift contextual cues maintained in working memory. For example, bilinguals might have continually reminded themselves that the on-screen orthographic forms of the pseudowords were introduced as Spanish words, or that the speaker was introduced as a native Spanish speaker.

4.2. Revisiting assumptions motivating strictly perceptually-driven language selection

Our results challenge an alternative type of language-selection model positing that selection in an input modality is a strict function of the perceptual input itself. It is therefore worth revisiting the assumptions that have motivated such an alternative model. Recall that one assumption has been that conceptually-based language selection is more effortful than perceptually-based selection (Caramazza et al., 1974; Macnamara & Kushnir, 1971). We would not dispute this assumption per se. As just suggested, conceptually-based language selection might recruit “top-down” inhibition and working memory processes, whereas perceptually-based selection might proceed automatically from “bottom-up” cues. We would just qualify this assumption by emphasizing that whatever cognitive resources get expended toward conceptually-based language selection may, on average, get expended anyway. While only conjectural at this point, this possibility can be understood within the ideal listener framework. Advocates of this framework describe the listener’s belief about the input’s underlying structure as comprising multiple uncertain estimates (e.g., Kleinschmidt & Jaeger, 2015; Pajak, Fine, Kleinschmidt, & Jaeger, 2016), a conservativeness reflecting the input’s inherently noisy and ambiguous nature. For example, the input is characterized by constant

variation across social groups, individuals, and speaking styles (Heald & Nusbaum, 2014). The ideal listener continually updates his or her probabilistic belief about the underlying structure. This updating entails incrementally integrating prior knowledge with all available incoming information from the input itself, for the highest likelihood of drawing an accurate inference. As Kuperberg and Jaeger (2016) theorize, this process may very well incur a cost when conceptual knowledge is used to inhibit context-irrelevant hypotheses. On average, however, it should reduce how much probability gets assigned to such erroneous hypotheses. This, in turn, should reduce “surprisal”—a theoretical quantification of how much probability must be redistributed across the hypothesis space to reflect new evidence favoring the correct hypothesis over the erroneous ones (R. Levy, 2008). Critically, R. Levy and others have shown that surprisal correlates positively with processing difficulty. Thus, conceptually-based language selection may indeed incur a processing cost, but one generally counterbalanced by reduced surprisal and hence reduced processing difficulty downstream. Interestingly, this theoretical framework offers a unifying way of understanding both the present study and previous studies demonstrating monolinguals’ use of conceptual cues to negotiate *within*-language phonetic variation (Johnson et al. 1999; Niedzielski, 1999).

The other assumption has been that strictly perceptually-based language selection is generally sufficient for selecting the relevant language (Grainger et al., 2010; Hartsuiker et al., 2011; Vitevitch, 2012). The implication is that even if the processing cost incurred from conceptually-based language selection is fully offset by reduced surprisal, listeners may find little incentive to develop a system supporting such selection in the first place. Vitevitch’s (2012) work represents the most rigorous effort to date to validate this rich input assumption.

His corpus analyses suggest minimal phonological overlap between English and Spanish word forms. Nevertheless, these analyses overlooked numerous potential sources of language confusion, since they only accounted for cross-language overlap between whole word forms, such as between English *pan* (/pæn/) and Spanish *pan* (/pan/). Most relevant to the present study, they did not account for cross-language overlap between utterance onsets, such as the case investigated here where the same onset stop may correspond to different sublexical categories depending on which language is being spoken. Cross-language onset overlap may also lead to confusion at the lexical level. For example, the consonant clusters at the beginning of English *floor* and Spanish *flauta* correspond to the same sequence of sublexical categories in both languages (/f/ followed by /l/), so neither cluster would be expected to lead to cross-language interference at the sublexical level. However, one cluster constitutes the beginning of a Spanish word whereas the other, the beginning of an English word. Thus, a Spanish-English bilingual hearing either of these two words unfolding in time may experience momentary cross-language competition between them for recognition. Future research should investigate whether bilinguals' conceptual knowledge of the language context helps them additionally mitigate this latter type of onset-based cross-language interference.

In theory, bilingual listeners may manage to avoid cross-language interference from overlapping onsets by selecting between languages as a strict function of perceptual cues afforded by the broader language context. In practice, however, perceptual cues may not always be so reliable. Consider when a Spanish-English bilingual hears Spanish *pan* at the beginning of a Spanish sentence, but before hearing this word hears an English sentence. Up to around the point when the listener hears this Spanish word, perceptual information from

the broader context may not strongly constrain the listener to identify the word's onset as Spanish /p/. Indeed, if the language transition happens fast, the listener may hear the Spanish word while still harboring strong residual activation of English elicited from previously processed perceptual cues to English. Therefore, the listener may actually be more likely to mistake the onset for English /b/. The listener may even continue to experience strong bottom-up activation of English as the Spanish sentence proceeds to unfold beyond the first word. This could happen, for example, if the speaker producing the Spanish sentence has Anglo facial features (Molnar et al., 2015; Zhang, Morris, Cheng, & Yap, 2013), or has an English accent (Llanos & Francis, 2016). Regarding accent, someone speaking English-accented Spanish may still pronounce stop consonants with a native-like VOT production boundary (Knightly, Jun, Oh, & Au, 2003). In this case, any phonetic characteristics of the English accent cueing the listener to an English rather than Spanish boundary would be misleading. Conceptual knowledge about which language is actually being spoken might help resolve any one of these potential sources of language confusion.

4.3. From perceptual to conceptual information and back? Processing and developmental considerations

None of this is to argue that bilingual listeners exploit conceptual knowledge to the complete exclusion of perceptual cues when selecting between languages. Indeed, a wealth of previous research indicates that they additionally exploit perceptual cues. In early work using a gating task, for example, Grosjean (1988) tested French-English bilinguals' ability to recognize an English word (e.g., *pick*) with a largely overlapping French counterpart (*piquer*, meaning "to sting"). Results indicated that recognition was aided by the two words'

fine-grained phonetic differences. In particular, bilinguals isolated the English word faster when hearing it pronounced in an English- than French-like manner. Importantly, this pronunciation effect did not extend to English words lacking largely overlapping French counterparts. Such evidence for perceptually-cued language selection based on word-internal cues has since been extended using a variety of other methodologies, including two-alternative forced-choice (2AFC; Hazan & Boulakia, 1993), cross-modal priming (Schulpen et al., 2003), eye-tracking (Ju & Luce, 2004; Quam & Creel, 2017), and even preferential looking with children (Singh & Quam, 2016). In addition, other research has shown perceptual cueing from the phonetics of a sentential context, both in an auditory lexical decision task (Lagrou et al., 2013) and in a 2AFC task (Llanos & Francis, 2016). Taken together with this literature, the present study therefore supports the possibility that conceptual and perceptual information facilitates listening *interactively*.

What might such interactive processing look like? In our study, the two language contexts were distinguished solely by explicit instructions. Typically, however, bilinguals are not conceptually cued to the target language in this way. Instead, they receive other types of cues, including both lexico-semantic cues (Zhao, Shu, Zhang, Wang, Gong, & Li, 2008) and perceptual cues (Hirschfeld & Gelman, 1997; Zhao et al., 2008). Regarding perceptual cues, Hirschfeld and Gelman (1997) found that adults could judge with high accuracy whether they were hearing English or Portuguese when the speech samples were rendered unintelligible via low-pass filtering, which preserved mostly just prosodic cues. In all the studies reviewed in the preceding paragraph, perceptual cues to the target language may have similarly activated a conceptual representation of the target language. We therefore suggest that conceptual

knowledge about which language is being spoken might facilitate language selection whether that knowledge is activated directly by conceptual cues as in our study, or indirectly by other types of cues like the perceptual cues in these previous studies. This hypothesized language selection, driven by top-down knowledge that is itself driven by bottom-up cues, is indeed consistent with models that permit a role of conceptual knowledge in mapping input to the target language. In Dijkstra and Van Heuven's (2002) BIA+, for example, abstract representations of the two languages take the form of "language nodes". Each language node is connected to representations of language-matching linguistic forms. For example, a Spanish node would be connected to representations of Spanish words, which would in turn be connected to representations of constituent phonemes like Spanish /r/. Each language node therefore receives activation from language-matching linguistic forms, and this bottom-up activation can in principle influence top-down decision criteria for selecting between languages (e.g., between Spanish /p/ and English /b/).

Of course, our results do not rule out the possibility that when strong perceptual cues are available as in previous research, bilingual listeners select between languages as a strict function of these cues themselves (e.g., based on "horizontal" excitatory connections between Spanish /r/ and Spanish /p/). To process the input most efficiently, for example, they might disregard whatever higher-level conceptual knowledge these cues may activate. Input-to-language mappings based on such conceptual knowledge might also be constrained by cognitive limitations. Such limitations might be specific to certain populations, such as young children (Singh & Quam, 2016) rather than cognitively mature adults like those tested here. They might also be specific to certain stages of processing, such as early stages

captured by eye-tracking (Quam & Creel, 2017) as opposed to later stages captured by our 2AFC task. In short, the possibility remains that bilingual listeners frequently select between languages without exploiting conceptual knowledge about the language context, either during childhood or thereafter. What our results indicate is that however frequently the early bilingual listeners tested here might have disregarded such conceptual knowledge during their lifetime as bilinguals, they did not do so frequently enough to preclude development of a language selection system sensitive to such knowledge at least some of the time.

Our results therefore revive longstanding questions about how this type of system might develop. Existing models consistent with such a system have been criticized for some time now for being developmentally opaque (French & Jacquet, 2004; Jacquet & French, 2002; Li, 1998). This is because these models comprise a hardwired network wherein abstract representations of the two languages take the forms of pre-specified language nodes or language tags (Dijkstra & Van Heuven, 2002; Green, 1998). Alternatively, the forms they take are altogether unaddressed (Grosjean, 2008). This contrasts sharply with the self-organizing models discussed previously, which exhibit only perceptually-cued language selection (French, 1998; Li & Farkas, 2002; Shook & Marian, 2013). In these models, the formation of language clusters proceeds in a principled way from the network's sensitivity to aspects of the input like co-occurrence statistics and similarity structure. One possibility is that bilinguals begin by forming language clusters much like in these self-organizing models. Eventually, however, they abstract from the two language clusters higher-level representations supporting conceptually-based language selection (Byers-Heinlein, 2014; Dijkstra & Van Heuven, 1998; Li & Farkas, 2002; Miikkulainen, 1993). Interestingly,

bilinguals who acquire both languages from infancy, like many of our participants did, might begin developing such higher-level representations even before speaking: By the end of their first year, infants can form abstractions from regularities in artificial language input, including when the input simulates two interleaved linguistic systems with conflicting rules (Gonzales, Gerken, & Gómez, 2015). More telling, Liberman, Woodward, and Kinzler (2016) found that by 9 months, infants register whether different people speak the same language or two different languages, and use this sociolinguistic information to make inferences about whether the people are likely to affiliate with one another. Together, these results suggest that preverbal infants may already be representing language variation at some abstract, conceptual level. It is worth noting, however, that language clusters may not *unilaterally* promote higher-level conceptual representations. In a continual feedback loop, language clusters may foster conceptual representations that in turn reciprocally foster the language clusters themselves (see also Grainger et al., 2010). Consider a French-English bilingual child who has already abstracted conceptual representations of her two languages from clusters thereof. The child might incorporate the French word *fiche* (homophonous with *fish* but meaning “card”) into the French rather than English cluster based at least in part on a conceptual understanding that the speaker only speaks French.

4.4. Conclusion

To conclude, the present study discredits the view that bilingual listeners adjust perception across languages as a strict function of the input, demonstrating for the first time that they can adjust perception based on higher-level information in the form of conceptual knowledge about which language is being spoken. In terms of a bilingual model focused

specifically on listening, this finding suggests a relatively complex architecture, insofar as it implicates a conceptual level of processing. In terms of a more comprehensive bilingual model encompassing both listening and speaking, however, it suggests a relatively simple architecture, in that conceptually-based language selection is possible across both modalities, rather than being the strict purview of the speaking modality.

Appendix

In the main text we dealt with variance heterogeneity across language contexts by performing WMW tests whose rank transformations eliminated detection of any such variance. An arguably more cautious approach to dealing with variance heterogeneity would be to perform an unpaired Welch's t -test, which does not assume equal variances. We reported the results of the WMW test because our raw data additionally exhibited departures from normality, and the WMW test is the standard approach for dealing with non-normally distributed data. As alluded to already, however, the reason that the WMW test does not assume normality is that it rank-transforms the data. In fact, when the Student's t -test is performed on the same rank-transformed data, its test statistic is a monotonically increasing function of that of the WMW test (Conover & Iman, 1981), and the two tests rarely diverge on whether to reject the null hypothesis (Zimmerman, 2012). This implies that the Welch's t -test could replace the WMW test as a distribution-free test if performed on the same rank-transformed. Zimmerman and Zumbo (1993; see also Ruxton, 2006) recommended precisely this approach for data like ours exhibiting both variance heterogeneity and non-normality. We therefore performed a two-tailed Welch's t -test over each bilingual group's rank-transformed data (Fig. 3), entering context as the between-subjects factor (alpha set at .05). Mirroring our WMW test results, each bilingual groups' mean boundary rank differed significantly across contexts (Spanish-English group: $t(27) = 2.11$, $p = .0443$; French-English group: $t(25) = 2.61$, $p = .0147$). Our results thus hold with this arguably more cautious approach.

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