The influence of native-language tones on lexical access in the second language

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When listening to speech in a second language, bilinguals' perception of acoustic-phonetic properties is often influenced by the features that are important in the native language of the bilingual. Furthermore, changes in the perception of segmental contrasts due to L1 experience can influence L2 lexical access during comprehension. The present study investigates whether the effect of L1 experience on L2 processing seen at the segmental level extends to suprasegmental processing. In an eye-tracking task, Mandarin–English bilinguals heard an auditorily presented English word and selected which of two visually presented Chinese characters represented the correct Mandarin translation. The pitch contour of the spoken word was manipulated to either match or mismatch the lexical tone of the Mandarin translation. Results revealed that bilinguals were significantly faster to correctly identify the target and made earlier eye movements to targets when the suprasegmental information of the word spoken in English matched that of its Mandarin translation. The findings provide compelling evidence for bilinguals' sensitivity to suprasegmental tone information, even when listening to a non-tonal language. These results have important implications for the effect of L1 experience on L2 lexical access and language interaction in bilinguals, and are consistent with a highly interactive account of language processing. © *2016 Acoustical Society of America*.
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I. INTRODUCTION

Languages differ in the elements of speech that can convey meaningful information during communication. For bilingual speakers, experience distinguishing words based on acoustic features in one language can result in changes to how that feature is perceived or learned in another language (Dupoux *et al.*, 2010; Mora and Nadeu, 2012). For instance, L1 speakers of Catalan who have extensive L2 Spanish experience are less accurate at distinguishing /e/ and /ɛ/, a phonetic contrast that is important for Catalan, but which does not exist in Spanish (Broersma and Cutler, 2008). Furthermore, differences in the ability to perceive phonetic distinctions that are driven by experience with multiple languages, as in the Catalan-Spanish example, can impact listeners' ability to recognize or discriminate lexical items (Broersma and Cutler, 2008; Cutler *et al.*, 2006; Mora and Nadeu, 2012; Pallier *et al.*, 2001). Japanese–English bilinguals, for example, show evidence of lexical competition from "locker" when hearing the word "rocker" (Cutler *et al.*, 2006). This effect occurs because Japanese listeners conflate the phonetic segments /r/ and /l/ into a single dominant category, based on the most similar L1 category (a similar effect has also been reported for Dutch, see Weber and Cutler, 2004). In other words, when segmental information, like phonemes, provides the primary cue for word identity, as in minimal pairs like rock and lock, L2 lexical access is affected by L1 phonetic (i.e., segmental) categories. Here, we explored whether relevant L1 *suprasegmental* information can influence word recognition in an L2 that does not rely on suprasegmental information as a cue to word identity.

In addition to conveying meaning through segmental information, like phonemes, morphemes or letters, many languages also rely on suprasegmental information, such as lexical tone or prosody, to differentiate between segmentally identical words. For example, speakers of Mandarin Chinese use one of four tones to distinguish between segmentally identical words—flat-high (tone 1), rising (tone 2), dipping (tone 3; v-shaped), and falling (tone 4). For example, the Mandarin word *shu* can be produced with one of four tones that carry word-meaning information in Chinese: *shu1*, produced with a flat tonal contour, means "book"; *shu2*, produced with a rising tonal contour, means "familiar"; *shu3*, produced with a dipping tonal contour, means "rat"; and *shu4*, produced with a falling tonal contour, means "tree." Because the segmental (i.e., phonetic) information in these words is identical for native speakers of Mandarin, suprasegmental tone information provides the salient cue to meaning, and is thus critical to lexical access during speech processing.

Native speakers of Mandarin may use the tone contour of a word to quickly constrain the activation of lexical candidates that are segmentally identical, but differ in tone (Cutler and Otake, 1999; Cooper *et al.*, 2002; Lee, 2007; Malins and Joanisse, 2010). For instance, Lee (2007) showed that hearing the Mandarin word *lou2* (hall) significantly primed responses to the identical target *lou2*. However, hearing the

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Mandarin word *lou3* (hug) did not prime *lou2*, despite the identical segmental overlap. Poss *et al.* (2008) provide further evidence that tone information constrains lexical activation. Across both a lexical decision and an auditory shadowing task, Mandarin speakers were slower to respond to target words that were preceded by a prime that was segmentally distinct but which contained a matching lexical tone (relative to a prime that did not match in either segment or tone). The authors suggest that these effects were driven by competition among lexical candidates that share tone. Together, these results provide consistent evidence for the constraining effect of lexical tone, but suggest that the mechanism by which tone constrains lexical access may differ depending on the source of ambiguity. That is, when presented with a prime, the tone information serves to limit access to just those other lexical candidates that share segments, while simultaneously increasing competition from segmentally distinct, but tonally related lexical entries. Critically, these findings also suggest that the effect of tonal suprasegmental information on lexical access is *dissociable* from that of segmental information, and therefore provides an independent cue for word identity.

In support of the dissociation between segmental and suprasegmental effects, research indicates that segmental and tonal information provide distinct effects on word recognition, primarily when presented in context (Liu and Samuel, 2007; Ye and Connine, 1999). Li *et al.* (2013) performed a Stroop task wherein native Mandarin speakers were asked to name the color of presentation of a Chinese character (e.g., *hong2*, "red"). In one experimental condition, the Chinese character consisted of a segmentally unique word that contained the same tone as the to-be-named color word (*ping2*, "bottle"). Relative to neutral trials, the tone-overlapping trials showed significant facilitation effects, indicating that tonal information plays a distinct and important role in lexical access. Neurological research has also highlighted the distinction between tone and segment for word recognition. In an ERP study, Malins and Joanisse (2012) asked Mandarin speakers to judge whether a picture (*hua1*, "flower") matched an auditory word that was either segmentally identical, but used a different tone (*hua4*, "painting") or was a cohort competitor (*hui1*, "gray"). The authors observed more brain activity in left-lateralized electrode sites for the segmental condition relative to the cohort condition, indicating that different cognitive or neural mechanisms may underlie tonal versus segmental processing in Mandarin listeners.

The dissociation between tonal processing and segmental processing is also supported by evidence from eye-tracking research. Malins and Joanisse (2010) presented Mandarin monolinguals with target images (e.g., *chuang2*, bed) alongside segmentally unique but tonally overlapping competitors (e.g., *niu2*, cow). They found that the Mandarin speakers were more likely to fixate the competitors than unrelated distractors, based upon the overlapping tonal information. Furthermore, when Mandarin monolinguals were asked to fixate targets (e.g., *chuang2*, bed) in the presence of a segmentally identical competitor that contained a different tone (e.g., *chuang1*, window), the time course of disambiguation was similar to when the competitor was a cohort (e.g., *chuan2*, ship). Because the segmental information did not provide a relevant cue, due to the complete overlap between target and competitor, the tone information alone cued the listener to the identity of the target image.

While it is clear that suprasegmental tone information provides an important independent cue for lexical access within a single language, the effect that relevant tone information can have *across* languages is less clear. Research exploring how experience with a tonal language may impact processing in a bilingual's *non-tonal* language has primarily focused on changes in perceptual salience. For example, when making stress judgments on English words, Mandarin–English bilinguals show an increased reliance on the pitch contour relative to English monolinguals (Gandour, 1983; Zhang and Frances, 2010). The increased weight that bilinguals placed on properties of the pitch relative to English monolinguals is likely due to the increased importance of pitch for determining meaning in their native language, Mandarin.

However, this finding merely suggests that bilinguals who speak a tonal language place increased importance on the pitch contour even when using their non-tonal language, but it does not speak to whether that increased attention to tone information influences word recognition in the non-tonal language. On the one hand, there is evidence that for monolingual Mandarin speakers, tone may be a weaker cue to meaning than segmental information (Repp and Lin, 1990; Tong *et al.*, 2008), and tones have been found to be less perceptually salient than segmental phonetic information (Burnham *et al.*, 2011). In addition, for speakers of non-tonal languages like English, intonation does provide the listener with non-lexical information, such as a speaker's mood or attitude, and bilinguals may focus more on those aspects of the speech signal when hearing their non-tonal language. As a result, for bilinguals listening to speech in their non-tonal language, lexically identifying tone information may not be salient enough to influence L2 lexical access. On the other hand, there is abundant evidence that bilinguals access lexical items in both of their languages simultaneously, even in single-language contexts (e.g., Shook and Marian, 2012; Wu and Thierry, 2010). Furthermore, Quam and Creel (2012) found that Mandarin–English bilinguals were better able to use tone information to identify novel objects with novel labels than English monolinguals, and this advantage positively correlated with dominance in Mandarin. Critically, this effect was found even though the novel words were designed to be equally phonotactically likely in Mandarin and English, and when presented in an English context (i.e., with the English carrier phrase, "Choose the _____"). Thus, there is reason to predict that bilinguals may be sensitive to the meaningful cue carried by the tone contour, even when processing in their non-tonal language.

To examine whether relevant suprasegmental information affects lexical access across languages, we investigated whether Mandarin–English bilinguals listening to their non-tonal L2 (English) are sensitive to tone information that is lexically relevant in their L1 (Mandarin), but not in L2. Participants' eye movements were recorded while they completed a translation recognition task, which involved hearing an English word and selecting the correct Mandarin translation from two visually presented, orthographic choices; the task was designed such that listeners can successfully identify the translation using segmental information alone. Critically, we manipulated the tone-contour of the English word to match or mismatch the tone contour of the Mandarin translation. If bilinguals are not sensitive to the meaningful lexical information carried by the tone during L2 English processing, then we expect their performance in the task to be unaffected by the match or mismatch between the auditorily presented pitch contour of the English word and that of the Mandarin translation. If, in contrast, bilinguals are sensitive to the potentially informative tone contour of the English words during translation and lexical access, we should expect different performance dependent on whether or not the L2 tone matches the L1 translation.

II. METHODS

A. Participants

Participants were 17 Mandarin–English bilinguals (12 female, $M_{age} = 22.8$ yr, SD = 6.0), who were native Mandarin speakers and were currently living in the United States. Using the Language Experience and Proficiency Questionnaire (LEAP-Q; Marian *et al.*, 2007), participants provided self-reported measures of proficiency (scale of 0–10, with 10 being fluent), age of acquisition, and current exposure for both Mandarin and English. Bilinguals' Mandarin proficiency (9.0, SD = 1.4) did not differ from their English proficiency (7.84, SD = 1.8), $t(16) = -1.6$, $p > 0.1$. The bilinguals had significantly earlier ages of acquisition for Mandarin (0.76 yr, SD = 0.83) relative to English (7.0 yr, SD = 4.28), $t(16) = 5.74$, $p < 0.01$, and significantly less current exposure to Mandarin (35.6%, SD = 20.5%) relative to English (64.3%, SD = 20.4%), $t(16) = 2.89$, $p < 0.05$. Participants were also administered measures of non-verbal intelligence [Wechsler abbreviated scale of intelligence (WASI); Wechsler, 1999], short-term memory [digit span and non-word repetition subtests of the comprehensive test of phonological processing (CTOPP); Wagner *et al.*, 1999), and English vocabulary [Peabody picture vocabulary test (PPVT); Dunn and Dunn, 1997]. Detailed information about the participants can be found in Table I.

TABLE I. Participant demographics.

A. Background and cognitive measures		
	Mean (standard deviation)	
Age	22.8 yr (6.0)	
Gender	12 F, 5 M	
Non-verbal intelligence (WASI)	114.9 (12.3)	
Digit span (CTOPP)	16.6 (2.7)	
Non-word repetition (CTOPP)	15.4 (2.8)	
PPVT standard score	98.6 (29.6)	
B. Bilingual language information		
	Mandarin	English
Proficiency	9.0 (1.4)	7.84 (1.83)
Age of acquisition[a]	0.76 yr (0.83)	7.0 yr (4.28)
Current exposure[a]	35.6% (20.5)	64.3% (20.4)

[a]Indicates a significant difference between Mandarin and English self-reported ratings at $p < 0.05$.

B. Materials

In the present study, 120 English words were selected to serve as targets in the task. Target words were monosyllabic, non-homophonous, were orthographically represented in Chinese by a single character, and had an average English spoken-word log frequency of 1.861 words per million (SD = 0.686). Each English word was recorded by a female Mandarin–English bilingual who was instructed to produce the English word with the tone contour of one of the four lexical tones in Mandarin. The decision to use natural speech, rather than synthesized speech, was made because bilingual listeners have been shown to have more difficulty understanding synthesized speech relative to natural speech (Axmear *et al.*, 2005; Mack *et al.*, 1990; Reynolds *et al.*, 1996). Thus, using synthesized speech may have imposed an additional cognitive load on the participants, making the task less natural, and may have further masked the already-low perceptual salience of the tone information (relative to segmental information).

To record the words, the speaker was taught a numerical label for each Mandarin tone, 1–4, and was given a list of English words with the target-tones marked as they would be in pinyin (e.g., "tree-4" or "tree-1"). Each word was recorded twice—once with the tone contour of its direct translation and once with a tone contour that did not directly match the translation. For example, the English word *tree* was produced once with a tonal contour corresponding to its Mandarin translation *shu* (the fourth tone, falling) and once with a mismatched tone contour (the first tone, level). The recordings were independently evaluated by a researcher trained in phonetics who was also a native speaker of Mandarin; recordings judged to poorly represent the target tone were re-recorded.

Two counterbalanced lists were created using all 120 target English words. In each list, half of the words were presented with a tone that corresponded to the Mandarin translation (match condition), and half were presented with a tone that did not correspond to the translation (mismatch condition). Thus, each target word was presented in the match condition for half of the participants, and the mismatch condition for the other half of participants.

The Mandarin translation for each target word was also presented visually (i.e., its Chinese character), and was paired with a phonologically and semantically unrelated Chinese character, which served as a filler item in a two-alternative forced choice task (see Fig. 1). The target items had a significantly higher log-frequency in Chinese (3.54, SD = 0.75) than the unrelated fillers (2.66, SD = 0.73), $t(238) = 9.138$, $p < 0.01$. However, our primary comparison of interest in the present study was between the target words in the match condition and *those same words* in the mismatch condition, and therefore, target and filler items were not directly compared. In addition, the tone contour of the filler item's spoken form did not overlap with either the matched or mismatched tone of the target item [for example, the target *tree*, which used tone 4 in the match condition and tone 1 in the mismatch condition, was paired with the filler *dragon* (Mandarin *Long*) which used tone 2]. Due to methodological constraints and the need to control for confounding variables in the present study (e.g., limiting stimuli to monosyllabic, single-character, non-homophonous words), we did not have an equal representation of all four tones within our target stimuli (proportion of target tones across the two lists: Tone 1 = 50.4%, Tone 2 = 9.6%, Tone 3 = 9.6%, and Tone 4 = 30.4%). However, this asymmetry is unlikely to affect the present study, which is focused on the first step of investigating bilinguals overall sensitivity to suprasegmental information; exploring tone-specific sensitivity could be an important addition for future work.

C. Procedure

After obtaining consent, participants were seated approximately 80 cm away from a computer screen (2560 × 1440 screen resolution), fitted with closed-back headphones, and instructed to place their chins into a chin-rest for the duration of the experiment. Participants' eye movements were tracked using an Eyelink 1000 eye-tracking system at 1000 Hz (1-ms sampling resolution).

At the beginning of the experiment, participants were given written instructions in English and provided with four practice trials to familiarize them with the task. During each trial, participants were instructed to click a fixation cross located in the bottom portion of the screen using a computer mouse. After clicking the fixation cross, participants viewed a blank screen for 500 ms, at which point an auditory word was presented over headphones. At the offset of the auditory word, two Chinese characters appeared in the top-left and top-right corners of the screen. Participants were instructed to select via mouse-click which of the two Chinese characters corresponded to the translation of the auditory word. After each trial, participants received feedback (the word "correct" or "incorrect" appeared on the screen for 300 ms). The location of the correct translation was counterbalanced; the target item appeared on the left and right side of the screen an equal number of times, and did not appear on the same side for more than three consecutive trials. In addition, the order of presentation was randomized across participants. After completing the translation recognition task, participants completed a series of cognitive tests and a questionnaire regarding their language background (see Table I).

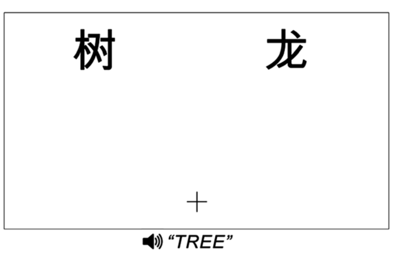

FIG. 1. Example of a translation recognition trial. Participants heard the spoken word "tree" while viewing a display containing the Chinese character for the target word (left side, 树) and the Chinese character for a phonologically and semantically unrelated word (right side, 龙, or *dragon*). In half of the trials, the tone contour of the spoken English word correctly matched that of the target word; in the other half of trials, the English word was presented with a tone contour that did not match either the target word or the semantically unrelated distracter.

D. Data analysis

The dependent measures recorded during the experiment included response time in milliseconds (mouse-click), time of first-fixation to target (ms), and the time-course of target fixation. Participants were highly accurate (97.8%, SD = 2.24%). Trials that were responded to incorrectly, or had a response time that was greater than 2.5 standard deviations from a participant's mean were removed from the dataset, totaling approximately 5.9% of the data.

Eye fixations were defined as any eye-movement event where the participant maintained a consistent gaze at a given spatial location on the screen for longer than 100 ms; fixations less than 100 ms in duration were not included in the analysis. The first-fixation to target was measured as the time-point at which a participant first moved their eye to the target (translation) word. For the first-fixation analyses, we included only those trials that contained a fixation to the target item (1696 of 1918 trials, or 88.4% of trials). For the time-course analyses, fixations were collapsed into 10 ms bins, and the average fixation to each item at each 10 ms bin was recorded. For both the first-fixation and time-course analyses, only fixations that occurred 200 ms post-onset of the display were included in order to ensure that the fixation data did not represent looks around the display prior to the appearance of the target and filler items.

Response time (ms) and time of first-fixation (ms) measures were analyzed using linear mixed effects model comparisons. All data were analyzed with linear mixed effects regression with subject and item as random intercepts and slopes; match status (match, mismatch) was contrast-coded and added to the model as a fixed effect. Fit comparisons were conducted using a likelihood ratio test to determine the best-fit random slope and intercept models.

The time-course of target fixation was analyzed using growth-curve analysis (GCA) using the *lme4* package in R Statistical Computing (Bates *et al.*, 2015). Analyses began at 200 ms post-offset of the target word, and ended at 2300 ms post-onset; the terminal time-point was determined by identifying the bin at which participants' fixation proportions to the target item were below 0.1 (10%). The overall time-course of target fixations was captured using a fourth-order (quartic) orthogonal polynomial (Mirman, 2014). To capture how the tone information in the English word modulated changes to fixations over time, the model included interactions of the fixed effect of match status (match, mismatch) with all time terms. Statistical significance for individual parameter estimates was assessed using the normal approximation. Random intercepts and slopes for the orthogonal polynomials representing changes over time were included for participants and the nested effects of participant by within-participant factors (match status).

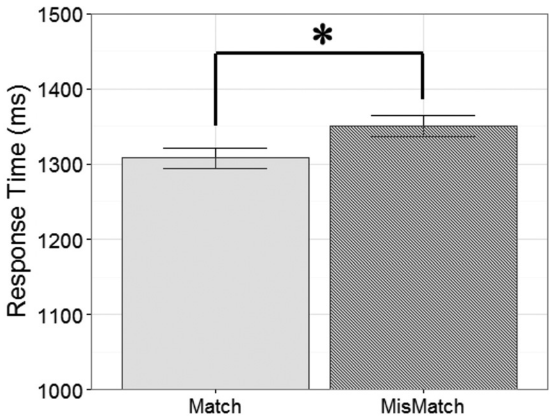

FIG. 2. Response time results (ms) during translation recognition. The asterisk denotes significance at alpha = 0.05, and the error bars represent +/− 1 standard error.

III. RESULTS

A. Behavioral response time (mouse click)

Comparison of a base model containing random intercepts and slopes of subject and item to a Model including match status as a fixed effect revealed a significant effect of match status on model-fit [$\chi^2(1) = 10.01$, $p < 0.01$],[1] with bilinguals responding more quickly in match trials (1308 ms, SD = 230 ms) than in mismatch trials (1350 ms, SD = 224 ms, see Fig. 2). In other words, when bilinguals heard an English word superimposed with a tone contour that matched the Mandarin translation of that word, they were faster to accurately select the corresponding Mandarin character than when the tone contour did not match the translation.

B. Time of first-fixation

Similar to the response time analyses, the addition of match status as a fixed effect resulted in an improved model fit [$\chi^2(1) = 5.03$, $p < 0.05$],[2] with bilinguals fixating the target item earlier in the Match condition (496 ms, SD = 108 ms) relative to the mismatch condition (537 ms, SD = 89.9 ms, see Fig. 3). This finding reflects the bilingual participants' sensitivity to the overlap between the tone counter of the target item (i.e., the translation) and the superimposed tone contour of the spoken English word.

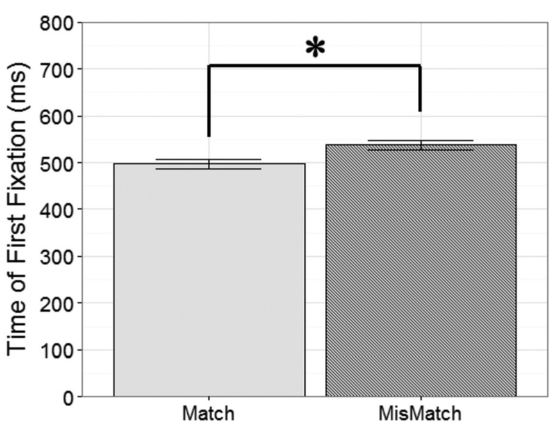

FIG. 3. Time of first fixation results (ms) during translation recognition. The asterisk denotes significance at alpha = 0.05, and the error bars represent +/− 1 standard error.

C. Time-course of fixation

Growth-curve analyses revealed that match status significantly influenced how participants fixated the target item over time [$\chi^2(5) = 69.8$, p < 0.001]. Specifically, a significant effect was found in the parameter estimates on the cubic term (*Estimate* = −0.21, SE = 0.03, p < 0.001); this finding suggests that the model fit to the match condition data showed an earlier rise in target looks relative to the model fit to the mismatch condition data (Fig. 4). This finding is consistent with the response time and time of first-fixation results, and suggests that the listeners were sensitive to the match between the superimposed tone of the English word, and its Mandarin translation.

IV. DISCUSSION

In the present study, we found evidence that Mandarin–English bilinguals listening to words in their non-tonal L2 (English) are sensitive to the suprasegmental tone information carried by the English word. Participants were faster to correctly identify the translation equivalent of the spoken English word when the tone information matched the Mandarin pronunciation of the visually presented Chinese character. Furthermore, the effect of tone on translation recognition occurred even though the contour was not only presented in the bilinguals' non-tonal language, but was also irrelevant to the task—listeners could have ignored the pitch contour of the spoken English word and successfully identified the translation by segmental information alone. However, our results provide clear evidence that the bilinguals were nevertheless sensitive to tone information during the task. In addition, the tone contours of the English words were not exact matches of the contours of Mandarin tones, but conveyed the overall patterns of pitch change and directionality. This suggests that L2 listener's sensitivity to suprasegmental information may be fairly robust. Our results

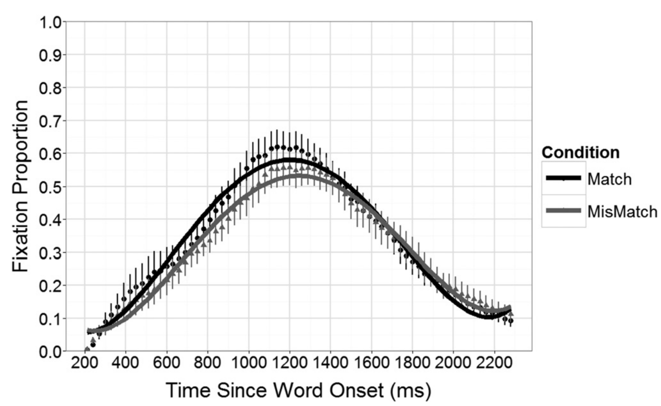

FIG. 4. Time-course results (ms) during translation recognition. Dots represent the raw fixation proportions to targets (i.e., fixations to target items divided by the total number of fixations) at each time point, with error bars indicating +/− 1 standard error. The lines represent the polynomial models derived from growth-curve analysis fit to data from the match (black) and mismatch (gray) conditions.

align with previous work indicating that L1 segmental acoustic-phonetic properties affect L2 lexical access (e.g., Cutler *et al.*, 2006) and extend to show that suprasegmental information that is critical to lexical access in one language affects spoken word recognition in a second language that does not use tone lexically.

While our results provide compelling evidence of L1 transfer of lexical tone processing to L2 lexical access, there are several possible explanations for the difference in translation performance between the match and mismatch conditions. First, the faster response times and earlier first-fixations to targets in the Match condition could reflect a facilitatory effect of the matching tone. When bilinguals hear a word in one language, they quickly and automatically access the translation of that word (Thierry and Wu, 2007; Zhang *et al.*, 2011). In addition, listeners begin activating possible lexical candidates during speech recognition prior to the completion of the spoken word (e.g., Dahan *et al.*, 2001; Marslen-Wilson, 1987). Thus, as our bilinguals heard a spoken English word, they began to access lexical items in both English and Mandarin. In the mismatch condition, the tone information was not informative and was unlikely to aid activation of the lexical representation of the translation. In contrast, in the match condition, the tone contour provided a complementary cue to the intended target, which may have increased the relative strength of the translation representation at the lexical level. The finding that tone information provides an independent online cue to word identity (Malins and Joanisse, 2010) further supports this account, and suggests that the bilinguals used every available cue to aid L2 lexical access during the task.

However, the nature of the study design allows for another possibility, wherein rather than indicating a *facilitatory* effect of the matching tone, our results reflect a *delay* in lexical access during the mismatch condition. Perhaps because the segmental information provided to the listeners in the current study was unambiguous (i.e., there was no overt phonological or orthographic competition in the task), participants were already sufficiently fast at accessing the translation without utilizing the corroborating tone information. In this scenario, the difference between match and mismatch performance would be driven by *slower* responses to translations in the mismatch condition. Under such an account, the mismatch between the tone information carried by the English word and the expected tone given the translation could result in bilinguals experiencing interference during lexical access.

Finally, the facilitatory account and the delayed access account are not mutually exclusive; both facilitation by way of tone-match and interference by way of tone-mismatch could be present in our bilinguals. To illustrate the combined account, consider the English word tree. In the match condition, the overlap in tone between the English word and the expected translation could result in the decreased activation of segmentally identical competitors that use different tones, which could aid lexical access through reduced lateral inhibition from those tone-neighbors. Indeed, Lee's (2007) findings suggest that tone serves primarily as a constraining factor during lexical access by reducing the activation of segmentally identical, but tonally distinct lexical items. In the mismatch condition, the results of Poss *et al.* (2008) suggest that the tone of the English word could activate tone-matched lexical items that compete for selection with the target; this competition would only occur in the mismatch condition, as Lee suggests that the matched tone would ultimately reduce the number of potential competing candidates. Future research is necessary to determine both the source and directionality of the effects observed in the present study.

The observation that L1 suprasegmental information influences L2 lexical processing in bilinguals may have important implications for language co-activation during processing. There is an exceedingly large amount of evidence to indicate that bilinguals access both of their languages simultaneously, even when they intend to only use one language (see Kroll *et al.*, 2006; Kroll *et al.*, 2013, for reviews). However, investigations into language co-activation have primarily hinged upon overlap at segmental (phonological or orthographic) and semantic levels, and little work has explored the impact that suprasegmental information may have on language co-activation. Our results cannot speak to this issue directly, as the nature of the task required bilinguals to overtly access both of their languages. However, the findings do provide evidence of the role of L1 tone information during L2 lexical access. If listeners are sensitive to L1 suprasegmental information even when processing a nontonal L2, as we observed here, then meaningful tone information may provide an additional route through which language non-selectivity can occur in bilinguals. Using an experimental design similar to the one outlined here, future work could explore the influence of tone information on language non-selectivity by manipulating the tone of the filler item to create competition with the target (for example, by imposing a tone on the spoken word that corresponded to the translation of the *filler* rather than that of the target). Investigating whether tonal information can provide an independent source of language co-activation is of critical importance to theories of bilingual language processing and second language learning.

In sum, we provide compelling evidence that the effects of L1 knowledge on L2 lexical access are not limited to segmental processing (Cutler *et al.*, 2006), but extend to suprasegmental processing as well. Indeed, Mandarin–English bilinguals appear to use the tonal information present in English words as potential cues for meaning when listening to speech. The influence of suprasegmental information on speech processing across languages could have important implications for native speakers of tonal languages who are learning English as a second language. For instance, novel English words presented with tonal contours corresponding to correct translations may help reinforce the meaning of these novel words in L2 and potentially aid in acquisition by providing additional cues during learning. Future work would do well to explore how instructors can best leverage their students' experience with L1 tone information in order to help them learn a second language.

Furthermore, the finding that bilinguals are sensitive to suprasegmental information that is relevant in their L1 while processing speech in their L2 indicates a high degree of interactivity between the two languages. This effect is predicted by highly interactive models of bilingual speech comprehension, such as the BLINCS model (Shook and Marian, 2013). In BLINCS, the presentation of tonal information could increase activation of corresponding lexical and semantic representations, independent of the segmental phonology. As a result, Mandarin words matching that lexical tone would be more strongly activated, and could prime activation of their English translations, thus increasing bilingual's speed of recognition and translation, as observed in the present study. Our findings suggest that when listening to speech information, bilinguals may bring to bear all of the strategies and tools at their disposal, regardless of language or level of processing (segmental or suprasegmental), in an effort to benefit language comprehension.

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[1]A comparison of response times with trial order as an additional fixed effect showed a similar pattern of results. Compared to a base-model with trial order, the model fit was significantly improved with the addition of match-status as a fixed effect ($\chi^2 = 8.71$, $p < 0.05$). In addition, we performed the reaction time analysis with target tone as a fixed-effect (Tone 1 vs Tone 4), and found that there was no significant benefit to adding target-tone to the model [$X^2(2) = 3.8796$, $p > 0.1$], suggesting target-tone did not significantly contribute to the match-status effect.

[2]A comparison of first fixation with trial order as an additional fixed effect showed a similar pattern of results. Compared to a base-model with trial order, the model fit was significantly improved with the addition of match-status as a fixed effect ($\chi^2 = 6.41$, $p < 0.05$). In addition, we performed the first fixation time analysis with target tone as a fixed-effect (Tone 1 vs Tone 4). We found that the addition of target-tone did significantly improve the model [$X^2(2) = 14.23$, $p < 0.001$], but that the interaction between match-status and target-tone was non-significant ($Est. = 52.04$, $p > 0.1$), suggesting that tone did not significantly contribute to the match-status effect.

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