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REGULAR ARTICLE

Dynamic effect of tonal similarity in bilingual auditory lexical processing

Junru Wu [a,b], Yiya Chen[b], Vincent J. van Heuven[b,c] and Niels O. Schiller[b]

[a]Department of Chinese Language and Literature, Laboratory of Language Cognition and Evolution, East China Normal University, Shanghai, People's Republic of China; [b]Leiden University Centre for Linguistics, Leiden Institute for Brain and Cognition, Leiden, Netherlands; [c]Department of Hungarian and Applied Linguistics, University of Pannonia, Veszprém, Hungary

ABSTRACT
Phonological similarity affects bilingual lexical access of etymologically-related translation equivalents (ETEs). Jinan Mandarin (JM) and Standard Chinese (SC) are closely related and share many ETEs, which are usually orthographically and segmentally identical but vary in tonal similarity. Using an auditory lexical decision experiment and Generalised Additive Modelling, the present study investigates how cross-linguistic tonal similarity interacts with language of operation and how the switching of language across blocks influences SC-JM bilinguals' auditory lexical processing of ETEs. Bilinguals showed a language dominance effect, indicating that ETEs are specified with separated word-form representations. Compared with SC tonal monolinguals, bilinguals showed a discontinuous bilingual auditory lexical advantage, instead of a classical bilingual lexical disadvantage. The dynamic role of cross-linguistic tonal similarity in auditory word processing is discussed in light of the bilinguals' attentional shift with the change of language mode at the pre-lexical and lexical stages.

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Bilingualism; lexical access; cognate; cross-linguistic similarity; tone

1. Introduction

The sound shapes of words can be more or less similar to each other. The degree of similarity varies depending on the phonemes in the words and how these phonemes are combined. Words can be compared not only within one language in terms of phonological similarity, but also across languages. Cross-linguistic[1] phonological similarity has been shown to influence bilingual auditory lexical processing. The way cross-linguistic tonal similarity influences auditory lexical processing, however, requires further research.

1.1. Cross-linguistic phonological similarity in bilingual auditory lexical processing

Previous auditory studies have repeatedly shown that bilingual auditory lexical processing is influenced by the strength of cross-linguistic phonological similarity (e.g. Cutler, Weber, & Otake, 2006) in an integrated bilingual lexicon (Canseco-Gonzalez et al., 2010; Lagrou, Hartsuiker, & Duyck, 2013; Marian & Spivey, 2003; Marian, Spivey, & Hirsch, 2003; Spivey & Marian, 1999; Weber & Cutler, 2004). Increased cross-linguistic phonological similarity, however, was found to either facilitate or interfere with bilingual auditory lexical processing, depending upon the specific context and task (e.g. in Marian, Blumenfeld, & Boukrina, 2008, experiment 3).

The prima facie inconsistent phonological similarity effect was explained by postulating different roles of phonological similarity at lexical and pre-lexical stages of language processing (Spinelli, Segui, & Radeau, 2011). On the one hand, lexical-level competition (or: parallel inhibition) has been proposed to account for the interfering effect of phonological similarity (e.g. by the TRACE model, McClelland & Elman, 1986, the Cohort model, Marslen-Wilson, 1987, and the Neighbourhood Activation Model, Luce & Pisoni, 1998). On the other hand, at the pre-lexical stage, phonological similarity is related to facilitation in a data-driven way (e.g. found as facilitatory auditory priming effect in Spinelli et al., 2001).

Observed processing costs (e.g. reaction times) in lexical tasks usually result from both lexical and pre-lexical stages. As demonstrated by hypothetical examples in Figure 1, with phonological similarity as the predictor, the pre-lexical processing cost can be modelled with various *decreasing* functions (the red solid lines), the lexical processing cost can be modelled with various *increasing* functions (the blue dash lines), and the observed processing cost can be modelled with the sum of the pre-lexical and lexical functions (the black dotted lines). The function for the observed

CONTACT Junru Wu jrwu@zhwx.ecnu.edu.cn
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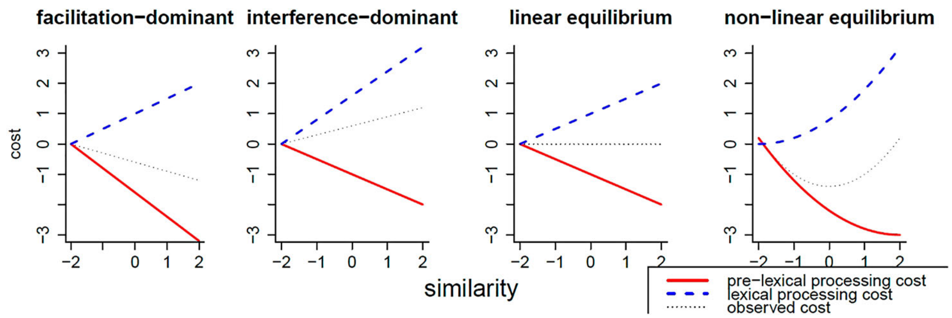

Figure 1. Hypothetical pre-lexical processing cost as decreasing functions of phonological similarity (red solid lines), lexical processing cost as increasing functions of phonological similarity (thick dash lines), and their sum as the function for observed cost (black dotted lines). The function for the observed processing cost can be facilitation-dominant (1st panel), interference-dominant (2nd panel), linearly balanced (3rd panel), or non-linearly balanced (e.g. concave, 4th panel), depending on the slopes and shapes of the pre-lexical and lexical functions.

cost can take various shapes (monotonous or non-monotonous; decreasing or increasing) depending on the slopes and shapes of the pre-lexical and lexical functions.

The patterns of observed cost such as shown in Figure 1 are not unprecedented (e.g. Dijkstra, Miwa, Brummelhuis, Sappelli, & Baayen, 2010). In return, the pre-lexical and lexical functions can be partly deduced from the shape of the function for the processing cost observed in the current study. Hence, by observing the processing cost as a function of phonological similarity using lexical tasks, we can tap into the mechanisms at the lexical and pre-lexical stages of processing with more details.

Returning to bilingual auditory lexical processing, it is known that the effect of cross-linguistic phonological similarity is modulated by a number of factors, such as speech context (Lagrou, Hartsuiker, & Duyck, 2011, 2012, 2015; Lagrou et al., 2013), monolingual versus bilingual modes of language processing (Canseco-Gonzalez et al., 2010; Grosjean, 1998, 2001), as well as the status of the language of operation[2], e.g. nativeness, proficiency, and age of acquisition (Athanasopoulos et al., 2015; Canseco-Gonzalez et al., 2010; Marian & Spivey, 2003; Weber & Cutler, 2004).

What remains unclear is how these various factors take effect in lexical and pre-lexical stages of bilingual lexical processing. Taking the lexical and pre-lexical mechanism into consideration, the divergent effects of cross-linguistic similarity may be explained more coherently.

The primary goal of this study is therefore *to further investigate the possibly dynamic interaction between cross-linguistic phonological similarity and the various factors characteristic of bilingual lexical representations and speech processing at the pre-lexical and lexical stages*. Specifically, we are looking into how the pre-lexical and lexical processing costs are modulated by *language dominance, the switching of the language of operation, as well as the dynamic change with the progress of the task*.

1.2. Cross-linguistic phonological similarity and cognate facilitation

One famous test case of cross-linguistic phonological similarity is etymologically-related translation equivalents (ETEs), which have a common origin, refer to the same concepts, and are similar in sound. They are either inherited from the common ancestor language as cognates or borrowed across languages as loan words.

Compared with unrelated translation equivalents, the effect of cross-linguistic phonological similarity on ETEs seems to be facilitatory. Using "cognates" to refer to ETEs, psycholinguists have found a "cognate facilitation effect" in many visual studies, under different tasks and conditions (Bultena, Dijkstra, & Van Hell, 2014; Costa, Caramazza, & Sebastian-Galles, 2000; Costa, Santesteban, & Caño, 2005; Dijkstra et al., 2010; Dijkstra, Grainger, & Van Heuven, 1999; Duyck, Assche, Drieghe, & Hartsuiker, 2007; Lemhöfer et al., 2008; Lemhöfer & Dijkstra, 2004; Van Hell & Dijkstra, 2002). ETEs are processed faster than unrelated translation equivalents by bilinguals of various languages. Since ETEs are phonologically more similar than unrelated translation equivalents, the cognate facilitation effect is more in line with facilitatory cross-linguistic phonological similarity effects.

Nevertheless, how the processing of ETEs themselves is influenced by the *strength* of phonological similarity is still unclear. Bilinguals' speed of lexical responses to ETEs can either increase (Dijkstra et al., 2010; Duyck et al., 2007; Nakayama, Verdonschot, Sears, & Lupker, 2014), decrease (e.g. Dijkstra et al., 1999), or remain unaffected (Lemhöfer & Dijkstra, 2004) with the strength of phonological similarity.

Moreover, although cognate facilitation has been well investigated in visual studies, relevant auditory studies are scarce and inconsistent. ETEs were found to yield comparable facilitatory cross-linguistic repetition priming in both visual and auditory experiments, (Woutersen, De Bot, & Weltens, 1995). However, in a study using a auditory visual world paradigm, ETEs are more susceptive to cohort competition than unrelated translation equivalents (Blumenfeld & Marian, 2007). Thus, the limited auditory findings are also inconsistent.

These inconsistencies are in line with what was noted for the cross-linguistic phonological similarity effect in auditory lexical processing. There may be several reasons for this inconsistency in findings regarding the influence of phonological similarity.

First, in visual studies, unlike semantic and orthographic similarities (Dijkstra et al., 1999, 2010), phonological similarity co-varies and interacts with orthographic similarity. For instance, Dijkstra et al. (2010) have shown that phonological similarity influences orthographically identical and non-identical ETEs differently.

Second, a pair of ETEs can vary along different phonemic dimensions. For instance, some have different vowels and others have different consonants. Nevertheless, the specific bilingual language combinations investigated in the earlier studies suffer from a relative scarcity of mono-dimensional variability. This encouraged us to look for a better test case for the effect of phonological similarity along one specific phonemic dimension at a time (e.g. onset, rime, or tone).

Finally and more importantly, similar to what was discussed in 1.1.2, evidence supports that cross-linguistic similarity also influences ETE processing via both lexical and pre-lexical mechanisms. On the one hand, cognate facilitation (e.g. Dijkstra et al., 1999) and similarity-related facilitation on ETE recognition (e.g. Duyck et al., 2007) are in-line with the facilitatory mechanism via pre-lexical overlapping. On the other hand, ETE-related increase of cohort-competition in auditory visual world paradigm (Blumenfeld & Marian, 2007) and similarity-related interference on ETE recognition (e.g. Dijkstra et al., 1999) suggest that the interference mechanism via lexical-competition is also playing a role. Whether facilitation or interference would finally be observed is probably modulated by various bilingual factors.

Thus, a more particular goal of this study is therefore to investigate *how cross-linguistic phonological similarity and various bilingual factors influence auditory recognition of ETEs*.

1.3. Tonal bilingualism of two Chinese Mandarin dialects

To investigate the above-mentioned research question, the present study tests bilinguals who speak two closely related tonal dialects, namely Standard Chinese (SC, or Mandarin in narrow sense) and Jinan Mandarin (JM).

It is widely accepted that lexical tones function as abstract lexical frames and prosodic cues in the mental representation of words (Chen, Chen, & Dell, 2002; Ye & Connine, 1999), similarly to lexical stresses (Cutler & Van Donselaar, 2001; Cutler, 1986; Jongenburger, 1996; Levelt, Roelofs, & Meyer, 1999; Van Heuven, 1988), and that tonal minimal pairs have distinct representations in lexical access (Chen, Shen, & Schiller, 2011; Malins & Joanisse, 2010, 2012; Nixon, Chen, & Schiller, 2014; Wu, Chen, Van Heuven, & Schiller, 2014). Bilinguals of two tonal languages access tonal information differently than those who use only one (Wiener & Ito, 2015). Subtle differences between the two tonal systems are also represented in the lexicon (Wu, Chen, Van Heuven, & Schiller, 2017; Zhang, Samuel, & Liu, 2012).

The current study focuses on pairs of ETEs which differ only in tone, for which the bilingualism of SC and JM present an ideal test case. Different from bilingualism between two remote languages, SC-JM bilingualism involves a larger number of ETEs[3], which are usually orthographically, morphologically and segmentally identical in the younger generation's pronunciation. However, these SC-JM ETEs can be either similar or dissimilar in their tonal patterns. For instance, SC has four monosyllabic citation tones: high-level, high-rising, low-rising(dip), and falling (Chao, 1948).[4] JM also has four monosyllabic citation tones: rising, high-falling, high-level and low-falling (Qian, 1997). Both dialects have limited tone sandhi patterns (Peng, 2000; Wu et al., 2017; Wu, Chen, Van Heuven, & Schiller, 2016; Wu, Chen, Van Heuven, & Schiller, 2018; Yuan & Chen, 2014). The SC and JM forms for "to own" are written with the same characters 拥有and share the same segmental structure, /ioŋ-iou/; similarly, the SC and JM forms for "thanks" are written with the same characters 谢谢 and share the segmental structure, /ɕiɛ-ɕiɛ/. However, the two pairs differ in terms of cross-linguistic similarity of lexical tone: the SC and JM forms for "own" carry very different tonal patterns, high-level + low-rising in SC and low+ high-level in JM. In contrast, the tonal patterns of SC and JM "thanks", falling + falling in SC and low-falling + low-falling in JM, are much more similar.

The bilingualism of SC and JM allows us to *focus on the tonal aspect of phonological similarity while keeping the orthographic, morphological, semantic, and segmental aspects constant*.

1.4. The role of language dominance in bilingual lexical processing

Previous research supports the view that orthographically non-identical ETEs (e.g. English *tomato* and Dutch *tomaat*) are stored separately and inhibit each other, while orthographically identical ETEs (e.g. English *film* and Dutch *film*) are instead represented with one single word-form representation, in visual modality (Dijkstra et al., 2010). However, when it comes to auditory modality, our understanding regarding ETE lexical representation is limited.

Particularly, *are orthographically and segmentally identical ETEs (which may only differ in tone) represented with shared or separate representations in auditory modality*? The answer is less straightforward, since how similar two ETEs need to be (especially regarding tonal similarity in auditory modality), in order for them to be counted as "identical", is open to discussion.

Language dominance may shed light on this ETE lexical presentation dilemma. Usually reported together with the asymmetrical translation priming effects (e.g. Basnight-Brown & Altarriba, 2007) and the asymmetrical cognate facilitation effects (e.g. Brenders, Van Hell, & Dijkstra, 2011; Van Hell & Dijkstra, 2002), language dominance effects are considered to be mediated by the relative frequencies of lexical representations in the integrated bilingual lexicon (Van Heuven, Dijkstra, & Grainger, 1998). Words from the dominant language are used more frequently than their translation equivalents from the non-dominant language and hence easier to retrieve.

This frequency-based account of the language dominance effect crucially assumes that the translation equivalents have two lexical representations (Altarriba, 1992). We would like to use language dominance effect to investigate whether even very similar tones from different languages distinguish bilingual lexical representations.

1.5. Trial order effect and bilingual dynamic attention control

The effect of trials has long been noticed in bilingual research. However, a trial order effect was generally believed to be largely decided by the participants' personal traits, fatigue, or task familiarity, and hence not interesting for the research questions.

Trial order effects in auditory lexical decision are usually controlled by presenting trials to each participant in a different randomised order (e.g. Andruski, Blumstein, & Burton, 1994; Goldinger, Luce, Pisoni, & Marcario, 1992; Radeau, Morais, & Dewier, 1989). More recent studies using mixed effect modelling either model the general trial-order effects within a fixed-term (e.g. Mitterer, Chen, & Zhou, 2011), or use by-participant random effects for trial order to model the individual differences in trial-order effect (e.g. Wu et al., 2014), but these studies did not provide an explicit characterisation of the effect of trial order.

We would argue that the trial order effect is attentional in nature (Cozby, 2011, p. 165). Considering that the dynamics of bilingual lexical processing is closely related to bilinguals' attentional control, we may ask *whether a consistent interaction effect between trial order and cross-linguistic phonological similarity can be found on the bilinguals' auditory lexical processing*.

1.6. Bilingual lexical disadvantage

Bilinguals were usually found to recognise and produce words slower and less accurately than monolinguals (e.g. Bialystok, 2009; Costa et al., 2000; Dijkstra et al., 1999; Lemhöfer et al., 2008; Lemhöfer, Dijkstra, & Michel, 2004; Martin et al., 2012; Mulder, Dijkstra, Schreuder, & Baayen, 2014), even when responding to ETEs (e.g. Dijkstra et al., 1999). Such a bilingual lexical disadvantage was commonly found in bilingualism of remote and non-tonal languages.

The bilingual lexical disadvantage was explained by assuming that bilinguals have a denser lexical neighbourhood and hence suffer more from the interference introduced by lexical-level competition than monolinguals (Ransdell & Fischler, 1987). However, this explanation is based on the assumption that translation equivalents are stored separately. This is still open to discussion for tonal ETEs in auditory modality as discussed in 1.4. Moreover, lexical-level competition in bilingual ETE processing may be modulated by cross-linguistic phonological similarity and its interaction with other bilingual factors.

Thus *whether the bilingual lexical disadvantage applies to the auditory lexical retrieval of tonal ETEs in closely related dialects* needs to be re-examined.

1.7. Design and hypotheses

The present study investigated how cross-linguistic tonal similarity affects the spoken word recognition of ETEs and the role of tone in bilingual lexical representation. More specifically, we ask whether tonal similarity affects the bilinguals' responses to segmentally identical ETEs. If it does, we will further look into how the tonal similarity effect interacts with word frequency, trial order (which reflects the progress of the experiment), target dialect (which reflects the influence of language dominance, with SC as the dominant dialect), as well as block (which reflects the influence of global language switching, with each language of operation tested within one block and the language of operation switched between blocks). In order to eliminate potentially confounding factors irrelevant to bilingualism, the tonal bilinguals' responses will be compared with the responses from SC tonal-monolinguals, whose responses to the SC version of the stimuli serve as the baseline in the present study.

(1) Language dominance effects can bring insights into whether a pair of ETEs which only differ in tone share a single word-form representation.

There can be a single word-form representation for orthographically identical ETEs, but at least two representations are needed for non-identical ETEs (Dijkstra et al., 1999). However, this is less clear-cut in auditory studies regarding the tonal aspect of orthographically and segmentally identical ETEs.

The frequency-based account of the language dominance effect predicts that, if a pair of ETEs share a single lexical representation, they cannot be assigned different lexical frequencies and should be activated with the same speed in both language varieties, showing no language dominance effect. Here we presume that, if the form in the dominant dialect is recognised faster than its counterpart in the non-dominant dialect, all else being equal, the two forms, however similar they are, are likely to be specified with two separated word-form representations. Although this question is more specific for the tonal ETEs under discussion, it needs to be discussed before we move on to the lexical and pre-lexical effects of tonal similarity.

(2) By looking into the effect of cross-linguistic tonal similarity, as well as its interaction with trial order and the other factors, the present study investigates the dynamic role of lexical tones at the pre-lexical and lexical stages of bilingual lexical processing. As noted in section 1.1, phonological similarity has a facilitatory effect at the pre-lexical stage but an interfering effect at the lexical stage. Which one would dominate may be influenced by the progress of the task.

The pre-lexical and lexical mechanisms may differ in timing. The pre-lexical mechanism seems to be short-lived, considering that the effect of interlingual category-goodness in cross-linguistic auditory lexical recognition was found to disappear between lexical and semantic levels (Wu et al., 2017). However, the lexical mechanism seems to be accumulative in nature (Dijkstra & Van Heuven, 2002).

Hence, we expect that the effect of cross-linguistic tonal similarity would change from facilitation-dominant to involving more lexical-level interference with the increase of trial order. Specifically, when the lexical-level competition has not yet fully kicked in, for instance, at the start of a task when not so many words are activated in the working memory, bilinguals may be primarily influenced by pre-lexical activations. Then cross-linguistic phonological similarity would primarily show a facilitation effect via overlapping pre-lexical representations (see the 1st panel of Figure 1). Alternatively, when lexical-level competitions accumulate in the bilingual lexicon, for instance, with the progress of the task, bilinguals' sensitivity to the lexical level is more likely to rise. In this case, interference may surface (see the 2nd panel of Figure 1).

We also expect cross-linguistic tonal similarity and trial order to further interact with target dialect and global language switching, as will be elaborated with more details in the following sections.

(3) By looking into the effect of language switching across blocks, the present study investigates how the *language mode* influences the bilinguals' sensitivity to tonal similarity on both pre-lexical and lexical levels.

At the stage of pre-lexical processing, it has been shown that bilinguals can give different category-goodness ratings for the same sound according to the language of operation (Antoniou, Tyler, & Best, 2012). This finding indicates that bilinguals can adapt their phonetic attention according to language of operation.

At the stage of lexical-competition, there is also plenty of evidence suggesting that the cross-linguistic lexical competition can be strengthened or weakened depending on whether the language mode is more "monolingual" or more "bilingual", again modulated by bilinguals' general control of attention (Canseco-Gonzalez et al., 2010; Grosjean, 1998, 2001).

Regarding the current study, the participants first come across a monolingual list of one dialect and then switch to the other dialect in the second block. We suppose that when the bilinguals hear the first-encountered dialect, their attentional control is first directed to this dialect alone; when the target dialect changes in the second block, they are more conscious of their bilingual identity and their attentional control adapts.

This hypothesis predicts that bilinguals would raise awareness of bilingual identity after language switching, and this would help them suppress cross-linguistic lexical-competition in the implicit monolingual task, and hence reduce similarity-related interference. Particularly, the interference at lexical level, although increasing with the progress of the task (see the discussion in (2)), may be cancelled out by the pre-lexical facilitation and fail to emerge on the surface (see the 3rd and 4th panel of Figure 1). Note that functions of processing costs do not need to be linear. A simple floor effect happening at both lexical and pre-lexical level, combined with a balance of the pre-lexical facilitation and the lexical interference, can yield the non-linear pattern of observed processing cost as shown in the 4th panel of Figure 1.

(4) By comparing tonal bilinguals with tonal monolinguals, the present study re-examines the bilingual lexical disadvantage on tonal ETEs of related dialects.

Following the hypothesis of increased bilingual neighbourhood density (Ransdell & Fischler, 1987), if the language dominance effect supports that tonal ETEs are stored separately, the SC-JM tonal bilinguals should show a classical lexical disadvantage, yielding slower responses, as found in bilingualisms of remote and non-tonal languages (e.g. Bialystok, 2009).

However, if a language dominance effect emerges but no bilingual lexical disadvantage is found, an alternative explanation is necessary. Moreover, the previously mentioned suppression of cross-linguistic lexical competition opens the possibility of bilingual lexical advantage.

2. Method

2.1. Participants

Forty-eight native tonal monolinguals of SC from Beijing, 7 male and 41 female, age ranging from 19 to 30, $M = 22.73$, $SD = 2.95$, and 54 native SC-JM tonal bilinguals from Jinan, 15 male and 39 female, age ranging from 19 to 36, $M = 22.59$, $SD = 3.88$, 44 SC dominant or balanced, 10 JM dominant, all highly proficient in both dialects, participated in this experiment in exchange for payment. The language dominance was derived from self-reported frequencies of language use on a ten-point scale, depending on which dialect was used more frequently. Only the results from the SC-dominant and balanced participants were taken into consideration in the analysis. All participants passed a selection procedure. They read aloud a small Chinese passage (bilinguals in both JM and SC, monolinguals in SC) and a trained phonetician familiar with both SC and JM excluded candidates who could not fluently read the passage or code-mixed more than three times.[5] Both groups were right-handed, had acquired their literacy in SC, and had learned some English at school.[6] A few participants from each group also had some knowledge of other non-tonal foreign languages, such as French and German.

2.2. Design and stimuli

A mixed design was adopted. *Tonal Similarity*, *Word Frequency*, *Participant Group*, *Target Dialect*, and *Block* were manipulated. We first composed a list including 54 pairs of disyllabic SC-JM ETEs (see Appendix). Since no measurement of phonological similarity between SC-JM ETEs was available before the experiment, the first author (a trained phonetician with Putonghua Proficiency Test Certificates- Level1B) judged the words from a JM audio corpus, with 200 high-frequency and 200 low-frequency words by 42 JM speakers collected in our earlier study (Wu et al., 2016) for their different degrees of phonological similarity to their SC counterparts. Afterwards, 27 more phonologically similar and 27 phonologically less similar pairs of ETEs were selected. Since many JM words were produced with different variants in the corpus (Wu & Chen, 2014), we selected words with dominant-variant probabilities greater than 0.85 and only used the sole variant or highly dominant (prob. ≥ 0.85) variant in our experiment. The two groups of words (as candidates) were matched with respect to their Chinese word frequency (61.5 versus 64.2 per million high-frequency words) and dominant-variant probability (0.96 versus 0.97). We also composed a list including 54 pairs of disyllabic non-words in SC and JM, using non-existing combinations of Chinese characters which have no homophones in either dialect. These words and non-words were then produced in both JM and SC by a male native bilingual who is highly proficient in both dialects (also a trained phonetician with Putonghua Proficiency Test Certificates – Level1B). Four pairs were later excluded because the speaker introduced segmental variation. After the main experiment, the phonological (tonal) similarity was rated for each pair of ETEs by all the SC monolingual and SC-JM bilingual participants. This rating was analysed in Analysis 1 and used in Analysis 2 as a major predictor.

The complete SC versions of the words and non-words were aurally presented to the Beijing tonal monolinguals. The bilinguals were tested in both SC and JM. To eliminate the possibility of within- and between-dialect repetition priming, each bilingual heard only one member of each pair and only heard each stimulus once. The list of pairs was split into two halves (List-A & List-B) which were matched based on the number of more similar candidates, word frequency, dominant-variant probability, style, and tonal category. Half of the participants heard the SC part of List-A and the JM part of List-B; the other half of the participants heard the SC part of List-B and the JM part of List-A. The SC words and JM words were presented in blocks separated by short breaks. Half of the bilinguals were tested with the SC block first and the other half were tested with the JM block first. Half-lists, target dialect, and the test order of target dialects were counterbalanced across the bilinguals as shown in Table 1.

Table 1. Counterbalanced design.

	JM	SC	Test order of target dialect
Bilingual 1	List-A	List-B	JM first
Bilingual 2	List-B	List-A	JM first
Bilingual 3	List-A	List-B	SC first
Bilingual 4	List-B	List-A	SC first

2.3. Procedure

Participants were tested individually in a quiet room using the E-Prime software (Schneider, Eschman, & Zuccolotto, 2002). They were told that they would hear a series of sound sequences and they had to decide whether or not each of these sound sequences was a real word. Each item was presented binaurally through headphones, with instructions on the screen. A new trial started 1,000 ms after the participant responded to an item, or 1,500 ms after the response time exceeded 5 s. SC and JM words were presented in two blocks separated by a break, in random order. The critical trials of each block were preceded by an auditory practice block including 10 words and 10 non-words in the target dialect.

The target dialect was implicitly hinted. At the beginning of each block, the participants heard instructions in the target dialect and all the trials in one block were in the same dialect.

After the main experiment, both bilinguals and monolinguals rated all the SC-JM item pairs for cross-linguistic phonological similarity on a five-point scale. Each pair was aurally presented twice to the same participant in two blocks, once with the SC item first and once with the JM item first. The order of SC-first and JM-first presentations was counterbalanced across participants. Before the rating phase, the experimenter asked the participants what they thought the experiment was testing. None mentioned the cross-linguistic tonal similarity of the ETEs. The ratings were analysed and used as the crucial predictor *Tonal Similarity* in the following analysis.

We then used Generalised Additive Modelling (GAM) (Wood, 2006, 2011) to model the dynamics of cross-linguistic phonological similarity effects with the progress of trials in a non-linear way, and to explore their interaction with other bilingual factors, such as word frequency and switch of language of operation. The non-linear individual variations of trial order effects were also modelled with random smooths.

3. Analysis 1: tonal similarity

Since the SC-JM ETEs in the present study are segmentally identical but vary in tonal similarity, we treated the rating of phonological similarity for each pair as based solely on the *Tonal Similarity* of the pair. Two values of *Tonal Similarity* were calculated for each pair of ETEs, as shown by the horizontal and vertical coordinates of the printed Chinese characters in Figure 2. The average by-pair *Tonal Similarity* by bilinguals and monolinguals showed a strong by-pair correlation, $r = .98$. Nevertheless, a by-pair t-test, comparing the bilinguals'

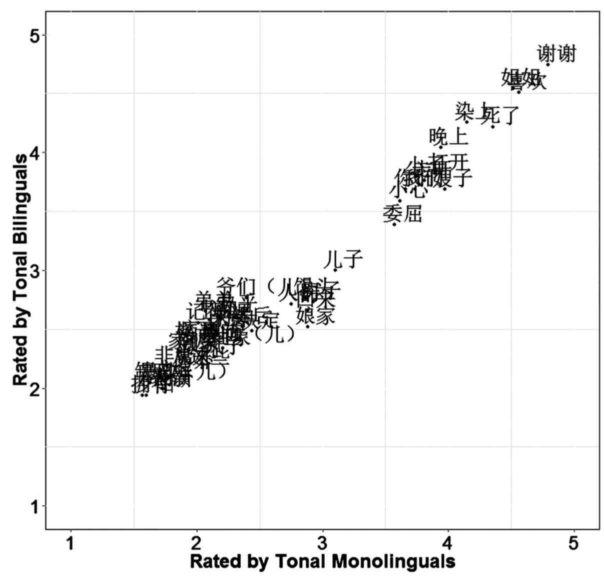

Figure 2. A scatter plot for the Tonal Similarity (1 = quite dissimilar, 5 = identical) by tonal monolinguals (along the horizontal axis) and tonal bilinguals (along the vertical axis). Each pair of ETEs is represented as a point in the plot with their common written form marked. The points on upper-right side represent more similar pairs.

and monolinguals' ratings, showed that bilinguals generally rated the pairs as more similar, $t\ (49) = -4.65$, $p < 0.001$. This bias was systematic across participants. It could be removed by z-normalizing the mean by-pair ratings, $t\ (49) = 0.79$, $p > 0.05$. The bilinguals' ratings were included as one predictor in the following GAM analysis.

Note that the most similar ETEs in the upper right part of Figure 2 happened to involve many pairs with the surface tonal pattern low + high (the "high" is the realisation of a neutral tone). These pairs all involve a specific pair of neutral tone sandhi rules in SC and JM, which result in the same surface tonal pattern. This phenomenon is specific between SC and JM and thus is not the focus of the current study. However, it resulted in more realizations of low + high tonal pattern in the test set, which may bias both groups' responses and confound with the effect of *Tonal Similarity*. In the following analysis, this bias and other biases from the stimuli were removed by comparing the bilingual participants' responses with the monolinguals' responses.

4. Analysis 2: Generalised Additive Modelling on reaction times

To investigate the dynamics of *Tonal Similarity* effect, we performed a GAM analysis in R Version 3.2.1 (R Core Team, 2013), using the mgcv package Version 1.8.9 (Wood, 2006, 2011, 2015), and plotted the figures with itsadug R package Version 1.0.1(Van Rij, Wieling, Baayen, & Van Rijn, 2015).

The analysis of reaction times (RTs) was based on correct trials only. We excluded the data of the 10 JM-dominant bilinguals and one bilingual with a non-typical accent from the RT analysis.[7] To normalise the distribution of the RT data, they were log-transformed (natural log). The RT outliers were excluded for each participant by using a distribution-based approach (method I) (Van der Loo, 2010) on the natural-log transformed RTs, leaving 2143 data points from the monolinguals and 1846 data points from the bilinguals (930 to JM stimuli, 916 to SC stimuli).

With the log *Reaction Times* as the dependent variable, GAMs were used to assess the possibly non-linear effect of *cross-linguistic Tonal Similarity* and its non-linear interaction with scaled *Trial Order (within each block, mean = 0, sd = 1)*. These two scaled variables were modelled within the same smooth function using the "s" type of spline. Since the tonal monolinguals were only tested in SC and within one block, *Target Dialect* (SC vs. JM), *Participant Group* (tonal bilinguals vs. tonal monolinguals), and *Block* (1st block vs. 2nd block) were combined into one five-level categorical predictor *Group-TargetDial-Block* (bilingual-SC-1st, bilingual-SC-2nd, bilingual-JM-1st, bilingual-JM-2nd, and monolingual-SC (control)) to avoid the problem of missing ranks and to allow the study of their joint non-linear interaction with *Tonal Similarity* and *Trial Order*. The categorical predictor *Word Frequency* (high vs. low according to the design of stimulus sets) was also included to test for their non-linear interaction with *Tonal Similarity*. The participant- and item-induced variations were included in the random terms.

Using this design and operating within the limits of computational power[8], the GAM model could still be built in different ways, for instance, including a non-linear interaction between the two scale predictors in a term and/or introducing several categorical predictors separately in different smooth terms (ignoring their possible non-linear interaction). We built different candidate models in a forward-dominant way (see the supplementary R codes for details). These models were then examined with "gam.check()" function and compared based on the Akaike Information Criterion likelihood values (Sakamoto & Ishiguro, 1986), yielding the final structure reported in the top cell of Table 2. In the final structure, two linear fixed predictors *Word Frequency* as well as *Group-TargetDial-Block* were included. The model also included two fixed smooth terms and three random smooth terms. One fixed smooth term was built with Scaled *Tonal Similarity* and its non-linear interaction with *Trial Order*, also including their non-linear interaction with *Group-TargetDial-Block*. This reflects the focus of the current study. The other fixed smooth term was built for the interaction between *cross-linguistic Tonal Similarity* and *Word Frequency*. The rest of the candidates of fixed smooth terms proved to be unnecessary and were not kept in the final model. One random term modelled the by-participant random smooth of *cross-linguistic Tonal Similarity*, a second random term modelled the by-participant random smooth of scaled *Trial Order*, and the third random term modelled the by-stimulus random smooth of scaled *Trial Order*. The rest of the

Table 2. Summary of the results of the GAM model for the effects of Tonal Similarity, Trial Order, Word Frequency, and Group-TargetDial-Block.

Model Specification				
LogRT ~ te(scaled Tonal Similarity, scaled Trial Order, d = c(1, 1), by = Group-TargetDial-Block) + s(scaled Tonal Similarity, by = Word Frequency) + Group-TargetDial-Block + Word Frequency + s(scaled Tonal Similarity, participant, bs = "fs", *m* = 1) + s(scaled Trial Order, participant, bs = "fs", *m* = 1) + s(scaled Trial Order, StimuliID, bs = "fs", *m* = 1)				
Parametric coefficients:	Estimate	Std.error	*t*-value	Pr(>|t|)
(Intercept)	6.791	0.021	319.227	< 2e-16***
Group-TargetDial-Block bilingual-JM-1st	0.004	0.035	0.112	0.911
Group-TargetDial-Block bilingual-JM-2nd	0.014	0.033	0.425	0.671
Group-TargetDial-Block bilingual-SC-1st	0.016	0.029	0.546	0.585
Group-TargetDial-Block bilingual-SC-2nd	−0.088	0.031	−2.825	0.005**
Word Frequency low	0.099	0.018	5.493	0.000***
Smooth terms:	Edf	Ref.df	F	*p*-value
te(scaled Tonal Similarity, scaled Trial Order):Group-TargetDial-Block monolingual-SC	3.421	3.744	1.203	0.307
te(scaled Tonal Similarity, scaled Trial Order):Group-TargetDial-Block bilingual-JM-1st	3.213	3.4	1.238	0.308
te(scaled Tonal Similarity, scaled Trial Order):Group-TargetDial-Block bilingual-JM-2nd	2.002	2.004	0.301	0.741
te(scaled Tonal Similarity, scaled Trial Order):Group-TargetDial-Block bilingual-SC-1st	3.001	3.002	0.945	0.418
te(scaled Tonal Similarity, scaled Trial Order):Group-TargetDial-Block bilingual-SC-2nd	8.702	11.266	1.749	0.056.
s(scaled Tonal Similarity):Word Frequency high	1.744	1.781	1.898	0.092.
s(scaled Tonal Similarity):Word Frequency low	2.38	2.444	5.06	0.004**
s(scaled Tonal Similarity, participant)	40.939	816	0.096	< 2e-16***
s(scaled Trial Order, participant)	186.058	816	0.495	< 2e-16***
s(scaled Trial Order, StimuliID)	82.957	880	1.28	< 2e-16***

(Significance codes: *** 0.001, ** 0.01, * 0.05, 0.1, 1).

candidates for random terms were not kept in the final model.[9]

Autocorrelation values were calculated based on the order of trials, which showed no autocorrelation problem (Wood, 2006, 2011). Thus no AR1 error model was built and the original model is the one reported.

5. Results of Generalised Additive Modelling

5.1. Model summary

The fitted models accounted for 61.6% of the variance in the data. Table 2 summarises the results of the GAM model, including the model specification (top), coefficients for the parametric predictors (middle), and the *F*-statistics for the smooth terms (bottom).

The parametric coefficients in the middle of Table 2 showed a model-constant word frequency effect: the participants responded 9.9% slower to low frequency words. Importantly, only the tonal bilinguals' responses to SC stimuli in the second block (bilingual-SC-2nd) were significantly different from the tonal monolinguals' responses (monolingual-SC, the baseline) in a model-constant way, in the way that the bilinguals reacted 8.8% faster than the monolinguals to the SC stimuli in the 2[nd] block.

The *F*-statistic for the smooth terms at the bottom of Table 2 showed a significant non-linear interaction between *Tonal Similarity* and low-frequency words. Also, non-linear patterns of the bilinguals' responses to SC stimuli in the second block (bilingual-SC-2nd), as well as the non-linear interaction between *Tonal Similarity* and high-frequency words, were marginally significant. All three random terms were significant, showing strong individual- and stimulus-based effects.

Note that the *F*-statistics for the smooth terms compares each manipulation level with the average level. To answer the research questions, different manipulation levels need to be compared post-hoc. To examine this, we calculated the estimated difference between smooth surfaces (Van Rij et al., 2015) and made plots with contours for standard errors, as shown in the following subsections (Figures 4–7). The original model estimates (i.e. partial effects) under different conditions were also depicted in a similar way (left panel of Figure 4).

5.2. Stimulus-inherent correspondence between word-frequency and tonal similarity

As shown in the left and middle panels of Figure 3, respectively, high- and low-frequency words appeared to have different non-linear correspondence with *Tonal Similarity*. The estimated difference curve comparing the high-frequency and low-frequency words indicates that the high-frequency stimuli with the highest or lowest *Tonal Similarity* showed more frequency-based advantage than the low-frequency words. Also, the stimuli with the greatest *Tonal Similarity* showed relatively larger variance.

However, these effects are probably stimulus-inherent. As shown in the model specification of Table 2, these relations apply to both the tonal monolinguals and

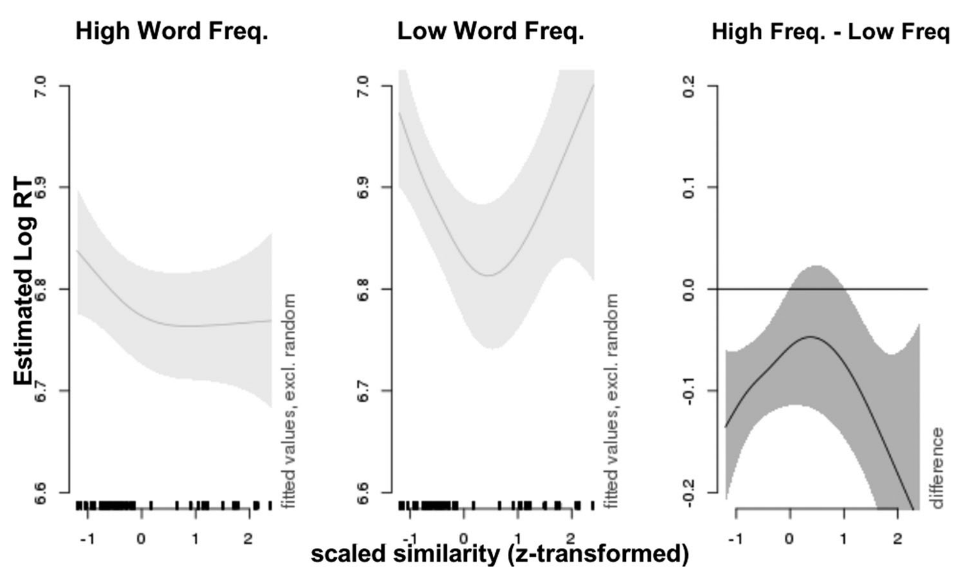

Figure 3. Partial effects for interaction of cross-linguistic Tonal Similarity and estimated log RTs for high-frequency (left panel) and low-frequency (middle panel) words, as well as the estimated difference curve comparing high-frequency and low-frequency words (right panel).

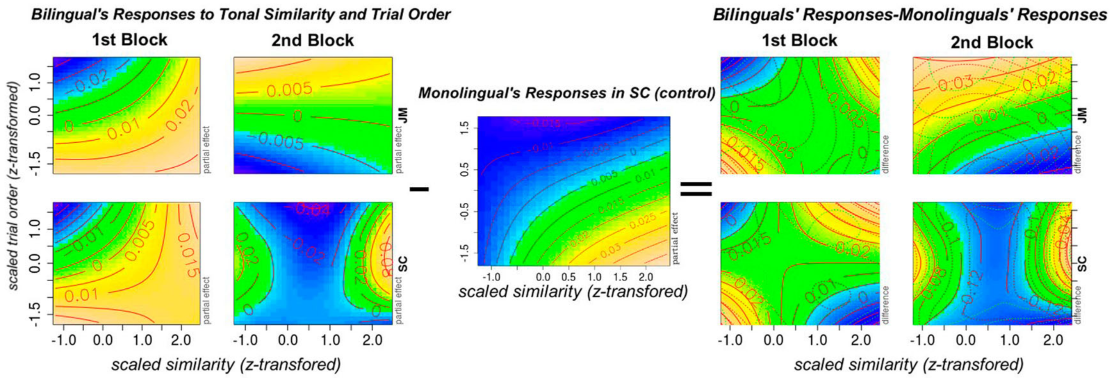

Figure 4. (1) Left panel: The four subplots show the bilinguals' partial effects for the interaction of cross-linguistic Tonal Similarity (horizontal axis) and trial order (vertical axis), in the first (left) and second (right) blocks, and in JM (top) and SC (bottom). (2) Middle panel: the monolinguals' partial effect for the interaction of cross-linguistic Tonal Similarity (horizontal axis) and trial order (vertical axis), as base-line. (3) Right panel: The four subplots show the estimated difference between bilinguals' and monolinguals' smooth surfaces for the interaction of cross-linguistic Tonal Similarity (horizontal axis) and trial order (vertical axis) with contours for standard errors, also split by the blocks (left-1st block, right-2nd block) and the target dialects (top-JM, bottom-SC). Warmer colour represents longer RT and values are marked on the isolines. Note that the same colour may represent different values in different plots.

bilinguals and hence are irrelevant to the difference between the participant groups. Only after partialling out this stimulus-inherent correspondence between word-frequency and *Tonal Similarity*, will the bilingual effect of cross-linguistic *Tonal Similarity* start to emerge.

5.3. Nonlinear interaction between tonal similarity and trial order (in general)

As depicted in the left panel of Figure 4, a nonlinear interaction between *Tonal Similarity* and *Trial Order* influenced the tonal bilinguals' RTs to the auditory stimuli. These patterns, nevertheless, need to be adjusted for the other stimulus-inherent effects. This was done by calculating the difference between the bilinguals and monolinguals. Also, the interaction between *Tonal Similarity*, *Trial Order*, and each factorial manipulation (i.e. *Participant Group*, *Target Dialect*, or *Block*) was logically inferred from the difference between levels (e.g. bilingual-JM-1st vs. bilingual-JM-2nd for the effect of block with JM as the target dialect).

The tonal monolinguals' RTs, shown as partial effect in the middle panel of Figure 4, increased with *Tonal Similarity* and decreased with *Trial Order*, with the two factors interacting in a nearly linear way. There seemed to be a *Tonal Similarity* effect for the tonal monolinguals.

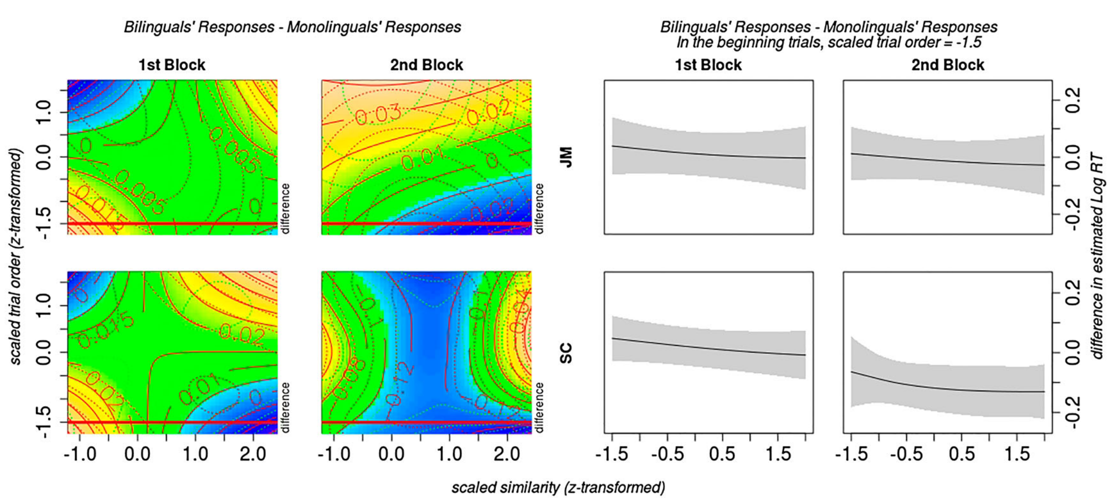

Figure 5. (1) Left panel: (repeats the right panel of Figure 4, but with sample slice for beginning trials marked) The four subplots show the estimated difference between the bilinguals' smooth surfaces and the monolinguals' smooth surfaces for the interaction of cross-linguistic Tonal Similarity (horizontal axis) and trial order (vertical axis) with contours for standard errors, split by blocks (left: 1st block, right: 2nd block) and target dialects (top: JM, bottom: SC). (2) Right panel: estimated difference curves between bilinguals' and monolinguals' smooths, depicted for the beginning trials (scaled trial order = −1.5, split in the same way as for the left panel). Warmer colour represents longer RT and values are marked on the isolines.

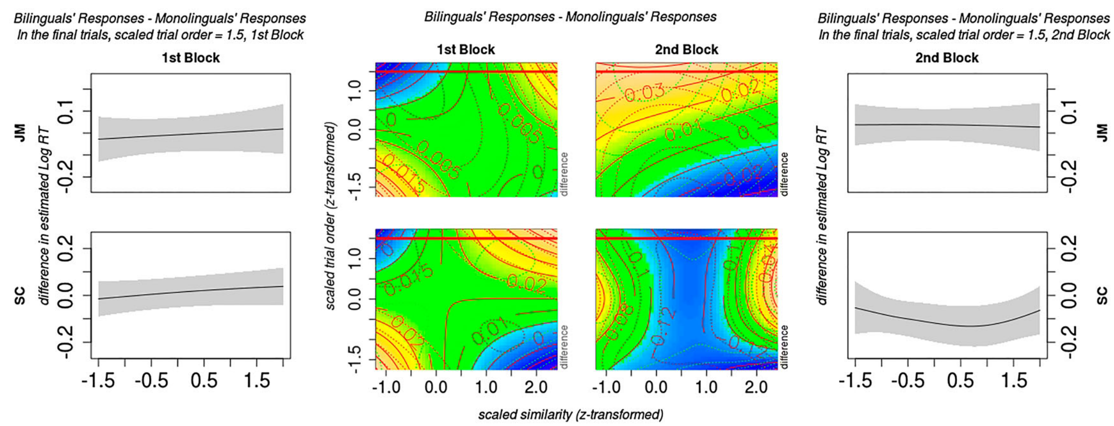

Figure 6. (1) Middle panel: (repeats right panel of Figure 4, but with sample slices for final trials marked). The four subplots show the estimated difference between bilinguals' and monolinguals' smooth surfaces for the interaction of cross-linguistic Tonal Similarity (horizontal axis) and trial order (vertical axis) with contours for standard errors, split by blocks (left: 1st block, right: 2nd block) and the target dialects (top: JM, bottom: SC). (2) Left panel: estimated difference curves between bilinguals' and monolinguals' smooths in the first block, depicting the final trials (scaled trial order = 1.5, top subplot for JM, bottom subplot for SC). (3) Right panel: estimated difference curves between bilinguals' and monolinguals' smooths in second block, depicting the final trials (scaled trial order = 1.5, top subplot for JM, bottom subplot for SC). Warmer colour represents longer RT and values are marked on the isolines.

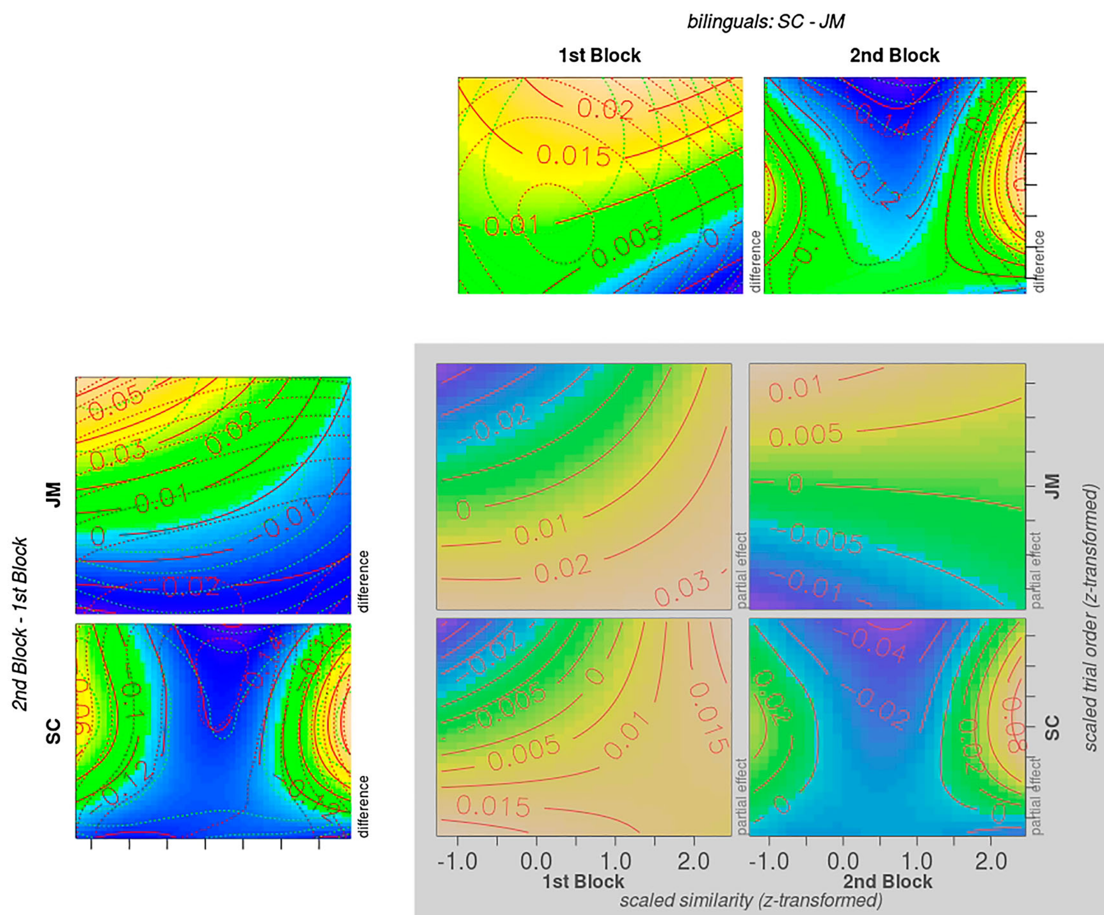

Figure 7. (1) Shadowed panel: (repeats the left panel of Figure 4): the four subplots show bilinguals' partial effects for the interaction of cross-linguistic Tonal Similarity (horizontal axis) and trial order (vertical axis), in first (left) and second (right) blocks, in JM (top) and SC (bottom). (2) Top panel: estimated difference between SC and JM smooth surfaces for the interaction of cross-linguistic Tonal Similarity (horizontal axis) and trial order (vertical axis) with contours for standard errors, split by blocks (left: 1st block, right: 2nd block), showing the influence of Target Dialect. (3) Left panel: estimated difference between smooth surfaces of 1st and 2nd blocks for the interaction of cross-linguistic Tonal Similarity (horizontal axis) and trial order (vertical axis) with contours for standard errors, split by target dialects (top-JM, bottom-SC), showing the influence of Block. Warmer colour represents longer RT and values are marked on the isolines.

However, no causal relationship should be inferred here. Instead, this effect is probably due to other lexical- and task- inherent factors, such as the increased recurrence of tonal patterns in the stimuli with higher cross-linguistic *Tonal Similarity* (as shown in Analysis 1).

After the monolinguals' partial effect was subtracted from the bilinguals', as shown in the right panel of Figure 4, the design-pertinent effect of cross-linguistic *Tonal Similarity* emerged. The effect of cross-linguistic *Tonal Similarity* was consistently facilitatory at the beginning. However, the effect gradually started to diverge in later trials.[10] In the following sections, based on the adjusted depiction in the right panel of Figure 4, we first describe the effect of *Tonal Similarity* by the tonal bilingual group in the processing of trials, and then move on to its interaction with the other predictors, such as *Trial Order*, *Target Dialect*, and *Block*.

5.4. Cross-linguistic tonal similarity facilitated lexical decision in the beginning trials

As depicted in the right panel of Figure 5, for the very early trials, the adjusted RTs decreased with the increase of *Tonal Similarity*. Thus, both target dialects in both blocks showed facilitatory effects of cross-linguistic similarity on lexical decision in the beginning trials.

The effect of *Tonal Similarity* was almost linear in the beginning trials under most conditions, except when tested in SC and in the second block (after switching). Under this condition, responses to the stimuli within the lower range of *Tonal Similarity* showed great sensitivity to *Tonal Similarity*, while responses to the stimuli within the higher range of *Tonal Similarity* were much faster, although the sensitivity to *Tonal Similarity* was reduced.

5.5. Diverging effects of cross-linguistic tonal similarity in the final trials

In later trials, cross-linguistic *Tonal Similarity* started to show complex interactions with target dialects and the influence of language switching emerged. (All the bilinguals experienced general switching when they listened to one dialect in the first block and switched to the other dialect in the second block). The slice plots are shown in Figure 6.

5.5.1. Interference of cross-linguistic tonal similarity with lexical decision in final trials before switching

Deviating from the beginning trials (as shown in Figure 5), as the tonal bilinguals approached the final trials of the block, the effect of cross-linguistic *Tonal Similarity* was reversed before the target dialect was switched. As depicted in the left panels of Figure 6, in the first block, the adjusted *Reaction Times* increased with the increase of *Tonal Similarity*, disregarding whether or not the target dialect was JM or SC.

5.5.2. Disappearance of sensitivity to tonal similarity in non-dominant dialect after switching

As shown in the top-right panel of Figure 6, which deviated from all the other panels, the adjusted *Reaction Times* did not change with an increase of *Tonal Similarity*. Thus, the *Tonal Similarity* effect, whether facilitating or interfering, disappeared after the target dialect was switched into the non-dominant dialect (i.e. JM).

5.5.3. Emergence of discontinuous effect of tonal similarity in the dominant dialect after switching

As depicted in the lower right panel of Figure 6, in the final trials (and also the non-initial trials) of the second block, when the target dialect was the dominant dialect SC, *Tonal Similarity* affected the adjusted *Reaction Times* in a non-linear way. Regarding the stimuli with relatively lower *Tonal Similarity*, the adjusted *Reaction Times* decreased with an increase of *Tonal Similarity*, showing a dominance of similarity-based facilitation. However, regarding the stimuli with relatively higher *Tonal Similarity*, the adjusted *Reaction Times* increased with an increase of *Tonal Similarity*, showing a dominance of similarity-based interference. In short, as the target dialect is switched, a discontinuous effect of *Tonal Similarity* emerged in the dominant dialect.

5.6. The effect of language dominance and language switching

We subtracted the surfaces of effects across different conditions to reveal the influence of *Target Dialect* and *Block*, as shown in Figure 7. The effect of *Target Dialect* revealed the influence of language dominance and the effect of *Block* revealed the influence of language switching.

5.6.1. Discontinuous language dominance effect

The top row of Figure 7 depicts the difference surfaces between the dominant dialect SC and the non-dominant dialect JM in the two blocks. The patterns differ greatly between blocks.

Tested in the first block (shown in the top left subplot of Figure 7), the dominant dialect SC did not differ much from the non-dominant dialect JM. Tested in the second block (shown in the top-right subplot of Figure 7), the dominant dialect SC yielded shorter RTs to most of the stimuli compared with the non-dominant dialect JM, revealing a relatively robust language dominance effect. However, this effect did not apply to the least and most similar ETEs. Moreover, *Trial Order* did influence how the dominant dialect SC differed from the non-dominant dialect JM in RTs: the advantages of SC were greater in the later trials than in the earlier trials.

5.6.2. Task familiarisation and discontinuous language switching effect

The left column of Figure 7 depicts the difference surfaces between the second and first block in JM and SC. In the second block, the bilinguals responded more quickly to the beginning trials than in the first block (without switching), revealing that they were benefiting from the increased familiarity of the task.

Nevertheless, in later trials, a discontinuous language switching effect emerged, which also interacted with the Target Dialect. Switching into the non-dominant dialect JM generally had little influence on the RTs. However, switching to the dominant dialect SC, the bilinguals responded more quickly to most ETEs, although the responses to the least and most similar ETEs were less facilitated.

6. Discussion

Results of the analyses shed light on the four above-mentioned research questions: (1) whether a pair of segmentally identical and ETEs share a single word-form representation, (2) what role cross-linguistic tonal similarity plays at the pre-lexical and lexical stages of bilingual lexical processing, (3) how the language mode influences the bilinguals' sensitivity to tonal similarity, and (4) whether bilinguals have lexical disadvantage in auditory lexical retrieval of ETEs compared with monolinguals.

6.1. Segmentally identical ETEs are specified with separated word-form representations

Most word forms from the dominant dialect SC were recognised more quickly than their counterparts from the non-dominant dialect JM in the second block (as shown by the parametric coefficient of bilingual-SC-2nd in Table 2 and the estimated surface of difference in the top right panel of Figure 7). These results show a language dominance effect. Since one common word-form representation could not carry two different relative frequencies (Van Heuven et al., 1998), this finding supports the view that SC and JM ETEs (segmentally identical but varying in tonal similarity) are specified with separated lexical representations.[11] It is consistent with the role of lexical tone in monolingual (Malins & Joanisse, 2010, 2012) and bilingual lexical representation (Wu et al., 2017; Zhang et al., 2012).

All the pairs of ETEs are orthographically identical in the present study. Earlier visual studies suggested that orthographically identical ETEs share one common lexical representation, both orthographically and phonologically (Dijkstra et al., 2010). Our finding of language dominance effects in auditory lexical recognition seems inconsistent with this claim. This inconsistency, however, may be attributed to several factors, such as the disputable activation of orthography during auditory lexical processing (Damian & Bowers, 2010; Seidenberg & Tanenhaus, 1979), and more importantly the involvement of tones in distinguishing lexical representations.

6.2. Dynamic role of cross-linguistic tonal similarity at the pre-lexical and lexical stages

6.2.1. Tonal similarity dynamically interacts with language dominance effect

The above-mentioned bilinguals' language dominance effect interacts dynamically with language mode and tonal similarity.

On the one hand, the language dominance effect was very subtle in the first block (pre-switching) but saliently emerged in the second block (post-switching). The monolingual versus bilingual language mode (Canseco-Gonzalez et al., 2010; Grosjean, 1998, 2001) may have played an important role here: the bilinguals become more sensitive to the relative frequencies of ETEs when they notice the bilingual situation.

On the other hand, the language dominance effect, after emerging in the second block, appeared to interact with cross-linguistic tonal similarity in a non-linear way. Presuming separate form representations for these ETEs (see the reasoning in 6.1), to explain the non-linearity, it may be more reasonable to hypothesise that the bilinguals' sensitivity to the relative frequencies of ETEs can be modulated in the auditory modality, via the interaction of the pre-lexical and lexical mechanisms, as will be discussed in more detail in the following section.

6.2.2. Dynamics of pre-lexical and lexical mechanisms

The present study found both facilitatory and interfering effects for tonal similarity in auditory lexical decision task, and it also found that tonal similarity influenced the reaction times in a non-linear way. This complex variability in the response pattern is unlikely to be the result of a single mechanism. Instead, the observed processing cost, as a function of tonal similarity, is probably the result of the combined influence from the pre-lexical and lexical stages.

As noted in the introduction, the observed reaction times reflect the combination of pre-lexical and lexical processing costs, as demonstrated in Figure 1.[12] The facilitatory effect mainly reflects the short-lived pre-lexical mechanism based on shared phonological representations (Wu et al., 2017), while the interfering effect mainly reflects the lexical mechanism based on the accumulative lexical-level competition (Dijkstra & Van Heuven, 2002).

Similarity-based facilitation was found across all the conditions in the beginning trials. The pattern shown in Figure 5 is consistent with the facilitation-dominant pattern as shown in Figure 1 (1st panel). In order for the observed effect to be facilitation-dominant, the pre-lexical processing, compared to lexical processing, should be more sensitive to phonological similarity. In other words, the pre-lexical facilitating mechanism is dominant at the beginning of each block. Also, the activation of viable competing word forms from the non-target dialect is limited at the beginning of each block, allowing the pre-lexical facilitation to surface.

With the progress of the experiment, however, similarity-based interference emerges. As shown in the left panels of Figure 6, in the first block (pre-switching), the influence of tonal similarity gradually changed from facilitation to interference, regardless of the language of operation. At the end of the block, reaction times increased with tonal similarity. This is consistent with the interference-dominant pattern as shown in Figure 1 (2nd panel). The interference-dominant observation suggests that the lexical-level competition mechanism is gradually taking control with the progress of the experiment, and the activation of viable non-target word forms is largely strengthened by the increase of tonal similarity.

In the second block (post-switching), similarity-based interference also emerged with the progress of the experiment, which, however, only took control of the more similar ETEs in SC (as shown in the bottom-right panel of Figure 6). Since the language dominance effects have provided evidence that all the ETEs are stored as separated word-form representations, the non-linear effect of tonal similarity on reaction times is better attributed to a change of sensitivity to cross-linguistic tonal similarity at the pre-lexical and lexical stages, as shown in Figure 1 (4th panel). The increase of cross-linguistic tonal similarity still strengthens pre-lexical facilitation and lexical interference. However, when pre-lexical and lexical costs are low, the influence of cross-linguistic tonal similarity is reduced. Considering that the reaction times under this condition were found to be the shortest across all the conditions, the non-linearity is probably due to a floor effect of processing cost.

When switching to the non-dominant dialect JM in the second block, nevertheless, the sensitivity to tonal similarity seems to be gradually removed (as shown in the top right panel of Figure 6). It is counter-intuitive that the bilinguals behave more language-selective (Lagrou, Hartsuiker, & Duyck, 2012, 2015) after switching to the non-dominant dialect. Moreover, it is not necessary to assume that the language-selectivity is modulated. An alternative explanation is more consistent with the general consensus that bilingual auditory lexical activation is language-non-selective in nature (Canseco-Gonzalez et al., 2010; Marian et al., 2003; Marian & Spivey, 2003; Spivey & Marian, 1999; Thierry & Wu, 2007; Weber & Cutler, 2004). Assuming that both SC and JM word-form representations are activated, when the lexical and pre-lexical functions are both linear and can cancel each other out, as shown as the linear equilibrium pattern in Figure 1 (3rd panel), the function for the observed processing cost can be parallel to the horizontal axis, showing no sensitivity to tonal similarity on the surface. Thus, tonal similarity effect in the non-dominant dialect is actually consistent with findings in the dominant dialect.

Taken together, cross-linguistic tonal similarity plays two dynamic roles at the pre-lexical and lexical stages of bilingual auditory lexical processing. The increase of cross-linguistic tonal similarity facilitates the pre-lexical processing but interferes with the lexical processing. Both effects are modulated by the progress of the experiment. In the beginning trials, the pre-lexical facilitation mechanism dominates. With the progress of experiment, the cross-linguistic lexical-level competition mechanism is gradually strengthened. However, the way it strengthens diverges under the influence of language mode and language dominance. In the first block (pre-switching), the lexical-level competition mechanism takes over and hence the observed tonal similarity effect turned into interference. Nevertheless, in the second block (post-switching), probably due to attentional inhibition, the lexical-level competition mechanism never overwhelms the pre-lexical facilitation mechanism. Instead, the two mechanisms gradually reach an equilibrium. When switching into the non-dominant dialect, they cancel each other and there appears to be a lack of sensitivity to cross-linguistic tonal similarity. When switching into the dominant dialect, a floor effect introduces additional non-linearity.

Note that due to the limitation of reaction time as a measurement to tap into the lexical and pre-lexical stage of processing, we believe that further research should employ techniques with better time-resolution, such as ERP and EMG, to confirm our findings and provide more direct evidence on the dynamics of pre-lexical and lexical processing.

6.3. The role of language mode across blocks

The differences between the first and second block across different language modes seem to be related to the bilinguals' general control of attention (Canseco-Gonzalez et al., 2010; Grosjean, 1998, 2001). In the current study, the participants first came across a monolingual list and then switched to the other language. Possibly, the bilinguals' attention was first directed to the first-encountered language alone and, when the language of operation changed, the bilinguals noticed that they were in a bilingual situation. While the cross-linguistic lexical-level competition mechanism finally took control before switching, it reached an equilibrium with the pre-lexical facilitation after switching. This difference suggests that a more bilingual mode can trigger tonal bilinguals of closely related languages to better suppress cross-linguistic lexical-level competition between the word-form representations of ETEs.

As introduced in 1.1 and 1.2, previous studies found that cross-linguistic phonological similarity either facilitated or interfered with bilingual auditory lexical processing, depending upon the specific context and task. These previous findings are echoed by the current results. Nevertheless, compared with an explanation based on lexical representation, the current study has shown that an explanation based on dynamic distribution of attentional resources offers a more coherent interpretation of the diverse similarity effects. Moreover, it is shown for the first time that, with the same task, the trial order also modulates cross-linguistic tonal similarity effects possibly due the adjusted balance of lexical-level competition and pre-lexical facilitation. This effect needs further investigation in future studies. Nevertheless, considering that the change from facilitation to interference is consistent across blocks and languages by bilinguals (but not by monolingual who participated in the same task), it is reasonable to claim that the effect is due to tonal bilingualism instead of the set-up of the experiment.

6.4. Bilingual auditory lexical advantage

Compared with the SC tonal monolinguals, the SC-JM tonal bilinguals showed an unexpected bilingual lexical advantage in auditory lexical recognition. The bilinguals' reactions times were systematically shorter than the monolinguals to the same SC stimuli after language switching (as shown in the estimate of parametric coefficients in Table 2). Also, even in the other conditions, the bilinguals' reaction times were not significantly slower than the monolinguals', confirming that no classical bilingual lexical disadvantage was found.

Classical researches usually found bilingual lexical disadvantage (e.g. Bialystok, 2009). It was attributed to a denser lexical neighbourhood and increased lexical-level competition in the integrated bilingual lexicon (Ransdell & Fischler, 1987). However, this view has difficulty explaining the co-existence of the language dominance effect and the bilingual lexical advantage in the current study. The language dominance effect indicates that SC and JM ETEs are stored as separated word-form representations. Thus, the lexical neighbourhood of the same SC words should be denser for the bilinguals than for the monolinguals. Nevertheless, rather than showing bilingual lexical disadvantage, the bilinguals responded more quickly to the SC words than the SC monolinguals.

First, we propose that the bilingual lexical advantage can be attributed to the emergence of a pre-lexical facilitation mechanism after language switching. It is important to note that this unusual bilingual lexical advantage was only found in the second block. As discussed in the previous section, the interaction between tonal similarity and *Block (language switching)* suggests that the switching of target dialect may suppress cross-linguistic lexical-level competition. This may allow the strengthened pre-lexical facilitation mechanism to surface and provide the bilinguals some advantage in lexical access compared with the monolinguals.

Second, the bilingual lexical advantage was only found after switching to the dominant dialect SC but not after switching to the non-dominant dialect JM. This asymmetry is related but not directly comparable to the asymmetrical cognate facilitation effects found in earlier visual studies (e.g. Brenders et al., 2011; Van Hell & Dijkstra, 2002). On the one hand, the difference in the type of control (bilinguals' responses to non-ETEs vs. monolinguals' responses to ETEs) and the type of bilinguals (sequential vs. simultaneous) make the current results not directly comparable to the earlier findings. On the other hand, if what we found counts as cognate facilitation, the cognate facilitation is stronger on the dominant dialect SC, which is inconsistent with the earlier findings where the cognate facilitation was stronger on L2 (which is also non-dominant).

An alternative explanation is to attribute the asymmetry to cross-linguistically asymmetrical phonemic activation at the pre-lexical stage. Regarding sequential bilinguals, it is widely accepted that non-native phonemes are perceptually assimilated to native categories of phonemes (Best, 1995). Nevertheless, the way early and highly-proficient bilinguals, such as the SC-JM bilinguals, process phonemes may be more flexible (Antoniou et al., 2012; Wu et al., 2017). It could be that the representations of phonemes shared by SC and JM are more easily activated by the auditory input from the dominant dialect SC than by the auditory input from the non-dominant dialect JM, causing smaller pre-lexical processing cost in SC than in JM. Moreover, in order to reach high proficiency in both dialects, the bilinguals need to use the bilingual representations of phonemes shared by SC and JM more frequently than the monolinguals use the corresponding SC phonemic representations. Thus, it is reasonable to speculate that the SC-JM bilinguals activate their shared representations of phonemes faster than the SC monolinguals activate their corresponding SC phonemes, hence showing asymmetrical bilingual lexical advantage.

It can be noted that the SC-JM bilingual lexicon is different from most previously studied cases of bilingualism, in that it is dominated by orthographically and segmentally identical ETEs. In other words, the SC-JM equivalents are more similar, especially phonologically, compared with previously studied ETEs. It is reasonable that the pre-lexical facilitation mechanism plays a more important role in the current case and provides the bilinguals some advantage in lexical access compared with the monolinguals. This would explain why a bilingual lexical advantage was rarely found in previous studies on the lexical processing of ETEs but is prominent in the current study.

High-order interactions and non-linearity were found regarding the effect of phonological similarity, confirming findings reported in previous studies on bilingual language processing (Cutler et al., 2006; Dijkstra et al., 1999; Dijkstra et al., 2010; Duyck et al., 2007; Lemhöfer & Dijkstra, 2004; Marian & Spivey, 2003). Although the adoption of GAM allows a relatively clearer interpretation of this complex dataset, the interpretation remains speculative and needs replication in future research.

7. Conclusion

The new findings of discontinuous language dominance effects and bilingual lexical advantage by the SC-JM tonal bilinguals remind us to pay more attention to the type of the bilingual lexicon. A bilingual lexicon filled with ETEs that are extremely phonologically similar, only different in tone, may function differently from a non-tonal bilingual lexicon dominated with etymologically unrelated ETEs.

The new findings of a nonlinear tonal similarity effect and its interaction with the language of operation and language-switching provide us with further insights into the role of lexical tones in bilinguals' lexical representation and lexical access. The strengths of pre-lexical facilitation and lexical-level competition may be not only related to the similarity of the ETEs but also dynamically modulated by the progress of the experiment and the switching of language of operation.

Notes

1. Sometimes the term "interlingual" is used, such as by Lemhöfer and Dijkstra (2004). We use the term "cross-linguistic" instead, because "Interlingual" suggests that the interlingua is involved, i.e. an in-between language that combines properties of L1 and L2.
2. In some of the references the term "target language" was used. To avoid the confusion with the target language of language transfer, we use "language of operation" following Athanasopoulos et al.'s (2015) practice.
3. There are around 100 JM-specific words in total, and many of these JM-specific words have alternatives which are etymologically-related to their SC translation equivalents.
4. However, SC is not equivalent to Beijing Mandarin, because some of the morphological lexical variants and specific words were not introduced into SC in the standardization.
5. Since JM is not standardized, whether a tonal variant is an incidental error or is a well-received variant is not clear-cut and far from transparent. In the screening procedure, if a participant candidate produced unusual variants more than three times, he or she would be excluded from the experiment, because unusual variants indicates that he/she either cannot distinguish JM from SC or get confused (or possibly lied) about his/her language background.
6. Both groups received comparable English education common in the Chinese college curriculum, which is not enough to sustain a fluent conversation with a native English speaker.
7. The 10-JM dominant participants seem to show a different pattern in reaction times. However, no contrast was significant and we were not able to recruit enough such participants.
8. The final model reported in the current study was fit in Linux environment with a SWAP of 20 GB, taking around 12 h.
9. The by-stimulus random smooth of *cross-linguistic Tonal Similarity* was not included, because each stimulus only has one *Tonal Similarity* value, which made this random smooth meaningless. Main factors are sometimes included in random terms because there is a reason to believe that the interaction between the random factor (such as "participant") and the main factor (such as "Group-TargetDial-Block") also contributed significantly to the participants' responses. The result of model comparison supported this idea.
10. Note that the standard errors (dashed contours) in the two JM surfaces of estimation were relatively large. Thus this finding needs to be interpreted with caution.
11. An alternative explanation is that a pair of SC-JM ETEs have the same lexical representation but differ in how efficiently they activate that representation. However, such difference probably would still depend on tone. Under current theoretical frameworks (e.g. BIA+, Dijkstra & Van Heuven, 2002), it would be more parsimonious to

assume different lexical representations instead of introducing a new mechanism.

12. The current study did not specify the linearity of the functions to avoid confusion about the relationship between the hypothesized functions (linear or nonlinear functions) and the modeling procedure (smoothing techniques).

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ORCID

Junru Wu http://orcid.org/0000-0002-2256-0637

References

Altarriba, J. (1992). The representation of translation equivalents in bilingual memory. *Advances in Psychology*, *83*, 157–174. doi:10.1016/S0166-4115(08)61493-4

Andruski, J. E., Blumstein, S. E., & Burton, M. (1994). The effect of subphonetic differences on lexical access. *Cognition*, *52*(3), 163–187. doi:10.1016/0010-0277(94)90042-6

Antoniou, M., Tyler, M. D., & Best, C. T. (2012). Two ways to listen: Do L2-dominant bilinguals perceive stop voicing according to language mode? *Journal of Phonetics*, *40*(4), 582–594. doi:10.1016/j.wocn.2012.05.005

Athanasopoulos, P., Bylund, E., Montero-Melis, G., Damjanovic, L., Schartner, A., & Kibbe, A. (2015). Two languages, two minds: Flexible cognitive processing driven by language of operation. *Psychological Science*, *26*(4), 518–526. doi:10.1177/0956797614567509

Basnight-Brown, D. M., & Altarriba, J. (2007). Differences in semantic and translation priming across languages: The role of language direction and language dominance. *Memory & Cognition*, *35*(5), 953–965.

Best, C. T. (1995). A direct realist view of cross-language speech perception. In W. Strange (Ed.), *Speech perception and linguistic experience: Issues in cross-language research* (pp. 171–204). New York: Timonium.

Bialystok, E. (2009). Bilingualism: The good, the bad, and the indifferent. *Bilingualism: Language and Cognition*, *12*(1), 3–11. doi:10.1017/S1366728908003477

Blumenfeld, H. K., & Marian, V. (2007). Constraints on parallel activation in bilingual spoken language processing: Examining proficiency and lexical status using eye-tracking. *Language and Cognitive Processes*, *22*(5), 633–660. doi:10.1080/01690960601000746

Brenders, P., Van Hell, J. G., & Dijkstra, T. (2011). Word recognition in child second language learners: Evidence from cognates and false friends. *Journal of Experimental Child Psychology*, *109*(4), 383–396. doi:10.1016/j.jecp.2011.03.012

Bultena, S., Dijkstra, T., & Van Hell, J. G. (2014). Cognate effects in sentence context depend on word class, L2 proficiency, and task. *Quarterly Journal of Experimental Psychology*, *67*(6), 1214–1241. doi:10.1080/17470218.2013.853090

Canseco-Gonzalez, E., Brehm, L., Brick, C. A., Brown-Schmidt, S., Fischer, K., & Wagner, K. (2010). Carpet or Carcel: The effect of age of acquisition and language mode on bilingual lexical access. *Language and Cognitive Processes*, *25*(5), 669–705. doi:10.1080/01690960903474912

Chao, Y. R. (1948). *Mandarin primer: An intensive course in spoken Chinese* (Vol. 1). Cambridge, MA: Harvard University Press.

Chen, J. Y., Chen, T. M., & Dell, G. S. (2002). Word-form encoding in Mandarin Chinese as assessed by the implicit priming task. *Journal of Memory and Language*, *46*(4), 751–781. doi:10.1006/jmla.2001.2825

Chen, Y., Shen, R., & Schiller, N. O. (2011). *Representation of allophonic tone sandhi variants*. Proceedings of Psycholinguistics Representation of Tone. Satellite Workshop to ICPhS, Hongkong.

Costa, A., Caramazza, A., & Sebastian-Galles, N. (2000). The cognate facilitation effect: Implications for models of lexical access. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*(5), 1283. doi:10.1037/0278-7393.26.5.1283

Costa, A., Santesteban, M., & Caño, A. (2005). On the facilitatory effects of cognate words in bilingual speech production. *Brain and Language*, *94*(1), 94–103. doi:10.1016/j.bandl.2004.12.002

Cozby, P. C. (2011). *Methods in Behavioral research* (11th ed.). New York: McGraw-Hill Humanities.

Cutler, A. (1986). Forbear is a homophone: Lexical prosody does not constrain lexical access. *Language and Speech*, *29*, 201–220.

Cutler, A., & Van Donselaar, W. (2001). Voornaam is not (really) a homophone: Lexical prosody and lexical access in Dutch. *Language and Speech*, *44*(2), 171–195. doi:10.1177/00238309010440020301

Cutler, A., Weber, A., & Otake, T. (2006). Asymmetric mapping from phonetic to lexical representations in second-language listening. *Journal of Phonetics*, *34*(2), 269–284. doi:10.1016/j.wocn.2005.06.002

Damian, M. F., & Bowers, J. S. (2010). Orthographic effects in rhyme monitoring tasks: Are they automatic? *European Journal of Cognitive Psychology*, *22*(1), 106–116. doi:10.1080/09541440902734263

Dijkstra, T., Grainger, J., & Van Heuven, W. J. B. (1999). Recognition of cognates and interlingual homographs: The neglected role of phonology. *Journal of Memory and Language*, *41*(4), 496–518. doi:10.1006/jmla.1999.2654

Dijkstra, T., Miwa, K., Brummelhuis, B., Sappelli, M., & Baayen, H. (2010). How cross-language similarity and task demands affect cognate recognition. *Journal of Memory and Language*, *62*(3), 284–301. doi:10.1016/j.jml.2009.12.003

Dijkstra, T., & Van Heuven, W. J. B. (2002). The architecture of the bilingual word recognition system: From identification to decision. *Bilingualism: Language and Cognition*, *5*(3), 175–197. doi:10.1017/S1366728902003012

Duyck, W., Assche, E. V., Drieghe, D., & Hartsuiker, R. J. (2007). Visual word recognition by bilinguals in a sentence context: Evidence for nonselective lexical access. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *33*(4), 663. doi:10.1037/0278-7393.33.4.663

Goldinger, S. D., Luce, P. A., Pisoni, D. B., & Marcario, J. K. (1992). Form-based priming in spoken word recognition: The roles of competition and bias. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *18*(6), 1211. doi:10.1037/0278-7393.18.6.1211

Grosjean, F. (1998). Studying bilinguals: Methodological and Conceptual Issues. *Bilingualism: Language and Cognition*, *1*(2), 131–149.

Grosjean, F. (2001). The bilingual's language modes. In J. Nicol (Ed.), *One mind, two languages: Bilingual language processing* (pp. 1–22). Oxford: Blackwell.

Jongenburger, W. (1996). The role of lexical stress during spoken-word processing (Ph.D. dissertation, University of Leiden): Holland Academic Graphics.

Lagrou, E., Hartsuiker, R. J., & Duyck, W. (2011). Knowledge of a second language influences auditory word recognition in the native language. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *37*(4), 952–965. doi:10.1037/a0023217

Lagrou, E., Hartsuiker, R. J., & Duyck, W. (2012). The influence of sentence context and accented speech on lexical access in second-language auditory word recognition. *Bilingualism: Language and Cognition*, *16*(03), 508–517. doi:10.1017/s1366728912000508

Lagrou, E., Hartsuiker, R. J., & Duyck, W. (2013). Interlingual lexical competition in a spoken sentence context: Evidence from the visual world paradigm. *Psychonomic Bulletin & Review*, *20*(5), 963–972. doi:10.3758/s13423-013-0405-4

Lagrou, E., Hartsuiker, R. J., & Duyck, W. (2015). Do semantic sentence constraint and L2 proficiency influence language selectivity of lexical access in native language listening? *Journal of Experimental Psychology: Human Perception and Performance*. doi:10.1037/a0039782

Lemhöfer, K., & Dijkstra, T. (2004). Recognizing cognates and interlingual homographs: Effects of code similarity in language-specific and generalized lexical decision. *Memory & Cognition*, *32*(4), 533–550. doi:10.3758/BF03195845

Lemhöfer, K., Dijkstra, T., & Michel, M. (2004). Three languages, one ECHO: Cognate effects in trilingual word recognition. *Language and Cognitive Processes*, *19*(5), 585–611. doi:10.1080/01690960444000007

Lemhöfer, K., Dijkstra, T., Schriefers, H., Baayen, R. H., Grainger, J., & Zwitserlood, P. (2008). Native language influences on word recognition in a second language: A megastudy. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *34*(1), 12. doi:10.1037/0278-7393.34.1.12

Levelt, W. J. M., Roelofs, A., & Meyer, A. S. (1999). A theory of lexical access in speech production. *BEHAVIORAL AND BRAIN SCIENCES*, *22*(1), 1–75. doi:10.1017/S0140525X99001776

Luce, P. A., & Pisoni, D. B. (1998). Recognizing spoken words: The neighborhood activation model. *Ear and Hearing*, *19*(1), 1.

Malins, J. G., & Joanisse, M. F. (2010). The roles of tonal and segmental information in Mandarin spoken word recognition: An eyetracking study. *Journal of Memory and Language*, *62*(4), 407–420. doi:10.1016/j.jml.2010.02.004

Malins, J. G., & Joanisse, M. F. (2012). Setting the tone: An ERP investigation of the influences of phonological similarity on spoken word recognition in Mandarin Chinese. *Neuropsychologia*, *50*(8), 2032–2043. doi:10.1016/j.neuropsychologia.2012.05.002

Marian, V., Blumenfeld, H. K., & Boukrina, O. V. (2008). Sensitivity to phonological similarity within and across languages. *Journal of Psycholinguistic Research*, *37*(3), 141–170. doi:10.1007/s10936-007-9064-9

Marian, V., & Spivey, M. (2003). Competing activation in bilingual language processing: Within-and between-language competition. *Bilingualism: Language and Cognition*, *6*(2), 97–115.

Marian, V., Spivey, M., & Hirsch, J. (2003). Shared and separate systems in bilingual language processing: Converging evidence from eyetracking and brain imaging. *Brain and Language*, *86*(1), 70–82.

Marslen-Wilson, W. D. (1987). Functional parallelism in spoken word-recognition. *Cognition*, *25*(1), 71–102.

Martin, C. D., Costa, A., Dering, B., Hoshino, N., Wu, Y. J., & Thierry, G. (2012). Effects of speed of word processing on semantic access: The case of bilingualism. *Brain and Language*, *120*(1), 61–65. doi:10.1016/j.bandl.2011.10.003

McClelland, J. L., & Elman, J. L. (1986). The TRACE model of speech perception. *Cognitive Psychology*, *18*(1), 1–86. doi:10.1016/0010-0285(86)90015-0

Mitterer, H., Chen, Y., & Zhou, X. (2011). Phonological abstraction in processing lexical-tone variation: Evidence from a learning paradigm. *Cognitive Science*, *35*(1), 184–197. doi:10.1111/j.1551-6709.2010.01140.x

Mulder, K., Dijkstra, T., Schreuder, R., & Baayen, H. R. (2014). Effects of primary and secondary morphological family size in monolingual and bilingual word processing. *Journal of Memory and Language*, *72*, 59–84. doi:10.1016/j.jml.2013.12.004

Nakayama, M., Verdonschot, R. G., Sears, C. R., & Lupker, S. J. (2014). The masked cognate translation priming effect for different-script bilinguals is modulated by the phonological similarity of cognate words: Further support for the phonological account. *Journal of Cognitive Psychology*, *26*(7), 714–724. doi:10.1080/20445911.2014.953167

Nixon, J. S., Chen, Y., & Schiller, N. O. (2014). Multi-level processing of phonetic variants in speech production and visual word processing: Evidence from Mandarin lexical tones. *Language, Cognition and Neuroscience*, *30*(5), 491–505. doi:10.1080/23273798.2014.942326

Peng, S. H. (2000). Lexical versus 'phonological' representations of Mandarin sandhi tones. In M. B. Broe & J. B. Pierrehumbert (Eds.), *Papers in laboratory phonology* (Vol. 5, pp. 152–167). New York: Cambridge University Press.

Qian, Z.-Y. (ed.). (1997). *Jinan fangyan cidian* [Jinan dialect dictionary]. Nanjing: Jiangsu Education Press.

Radeau, M., Morais, J., & Dewier, A. (1989). Phonological priming in spoken word recognition: Task effects. *Memory & Cognition*, *17*(5), 525–535.

Ransdell, S. E., & Fischler, I. (1987). Memory in a monolingual mode: When are bilinguals at a disadvantage? *Journal of Memory and Language*, *26*(4), 392–405. doi:10.1016/0749-596X(87)90098-2

R Core Team. (2013). R: a language and environment for statistical computing [Computer program]. R Foundation for Statistical Computing, Vienna, Austria, version 2.15.

Sakamoto, Y., & Ishiguro, M. (1986). Akaike Information Criterion Statistics.

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-Prime: User's guide*. Pittsburgh: Psychology Software Incorporated.

Seidenberg, M. S., & Tanenhaus, M. K. (1979). Orthographic effects on rhyme monitoring. *Journal of Experimental Psychology: Human Learning and Memory*, *5*(5), 546–554.

Spinelli, E., Segui, J., & Radeau, M. (2001). Phonological priming in spoken word recognition with bisyllabic targets. *Language and Cognitive Processes*, *16*(4), 367–392. doi:10.1080/01690960042000111

Spivey, M. J., & Marian, V. (1999). Cross talk between native and second languages: Partial activation of an irrelevant lexicon. *Psychological Science*, *10*(3), 281.

Thierry, G., & Wu, Y. J. (2007). Brain potentials reveal unconscious translation during foreign-language comprehension. *Proceedings of the National Academy of Sciences*, *104*(30), 12530–12535. doi:10.1073/pnas.0609927104

Van der Loo, M. P. J. (2010). *Distribution based outlier detection for univariate data*. Discussion paper 10003. The Hague: Statistics Netherlands.

Van Hell, J. G., & Dijkstra, T. (2002). Foreign language knowledge can influence native language performance in exclusively native contexts. *Psychonomic Bulletin & Review*, *9*(4), 780–789. doi:10.3758/BF03196335

Van Heuven, V. J. (1988). *Effects of stress and accent on the human recognition of word fragments in spoken context: Gating and shadowing*. Proceedings of the 7th FASE/Speech-88 Symposium, The Institute of Acoustics, Edinburgh.

Van Heuven, W. J. B., Dijkstra, T., & Grainger, J. (1998). Orthographic neighborhood effects in bilingual word recognition. *Journal of Memory and Language*, *39*(3), 458–483. doi:10.1006/jmla.1998.2584

Van Rij, J., Wieling, M., Baayen, R. H., & Van Rijn, H. (2015). itsadug: Interpreting Time Series, Autocorrelated Data Using GAMMs. [Computer program] Retrieved from https://cran.r-project.org/web/packages/itsadug

Weber, A., & Cutler, A. (2004). Lexical competition in non-native spoken-word recognition. *Journal of Memory and Language*, *50*(1), 1–25. doi:10.1016/S0749-596X(03)00105-0

Wiener, S., & Ito, K. (2015). Do syllable-specific tonal probabilities guide lexical access? Evidence from Mandarin, Shanghai and Cantonese speakers. *Language, Cognition and Neuroscience*, *30*(9), 1048–1060. doi:10.1080/23273798.2014.946934

Wood, S. N. (2006). *Generalized additive models: An introduction with R* (pp. 1–476). Florida: CRC Press.

Wood, S. N. (2011). Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. *Journal of the Royal Statistical Society: Series B (Statistical Methodology)*, *73*(1), 3–36. doi:10.1111/j.1467-9868.2010.00749.x

Wood, S. N. (2015). mgcv: Mixed GAM computation vehicle with GCV/AIC/REML smoothness estimation and GAMMs by REML/PQL. (R package version 1.8-5) Retrieved from https://cran.r-project.org/web/packages/mgcv/index.html

Woutersen, M., De Bot, K., & Weltens, B. (1995). The bilingual lexicon: Modality effects in processing. *Journal of Psycholinguistic Research*, *24*(4), 289–298. doi:10.1007/bf02145058

Wu, J., & Chen, Y. (2014). *Tonal variants in the bilingual mental lexicon*. The Fourth International Symposium on tonal aspects of languages (TAL 2014), Nijmegen.

Wu, J., Chen, Y., Van Heuven, V. J., & Schiller, N. O. (2014). Tonal variability in lexical access. *Language, Cognition and Neuroscience*, *29*(10), 1317–1324. doi:10.1080/23273798.2014.915977

Wu, J., Chen, Y., Van Heuven, V. J., & Schiller, N. O. (2016). Predicting tonal realizations in one Chinese dialect from another. *Speech Communication*, *76*, 1–27. doi:10.1016/j.specom.2015.10.006

Wu, J., Chen, Y., Van Heuven, V. J., & Schiller, N. O. (2017). Interlingual two-to-one mapping of tonal categories. *Bilingualism: Language and Cognition*, *20*(4), 813–833. doi:10.1017/s1366728916000493

Wu, J., Chen, Y., Van Heuven, V. J., & Schiller, N. O. (2018). Applying Functional Partition in the investigation of lexical tonal-pattern categories in an under-Resourced Chinese dialect. In J. Tao, T. F. Zheng, C. Bao, D. Wang & Y. Li (Eds.), *Man-Machine speech Communication* (Vol. 807, pp. 24–35). Singapore: Springer Singapore.

Ye, Y., & Connine, C. M. (1999). Processing spoken Chinese: The role of tone information. *Language and Cognitive Processes*, *14*(5-6), 609–630. doi:10.1080/016909699386202

Yuan, J. H., & Chen, Y. Y. (2014). 3rd tone sandhi in standard Chinese: A corpus approach. *Journal of Chinese Linguistics*, *42*(1), 218–237.

Zhang, X., Samuel, A. G., & Liu, S. (2012). The perception and representation of segmental and prosodic Mandarin contrasts in native speakers of Cantonese. *Journal of Memory and Language*, *66*(3), 438–457. doi:10.1016/j.jml.2011.12.006