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Author
Shen, Alice

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Costs and Cues to Code-switched Lexical Access

Alice Shen

1 Introduction

Code-switching is a common practice among bilinguals that seems effortless. It indicates linguistic competence in both languages, as bilinguals are able to uphold grammatical rules for this bilingual language mode while fluently switching at various loci in a sentence (Poplack, 1980). However, perception studies on code-switched speech have generally found that perceiving lexical switches incurs a processing cost (Soares and Grosjean, 1984; Li, 1996). This seems to suggest that bilinguals should slow down when processing a code-switch. How then are these accounts reconciled, and how do bilingual listeners manage the perception of a code-switch, a potentially difficult processing task?

A recent line of research might have an answer as to how bilinguals manage code-switched perception, with the finding that bilingual listeners are able to detect and use subtle phonetic information in the acoustic signal to their advantage during recognition. Balukas and Koops (2014), Piccinini and Garellek (2014), and Fricke et al. (2016) have found that Spanish-English bilinguals produce subtle changes in VOT and prosody leading up to a code-switch, and the latter two studies have found that listeners exploit those cues in perception. Generally, these results suggest that any processing difficulty could be canceled out by the presence of phonetic cues to the code-switch. Specifically, these results are informative with regard to cues to Spanish-English code-switching, which manifest because Spanish and English intonation patterns differ in the location of nuclear pitch accents (Piccinini and Garellek, 2014). The prosodic cues that occur prior to a Spanish-English code-switch are based on this difference between the two languages. Language pairs differing in other ways might therefore exhibit their own distinct code-switch cues in speech.

Mandarin and English are typologically different in that Mandarin uses pitch for lexical tone in addition to intonation. Mandarin has four lexical tones: high level, rising, low falling, and falling. An anticipatory cue to a Mandarin-English code-switch might very well be prosodic, considering the different function of pitch in these two languages. This cue could be assimilatory; for example, the pitch of the English utterance could be increased to match a high level tone Mandarin word. But it is also possible that the cue is dissimilatory. If productions are listener-oriented, the pitch of the English utterance could be decreased in order to highlight the high level tone Mandarin word. It is also necessary to consider that code-switched productions may differ from monolingual productions, i.e. a code-switched Mandarin high level tone word may not have as high a pitch as when it is produced in a fully Mandarin utterance. Any of these cases are potential types of prosodic cues to a Mandarin-English code-switch. Considering the differences between Mandarin and English prosody, and that previous studies found anticipatory cues in Spanish-English code-switching reflecting the intonational differences between the languages, it seems likely that Mandarin-English bilinguals produce such cues as well.

Such anticipatory cues potentially being present in the signal could mean that perceiving code-switched speech is not actually hard on listeners. If it is true that bilingual speakers produce anticipatory code-switch cues and listeners use them in recognition, then manipulating the acoustic signal to remove those cues would make recognition more difficult. Bilingual listeners would not have the information necessary to anticipate an upcoming code-switch, and would therefore encounter some processing difficulty in spoken word recognition.

To test this hypothesis, this study employs an experiment with a splicing manipulation, so that in audio stimuli for that condition, a code-switched Mandarin target word is spliced into an English utterance. This is meant to eliminate information in the acoustic signal that would have prompted the listener to expect a code-switch to Mandarin. The resulting manipulated utterance should instead bias the listener toward English, as code-switch cues are absent. These spliced stimuli are compared to unspliced, natural stimuli, where the target word remains in the utterance in which it was recorded.

The prediction is that listeners will take longer to perceive code-switched target words in the spliced condition, as they do not have the prosodic cues necessary to help them anticipate the code-switch. To test this prediction, bilingual participants' reaction times to audio stimuli with English and code-switched targets and spliced and unspliced targets are compared. If listeners have trouble perceiving code-switched targets without anticipatory cues, reaction times to spliced code-switched targets should be slowest.

Lexical access can potentially explain why bilingual listeners experience processing difficulty. Research on bilingual lexical access has shown that for bilingual listeners, lexical candidates from both languages are activated, even during spoken word recognition of one language (Spivey and Marian, 1999; Weber and Cutler, 2004; Schulpen et al., 2003; Lagrou et al., 2011). For example, if a Spanish-English bilingual hears the Spanish word "playa" (beach), the English competitor "pliers," which begins with the same phonological onset cluster, is also activated (Ju and Luce, 2004). Thus, when perceiving a code-switched spoken word (i.e. perception of two languages), having prosodic cues to a code-switch would primarily activate lexical items from the code-switch language. In particular, anticipatory cues would result in constraints on the set of activated lexical items, or higher activation levels for those lexical items prior to the onset of the word. Inversely, not having such cues means those lexical items could start off with lower activation levels, thus resulting in slower resolution of lexical competition, and manifesting as processing difficulty.

Therefore, it is predicted that lexical competitors from the same language as the experimental target word will be more activated in the unspliced condition. This is because prosodic information will be present in the acoustic signal, and listeners will pick up on those cues to constrain activation to lexical candidates in the appropriate language. This is tested in an eye tracking experiment with the visual world paradigm, in which participants see a visual display of pictures corresponding to the target word and phonological onset competitors in English and Mandarin, while hearing an auditory stimulus mentioning the target word. If listeners indeed use top-down phonetic information to constrain lexical activation to congruent candidates, then fixations to Mandarin competitor images will be higher than fixations to English competitors in the unspliced condition. In the spliced condition, where listeners do not have constraining phonetic information, there will be more fixations to English competitors.

This study explores whether recognition of the intra-sententially code-switched spoken word is costly, by looking at how phonetic cues affect lexical activation. The experiments aim to approximate natural code-switched speech as much as possible in the stimuli, with target words occurring in sentential context, and with a splicing manipulation asking whether the absence of naturally-occurring code-switch cues has a negative effect on processing. The first experiment is a concept monitoring experiment in which participants are presented with a colored line drawing on each trial, and upon hearing the pictured object named in an audio sentence, must press a button. The second is an eye tracking experiment in which participants are displayed the visual world paradigm, consisting of four colored line drawings on each trial. Upon hearing a pictured object named in an audio sentence, their task is to press a button. In both experiments, trials are presented in mixed mode (monolingual or code-switched), and stimuli are either spliced or natural, with target words varying in their location in the sentence. The goal of this study is to understand how bilingual listeners, in particular those proficient in Mandarin and English, use cues to manage bilingual perception, by looking at both offline and online measures of code-switched word recognition.

2 Experiment 1: Concept Monitoring

This experiment tests whether listeners will be slower to perceive code-switches if there is no information present in the acoustic signal that cues them in to an upcoming code-switch. This is tested by comparing reaction times to spliced and unspliced (natural) stimuli, in a concept monitoring experiment where participants see a pictured object and react to the object being named in an audio sentence. Spliced code-switched stimuli consist of a Mandarin target word in an originally English utterance, so that the prosodic cues in the part of the utterance leading up to the target word will bias the listener incorrectly toward English. On the other hand, natural stimuli consist of congruent phonetic information across the entire utterance. The prediction is that listeners will detect the target more slowly when the phonetic information available is incongruent with the code-switch, so reaction times to spliced code-switched stimuli will be slower than to natural code-switched stimuli.

2.1 Method

2.1.1 Speaker

A female 21-year-old Mandarin-English bilingual produced all audio stimuli. She self-reports balanced usage of both languages in home and school environments, having acquired Mandarin from birth and English around age 4. The speaker was given a written language background questionnaire asking for speaking, listening, reading, and writing proficiency self-ratings in both languages. She self-reports being proficient in both languages on a scale of 0-6, with 0 being low and 6 being high, as shown in Table 1. All stimuli were checked by the speaker prior to being used in the experiment, to The speaker was also administered the Bilingual Language Profile (Birdsong et al., 2012), on which she scored -23 on a scale from -218 (very Mandarin dominant) to 218 (very English dominant), suggesting that she is a relatively balanced bilingual, but slightly more dominant in Mandarin. In addition, she reports frequently engaging in code-switching with friends, and occasionally with family.

Table 1: Speaker Self-rated Proficiency

	English	Mandarin
Speaking	5	6
Understanding	6	6
Reading	5	6
Writing	5	4

2.1.2 Participants

Screening. Participants were screened for proficiency prior to the experiments with two tasks. First, they were administered the same written language background questionnaire as was given to the speaker. They then completed a familiarization task, to check participants' vocabulary size and to ensure they associated the appropriate Mandarin and English names with the pictured objects. Participants were presented all visual stimuli one by one on a computer screen, along with printed English and Mandarin names for the pictured objects. The positions of the English and Mandarin names (left or right underneath the picture) were randomized. The task was self-paced, and participants were given an index card to note down any English and Mandarin words they were unfamiliar with, or if the words were not ones they would use to name the pictured object. If the participant was not proficient enough according to the questionnaire, their vocabulary was too limited based on the familiarization task, or if they associated the picture with a different word than intended (due to dialectal differences), they were disqualified from participating. A substantial vocabulary in both English and Mandarin, as well as familiarity with specific names of pictured objects was desirable, as the study relies on participants' being able to associate pictures with their spoken names in both experiments. Therefore, any participants marking more ten words (in either language) as unfamiliar or not their primary choice for describing the picture was disqualified from participating. The entire screening process lasted approximately twenty minutes.

Language Background. A total of 42 Mandarin-English bilinguals (35 female, 7 male) with no reported speech or hearing defects participated in this study. All participants except one completed both experiments. Thirty-five participants were L1 Mandarin speakers, one participant was an L1 English speaker, while six acquired Mandarin and English as simultaneous L1s. Twenty-three participants reported speaking other languages as well, though only four participants reported acquiring other L1s simultaneous to Mandarin, with those languages being Wu (Shanghainese), Yue (Cantonese), and Southern Min. The average age was 20.4 years (SD = 2.2). While most participants were 18-24, one male participant was 31 years of age. The average age of arrival to the U.S. was 15 years (SD = 7), although two participants first lived in Canada starting at ages 4 and 8, before moving to the U.S. at ages 12 and 18, respectively. Additionally, several participants grew up in Singapore, where English is an official language. Most participants moved from China to the U.S. for college, while two each moved from Malaysia and Singapore, and one each from Taiwan and Hong Kong. Four participants were born and raised in the U.S. All participants reported occasionally or regularly code switching with friends or family. Three participants were left-handed.

Based on scores from the Bilingual Language Profile (Birdsong et al., 2012), participants scored on average -31 (SD = 59), meaning most participants leaned Mandarin-dominant. Twenty-seven participants had negative scores, suggesting Mandarin dominance, while the other fifteen had positive scores. Considering that the Bilingual Language Profile treats dominance as a continuum, this summary is not representative of scores' distances from zero; e.g. a score of 1 is as technically English-dominant as 218, while -1 and -218 are Mandarin-dominant.

Table 2 provides participants' average age of acquisition of English and Mandarin, as well as their self-rated proficiency of each language on a scale of 0-6, where 0 means "not well at all" and 6 means "very well." As can be seen in Table 2, participants' rated themselves as being similarly proficient in speaking, understanding, reading, and writing both languages.

Table 2: Participant Language Background

	English	Mandarin
	Mean (SD)	Mean (SD)
Age of acquisition (years)	5.4 (2.7)	1.2 (0.6)
Self-rated Speaking	5.12 (0.89)	5.6 (0.73)
Self-rated Understanding	5.36 (0.76)	5.7 (0.6)
Self-rated Reading	5.3 (0.82)	5.5 (1.1)
Self-rated Writing	5 (1)	4.98 (1.55)

2.1.3 Materials

Visual stimuli. Sixty-four pictureable nouns (thirty-two Mandarin, thirty-two English) were selected as experimental items. Visual stimuli consisted of pictures from the Rossion and

Pourtois (2004) colored line drawing database, or other public domain colored line drawings that visually resembled the Rossion and Pourtois (2004) pictures. Sixteen more pictures were chosen as fillers.

Auditory stimuli. There were a total of 64 auditory stimuli, which were spoken English sentences with either English target words (32 monolingual sentences) or Mandarin target words (32 code-switched sentences), recorded by the speaker in random order. These sentences were constructed so that each sentence mentioned one of the forty-eight pictureable nouns. In half of the sentences, target nouns occurred sentence-medially, while they occurred sentence-finally in the other half. So there was a total of 16 English sentences with medial targets, 16 English sentences with final targets, 16 code-switched sentences with medial targets, and 16 code-switched sentences with final targets. Sentences were designed with similar syntactic structures to control for intonational patterns: either 1) a main clause beginning with a subject pronoun, followed by a transitive verb and direct object, ending with a prepositional phrase, or 2) a subject pronoun, main verb, and embedded clause. In the former case, medial targets occupied the direct object position, while final targets were located in the prepositional phrase. In the latter case, final targets were located in the embedded clause. Target words varied on whether they were introduced by a definite article, indefinite article, or possessive pronoun.

Sixteen filler sentences were constructed, that did not include mention of the pictured object. The fillers functioned as catch trials, to ensure that target loci were not predictable from the similar syntactic structures of the stimuli sentences. Eight of the filler sentences had sentence-medial targets, and eight had sentence-final targets. These catch trials prevented the possibility of participants using syntactic or contextual predictability to respond whenever they expected to hear a noun, e.g. pushing a button when they heard the determiner preceding the target noun. The sixty-four sentences can be found in Appendix A.

Splicing. This study utilizes a splicing manipulation in both experiments to test the expectation that listeners will have trouble recognizing a code-switch if the information in the acoustic signal leading up to the code-switch does not prepare them for the language of the code-switch. Specifically, in an English-Mandarin code-switch, that phonetic information might consist of changes in pitch (F0) in the part of the English utterance leading up to the Mandarin target word. The prediction is that listeners will a) be slower to recognize a code-switch without such information, because b) they are unable to constrain lexical access to candidates of the appropriate language.

The speaker recorded multiple repetitions of each auditory stimulus sentence, including English-only versions of code-switched sentences.

To eliminate any phonetic information provided in the sentence leading up to the target word that could cue the listener in to the language of the target word, stimuli were cross-spliced to paste a Mandarin target originally recorded in a code-switched sentence into what was originally a monolingual English sentence. As a control-splice, English sentence stimuli were recorded twice, and English targets were identity-spliced into another repetition of the same English sentence. This procedure is illustrated in (3).

Table 3: Stimuli Construction

Sentence type	Condition	Stimuli
English		
	Original	We watched the goat from a distance$_a$
		We watched the goat from a distance$_b$
	Spliced	We watched the [goat]$_a$ from a distance$_b$
Code-switched		
	Original	We saw the maozi in a tree$_a$
		We saw the hat in a tree$_b$
	Spliced	We saw the [maozi]$_a$ in a tree$_b$

Since the spliced and natural versions of each sentence would sound identical aside from the splicing effect, two stimuli lists were created in each experiment to avoid participants hearing the same sentence in both conditions. In each list, half of the items were spliced. The concept monitoring experiment had sixty-four distinct sentences, so that each list had thirty-two spliced items. The eye tracking experiment had thirty-six distinct sentences, resulting in eighteen spliced items on each list. Participants were randomly assigned to either List 1 or List 2 at the start of the experiment, with an equal number of participants assigned to each list.

In addition to being run on different lists, participants were also randomly assigned an order in which to complete the two experiments, so that half of the participants finished the reaction time experiment before eye tracking, and half in the other order.

2.1.4 Procedure

Data collection took place in a sound attenuated booth in the Department of Linguistics at UC Berkeley. Participants were presented printed English instructions on a computer screen, informing them that the experiment would involve English sentences and Mandarin-English mixed-language sentences. They wore headphones for the presentation of audio stimuli. During each trial, participants saw a picture on the computer screen, and heard a spoken sentence that mentioned the pictured object. Their task was to press a button as soon as they heard the object mentioned. Participants were instructed that the pictured object was not always mentioned (as in the fillers), and in that case, to not press anything. Presentation of trials was randomized, and a 1000 ms delay occurred between trials. Each trial lasted 3000 ms. The reaction time experiment took approximately fifteen minutes, and participants were compensated $5.

This experiment (concept monitoring) was counter-balanced with the next experiment (eye tracking); participants were randomly assigned the order in which to complete the two experiments. After completion of both experiments, participants were administered the Bilingual Language Profile (Birdsong et al., 2012), an assessment of bilinguals' language dominance, on which individuals can score in the range -218 to 218, with negative scores indicating dominance in Mandarin, positive scores indicating dominance in English, and scores near 0 indicating balanced bilingualism. The Bilingual Language Profile (BLP) was supplemented with a questionnaire on participants' code-switching attitudes and behaviors. The entire study took around 45 minutes, and participants were compensated $5 for the completion of each of the three components.

Reaction times were measured as the latency between the onset of the target word and the subject's keypress response. Catch trials were first excluded from analysis, so that there were a total of 2688 target trials (64 unique stimuli x 42 participants). Data was then trimmed to remove trials with reaction times under 200 ms, and reaction times that were too long (i.e. equal to the trial duration). This resulted in the loss of 47 observations. Additionally, reaction times from trials in which the target word was one that the participant noted as unfamiliar during the familiarization task were excluded. Finally, each participant's mean was calculated, and any reaction times that were more than two standard deviations from that participant's mean were excluded from analysis. Only three observations were removed in this manner as outliers. After trimming, 2430 observations remained for analysis, so that approximately 10% of the data were excluded.

2.1.5 Data Analysis

The log-transformed data was modeled with a linear mixed effects regression model, shown in (5). The model considers an interaction between whether a target word is English or Mandarin (code-switched) and whether it is spliced or natural, the position of the target in the sentence, and by-item and by-subject random slopes (Baayen et al., 2008).

2.2 Results

Table 4 shows average reaction time (in milliseconds) as a function of stimulus language, position of the target word, and whether or not the target word was spliced. Generally, reaction times to code-switched targets were slower than to English targets (with the exception of final, unspliced targets), and reaction times to spliced targets were slower than to unspliced targets. However, the most noticeable difference is between reaction times to sentence-medial and sentence-final targets.

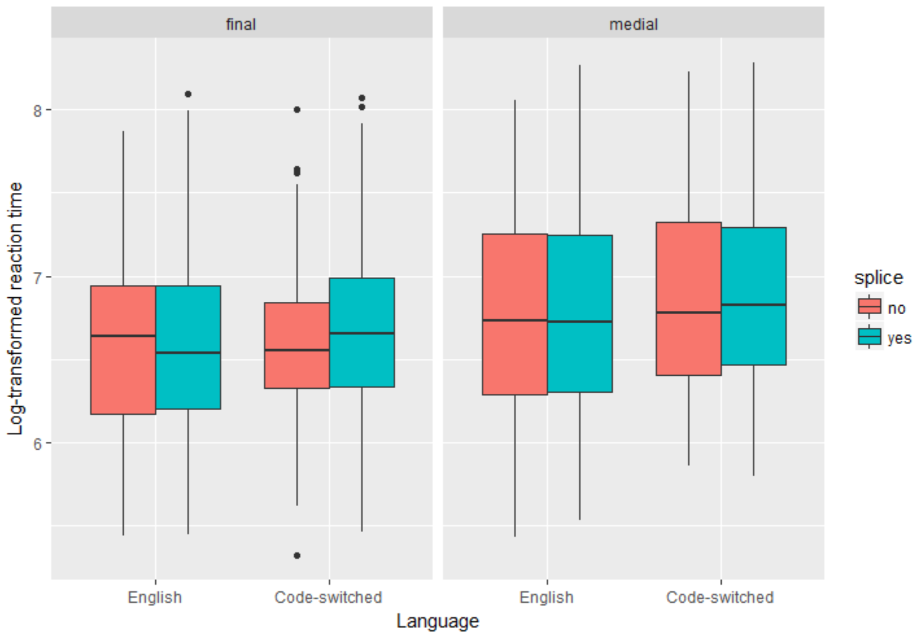
Table 4: Average reaction times (ms), as a function of stimulus language, target word position, and splicing

	English		Code-switched	
Sentence position	Medial	Final	Medial	Final
Unspliced	1004 (549)	819 (410)	1097 (616)	798 (378)
Spliced	1033 (631)	826 (473)	1126 (611)	890 (474)

Standard deviations are shown in parentheses.

Since the data distribution is right-skewed, Figure (1) plots log-transformed reaction times with targets subtyped as in (4). Similar to (4), Figure (1) suggests most strongly that there was a difference between reaction times to sentence-medial and sentence-final targets.

Figure 1: Average log-transformed reaction times, by target position



The model summarized in Table (5) suggests that the presence of a code-switch and its position in the sentence are significant predictors for reaction time. The target being code-switched is predictive of significantly longer reaction times (*Estimate* = 0.091, *SE* = 0.048, p = 0.059), and significantly longer reaction times to sentence-medial words than to sentence-final words (*Estimate* = 0.217, *SE* = 0.046, p <0.001). However, whether or not the target was spliced was not a significant effect (*Estimate* = 0.047, *SE* = 0.034, p <0.176). Additionally, the interaction between whether the target is a code-switch and whether it is spliced is not significant, suggesting that reaction times for code-switched trials are not predicted to differ significantly depending on whether the target was spliced in or not.

Table 5: Linear mixed effects model of reaction time

	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	6.56940	0.07348	59.09000	89.400	<2e-16 ***
language-codeswitch	0.09113	0.04766	79.03000	1.912	0.0595 .
splice-yes	0.04653	0.03367	58.68000	1.382	0.1722
wordposition-medial	0.21737	0.04620	63.27000	4.705	1.42e-05 ***
langcs:splicey	-0.05988	0.05089	61.79000	-1.177	0.2438
langcs:wordposmedial	0.01130	0.06449	66.30000	0.175	0.8614
splicey:wordposmedial	-0.01835	0.04742	58.17000	-0.387	0.7002
langcs:splicey:wordposmedial	0.04015	0.07000	59.63000	0.574	0.5684

*log(RT) ˜ language*splice*wordpos+(1+language |subject)+(1+splice |item)*

2.3 Discussion

The linear mixed effects regression suggests that while listeners are slower to recognize code-switches, the presence or absence of anticipatory cues apparently does not affect their ability to process the code-switch, contrary to the initial prediction of this study. Perhaps Mandarin-English bilingual listeners do not use prosodic cues to anticipate a code-switch and facilitate its perception. However, it is also possible that the speaker failed to produce the expected cues, if the extent of such cues varies between speakers, or if recording stimuli in reading mode results in a lack of cues. If so, the splicing manipulation may have failed to function as intended, in which case no conclusions regarding the presence of phonetic information or listeners' use of it can be drawn. Interestingly, though the position of the target word was originally varied to prevent predictability, this has a significant effect on reaction time. This could be attributed to English intonation marking the end of a sentence, and the reduction of uncertainty as the sentence progresses. When the sentence has a sentence-medial target, prior to target onset, the participant must consider whether the target occurs medially, finally, or not at all (filler). However, when the target is sentence-final, it either occurs or is a filler. It would be interesting to look at whether listeners' use of phonetic information in perception is affected by the amount of time they have to incorporate such information; all sentence stimuli were similar lengths so that trials with sentence-final targets are preceded by a longer utterance than trials with sentence-medial targets.

3 Experiment 2: Eye Tracking

Experiment 1 showed that while bilingual listeners are slower when perceiving a code-switched word compared to perceiving monolingual speech, phonetic information does not seem to be used to anticipate a code-switch, at least as revealed by the splicing manipulation. But while an offline measure like the concept monitoring experiment can reveal whether code-switched perception incurs a switch cost, it does not give insight into the time course of a processing cost, such as phonetic cues constraining lexical activation ((Huettig et al., 2011)).

Eye tracking with the visual world paradigm is a particularly good method for studying activation in lexical access. Eye tracking is an online measure advantageous for understanding the time course of lexical activation during speech perception (Huettig et al., 2011). The visual world paradigm involves a visual display of four pictures, with a simultaneous audio stimulus naming one of the pictures. The pictures can represent the target word and various lexical competitors, with the paradigm revealing which lexical items are activated during spoken word recognition. The audio stimulus can be manipulated to test the role of different phonetic details in the process of recognizing a spoken word. Altogether, the paradigm gives insight into how fine phonetic details affect the activation levels of various lexical candidates.

Experiment 2 utilizes eye tracking to gain insight into the online processing of a code-switch, specifically to determine activation levels of the target and various lexical candidates during processing. The visual world paradigm involves a visual display of four pictures, each corresponding to a different type of lexical candidate, and a simultaneous auditory stimulus so that the time course of lexical access is elucidated by the participant's fixations to pictures during perception of that continuous speech. The goal of this experiment is to probe which lexical candidates are considered during the processing of a code-switch, and whether bilingual listeners use phonetic information to constrain lexical access to candidates in the appropriate language. The prediction is that listeners do use prosodic information in the context leading up to a code-switch to constrain lexical competition. Therefore, in the spliced code-switched condition, listeners would be more likely to consider English lexical competitors, because the phonetic context would bias them toward English. In the natural code-switched condition, listeners would be more likely to consider Mandarin lexical competitors.

3.1 Method

The same speaker who recorded the audio stimuli for the concept monitoring experiment recorded the audio stimuli for this experiment.

Of the 42 participants who completed Experiment 1, data from one participant was excluded in Experiment 2 due to corrective lenses interfering with the eye tracker's calibration process.

3.1.1 Materials

Visual stimuli. Thirty-six pictureable nouns (eighteen Mandarin nouns, eighteen English nouns) that have pictureable Mandarin and English noun cohort competitors were selected, for eighteen sets of three pictureable nouns. To each set, a distractor that was not a cohort competitor was added. This resulted in thirty-six sets of four pictureable nouns. Colored line drawings from the Rossion and Pourtois (2004) database or available to the public domain were selected for the pictureable nouns.

Auditory stimuli. For the thirty-six sets of four pictureable nouns, thirty-six English sentences were constructed. Eighteen sentences had sentence-medial target nouns, while the other eighteen had sentence-final target nouns. The portions of these sentences preceding the target were constructed so that any of the four pictureable nouns in the set were semantically congruous with the verb. For example, in a trial where the Mandarin target is *maozi (hat)*, the cohort competitors in English and Mandarin are *mouse* and *maojin (towel)*, and the distractor is *hua (flower)*, the sentence is "We saw the *maozi* in a tree," where any of the four pictureable nouns in the set are semantically congruous with the verb "saw."

Therefore, there were 9 monolingual stimuli with sentence-medial targets, 9 monolingual stimuli with sentence-final targets, 9 bilingual stimuli with sentence-medial targets, and 9 bilingual stimuli with sentence-final targets.

Table 6 shows an example set of visual stimuli with a corresponding auditory stimulus sentence (where the target is sentence-medial) for both the English and code-switched conditions.

Table 6: Stimulus Example from Experiment 2

	English	Code-switched
Visual stimuli		
Target	goat	maozi (hat)
English competitor	gorilla	mouse
Mandarin competitor	gou (dog)	maojin (towel)
Distractor	kangaroo	flower
Auditory stimuli		
	We watched the goat from a distance.	We saw the maozi in a tree.

The sets of pictureable nouns and their corresponding sentences can be found in Appendix B.

3.1.2 Procedure

Participants were seated a comfortable distance from the computer screen and an eye tracker (The Eye Tribe), which was then calibrated with a nine-point calibration. Sampling of the gaze location of the eyes took place at 60 Hz. Participants wore headphones for presentation of auditory stimuli. Written instructions informed participants that they would be hearing both English and mixed-language English-Mandarin sentences.

During each trial, participants saw a visual world display of four line drawings corresponding to the four pictureable nouns (target, English cohort competitor, Mandarin cohort competitor, and distractor). These four pictures were centered in the four quadrants of the screen. Then after a delay ranging - to – ms, participants heard a spoken sentence. Their task was to press a button as soon as they heard any pictured object in the display be named in the sentence. Each trial lasted 4000 ms. The positions of the four types of pictured objects in the visual world display were randomized across the four fixed quadrant positions for each trial.

The presentation of trials was randomized, and a 1000 ms delay occurred between trials with a central fixation cross. The eye tracking task lasted approximately ten minutes.

3.1.3 Data Analysis

Data collected on trials in which the visual display included any pictureable noun the participant reported being unfamiliar with in either English or Mandarin were excluded.

Looks to any point within the quadrant of each type of picture in the visual world display (Mandarin or English target, English cohort competitor, Mandarin cohort competitor, distractor) were counted as fixations to that picture. To calculate average proportion of fixations for a condition, the number of fixations toward a type of picture were summed across all trials in that condition and all participants, and then divided by the total number of trials in that condition.

The following analyses focus on the time window up to 1200 ms after target word onset, which is when target fixations plateaued. Following Mirman (2014), growth curve analysis with orthogonal polynomials was used to model the time course of fixations to the pictures corresponding to the target word and competitors. Growth curve analysis is especially advantageous for analysis of eye tracking data, as time is treated as a continuous variable. The addition of orthogonal polynomials allows for the shape of the time course of fixations to be captured. Upon visual inspection of the time course data, cubic orthogonal polynomials were chosen as the best approximation of the shape of the curve of proportion of looks over time. The random effects structure for each model includes by-participant random slopes (Baayen et al., 2008).

To assess the best-fitting models for the data, a baseline model was used as a starting point. Variables were added gradually to produce several models varying in complexity, and ANOVA was used to compare the baseline model and these models. Log likelihood and Akaike information criterion (AIC) were then used to assess the best-fitting models for the data. Alpha levels of 0.05 are used to evaluate the significance of each predictor. Cubic orthogonal polynomials interacted with all fixed and random variables.

3.2 Results

3.2.1 Looks to Target

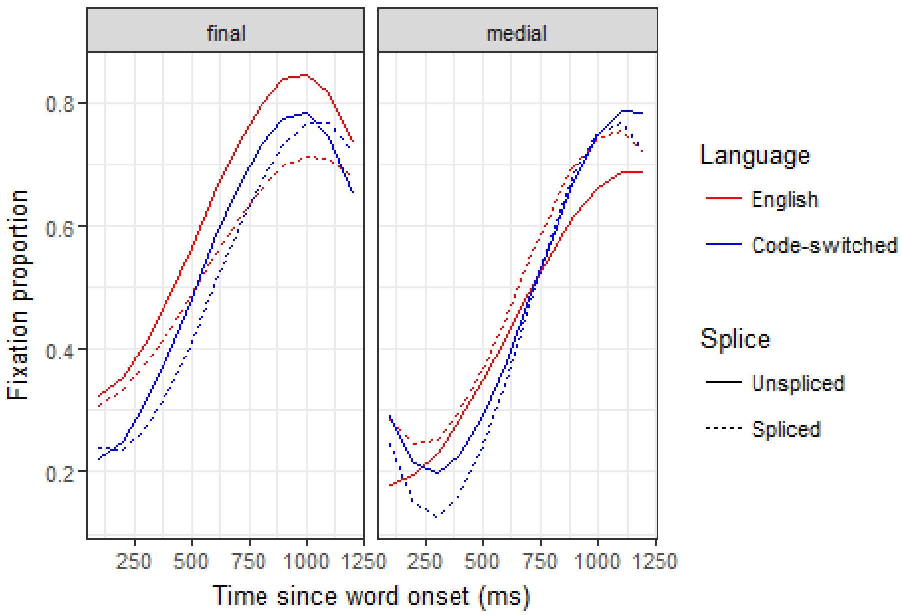
The model for looks to the target had the fixed effects of Position (whether the target occurred sentence-medially or -finally), Language (whether or not the target was code-switched), and Splice. It treated sentence-final, English, and unspliced as the reference points, and statistical significance was calculated using the normal approximation. The model is shown in (1), and plotted in (2), with model fits as lines and empirical data as points.

All three fixed effects in the interaction were significant in this model. The model predicts more looks to the target when it is English than when it is code-switched (*Estimate* = -0.0768, *SE* = 0.0200, p = 0.0001). Position was also significant; fewer looks to sentence-medial targets are predicted (*Estimate* = -0.1849, *SE* = 0.0172, p <0.001). The model predicts fewer looks to a spliced target (*Estimate* = -0.0834, *SE* = 0.0159, p <0.001).

The only interaction with an orthogonal polynomial to be significant was that between the linear term and Position. Although there are initially fewer looks to a sentence-medial target, the rate of looks to that target increases faster (*Estimate* = 0.1706, *SE* = 0.0593, p = 0.004).

The interaction between Position and Language shows that the model predicts more looks to a medial target when it is code-switched (*Estimate* = 0.1023, *SE* = 0.0297, *p* = 0.0006). The interaction between Position and Splice shows that the model predicts more looks to a medial target when it is spliced (*Estimate* = 0.1396, *SE* = 0.0253, *p* <.001). Finally, the three-way interaction was significant; the model predicts fewer looks to a sentence-medial code-switched target when it is spliced.

Figure 2: Looks to the Target Picture

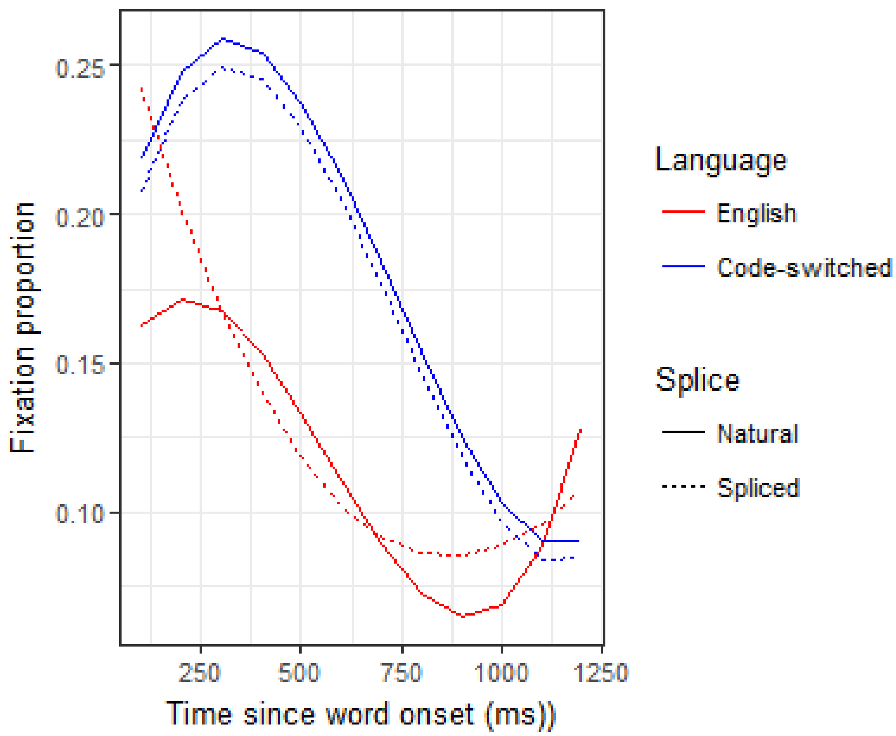


3.2.2 Looks to the Mandarin Competitor

Looks to the Mandarin competitor were modeled with cubic orthogonal polynomials, fixed effects of Language and Splice (baseline: English, unspliced), and by-participant random slopes. The model can be found in (2), and plotted in (3), with model fits as lines and empirical data as points.

There was a main effect of Language, showing that there were more looks to the Mandarin competitor in code-switched trials compared to English trials (*Estimate* = 0.0641, *SE* = 0.0118, *p* <0.001). Interactions between Language and both the linear and quadratic terms were significant. The decay in looks to the Mandarin competitor was steeper in code-switched trials than in English trials (*Estimate* = -0.1035, *SE* = 0.0375, *p* = 0.0057; *Estimate* = -0.1114, *SE* = 0.032, *p* = 0.0005). There was no main effect of Splice, although the interaction between the cubic term and Splice is significant (*Estimate* = -0.07, *SE* = 0.0279, *p* = 0.01247). Therefore, the shape of the function capturing fixations to the Mandarin competitor differs in spliced versus natural trials, although there is no difference between those conditions in proportion of fixations. Finally, the interaction between Language and Splice is significant (*Estimate* = -0.0232, *SE* = 0.0117, *p* = 0.0478). There are fewer looks to the Mandarin competitor in code-switched trials when the target is spliced, compared to when the target is unspliced.

Figure 3: Looks to the Mandarin Competitor

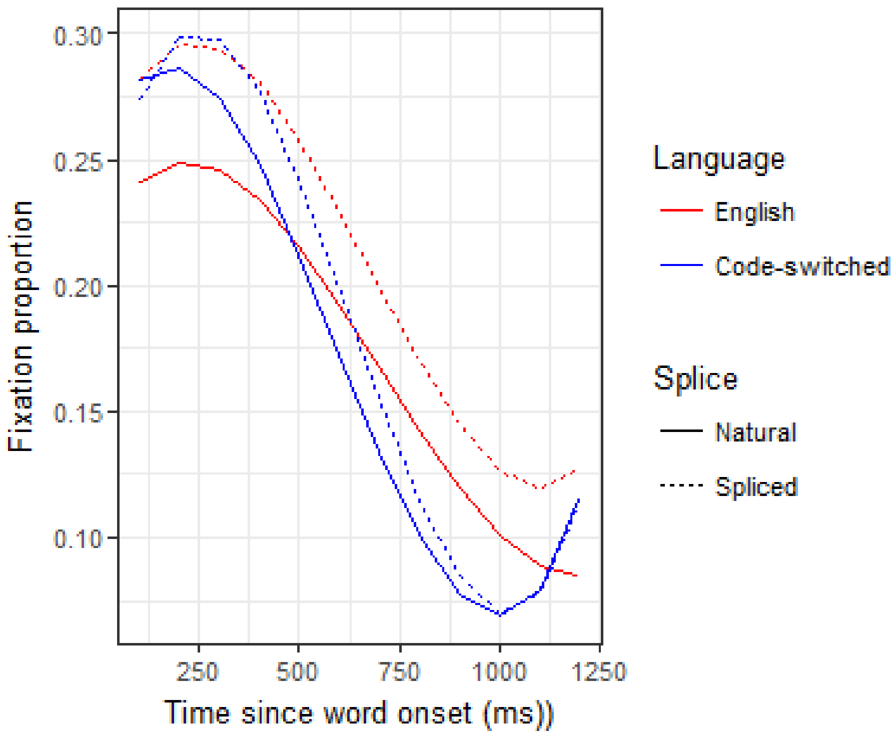


3.2.3 Looks to the English Competitor

Looks to the English competitor were modeled similar to looks to the Mandarin competitor, with cubic orthogonal polynomials, Language, Splice, and by-participant random slopes. This model can be found in (3), and plotted in (4), with model fits as lines and empirical data as points.

Splice suggests an increase in looks to the English competitor when the target word was spliced ($Estimate = 0.0355$, $SE = 0.0182$, $p = 0.0512$), but none of the effects in the model were significant.

Figure 4: Looks to the English Competitor



3.3 Discussion

Experiment 2 revealed that there is a switch cost and that the absence of cues hinders the bilingual listener during perception of a code-switch. Growth curve analysis predicts fewer looks to a code-switched target than a monolingual English target, and fewer looks to a sentence-medial code-switched target when it is spliced. Moreover, cues do bias the listener toward competitors in the language that the cues indicate: there are more looks to the Mandarin competitor when the code-switched target is unspliced and therefore retains cues to Mandarin.

4 General Discussion

This study provides support for the notion that bilingual listeners use cues in the lexical access of code-switches. The online measure in Experiment 2 was able to pick up on bilingual listeners experiencing processing costs while perceiving a code-switch, but still using phonetic cues during perception. When phonetic cues to a code-switch were present, Mandarin lexical candidates were more activated, whereas English lexical candidates were only more activated when cues were manipulated to bias the listener toward English. Coupled with the results of Experiment 1, which found a processing cost but not the use of cues, this study concludes that prosodic cues affect lexical activation, but may not be enough to overcome processing cost, and/or may not be integrated quickly enough to be obvious in the concept monitoring experiment. Without replicating Experiment 1 using the same stimuli sentences as in Experiment 2, it is unclear whether the results could be due to stimuli differences. But eye tracking provides fine-grained temporal resolution for understanding code-switched spoken word recognition, and it seems that any cue-related effect occurs on a shorter time scale than is captured through the reaction time measure. This study reinforces such methodological advantages of eye tracking. Though the concept monitoring experiment was unable to detect listeners' use of cues, the eye tracking experiment revealed that in spite of code-switches incurring a processing cost, the presence of cues allowed for activation of congruent-language lexical candidates. Moreover, instead of switch-stay trials, which are more representative of inter-sentential code-switching, this study uses code-switched sentences produced by a bilingual native speaker who regularly code-switches in daily life. A further improvement on stimuli would be to use extracts from a corpus, so that code-switching is not lab-induced. Finally, the position of the target word in the stimulus sentence makes a great deal of difference as to what effect is observed in the experimental results. The reported effect due to the presence of phonetic cues in Experiment 2 was only observed for trials with sentence-medial targets. This indicates that prosody marking the end of a sentence is an important factor to consider in designing stimuli for such experiments, and is a sign of the extent of questions left to answer regarding perception of code-switches.

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A Experiment 1 stimuli

Chinese target words are in Pinyin, with English translations enclosed in parentheses.

1. We got a qì qiú (balloon) for her birthday.
2. She saw a wáng guān (crown) in the museum.
3. They could see the líng dāng (bell) from the window.
4. He found his pí dài (belt) in the drawer.
5. I took the yùn dǒu (iron) from the shelf.
6. She picked up the xiàng liàn (necklace) from the dresser.
7. He put his xuē zi (boots) by the door.
8. I used the sào zhou (broom) to sweep the floor.
9. They looked for a shuā zi (brush) in the room.
10. We saw the māo tóu yīng (owl) in the tree.

11. We heard the dà pào (cannon) from far away.
12. He picked up the máo mao chóng (caterpillar) from the leaf.
13. We needed a nán guā (pumpkin) for the pie.
14. She observed the wō niú (snail) on the wall.
15. I found a cāng ying (fly) in my house.
16. He searched for his kù zi (pants) in the pile.
17. They watched the movie about the xiǎo chǒu (clown).
18. I moved the papers on his zhuō zi (desk).
19. He took the letter out of the xìn fēng (envelope).
20. I wanted the dessert with the cǎo méi (strawberry).
21. She practiced the piece on her dí zi (flute).
22. He saw a child with a sōng shǔ (squirrel).
23. They watched the game of gǎn lǎn qiú (football).
24. We read the story about the qīng wā (frog).
25. She wanted the guide to talk about the cháng jǐng lù (giraffe).
26. We picked up the cage of the zhà měng (grasshopper).
27. I reached for the dress on the yī jià (hanger).
28. He heard the music of the shù qín (harp).
29. They found the wreck of the zhí shēng jī (helicopter).
30. She broke the string on her xiǎo tí qín (violin).
31. We watched the documentary on the qǐ é (penguin).
32. I handed the waiter the jiǔ bēi (wine glass).
33. I passed her house on the way home.
34. He used the kettle on the counter.
35. We stared at the moon in the sky.
36. She bought a bike from her neighbor.
37. They looked for the needle in the haystack.
38. We listened to the bird in the tree.
39. I used the pepper in my stirfry.
40. She put the orange in the bowl.

41. They wanted the cake from the bakery.
42. He found a peanut in his pocket.
43. She took the pencil from the case.
44. I played the piano in the hall.
45. She found her purse in the closet.
46. I needed a chain for my bike.
47. We saw the church on the hill.
48. They heard the clock in the hall.
49. She took the box with the ring.
50. I wore the sweater with the skirt.
51. They found the web of a spider.
52. We saw the plane above a cloud.
53. He saw the wings of a swan.
54. They looked for the clues by the fence.
55. He broke the bones in his finger.
56. We wanted the sauce on the fish.
57. She heard the cry of the rooster.
58. I broke the nail of my toe.
59. They chased the thief onto the train.
60. I moved the furniture with the truck.
61. He saw the outline of the foot.
62. They found the body in the well.
63. I took the cans that were near the wheel.
64. We watched the scene from the window.

B Experiment 2 stimuli

B.1 Visual stimuli

Target	Cross-language Competitor	Within-language Competitor	Distractor

English target	Mandarin cohort	English cohort	Distractor
bee	bǐ (pen)	beans	candle
beetle	bí zi (nose)	beer	camel
mountain	māo (cat)	mouth	bear
lamp	lán zi (basket)	ladder	airplane
goat	gǒu (dog)	gorilla	kangaroo
monkey	mén (door)	mushroom	fox
artichoke	ěr duo (ear)	arm	peach
diamond	dài zǐ (ribbon)	dice	glasses
leaf	lí zi (pear)	leek	key
shark	xiàng (elephant)	shovel	refrigerator
tulip	tǔ dòu (potato)	tuba	ruler
bus	běn zi (notebook)	butterfly	turtle
coat	kòu zi (button)	comb	vase
pipe	pái (playing cards)	pineapple	hammer
cherry	qié zi (eggplant)	chair	suitcase
bomb	bāo (bag)	box	lock
phone	fēng chē (windmill)	fork	stove
tiger	tài yáng (sun)	tie	horse
Mandarin target	**English cohort**	**Mandarin cohort**	**Distractor**
píng zi (bottle)	pig	píng guǒ (apple)	alligator
xī hóng shì (tomato)	sheep	xī guā (watermelon)	eagle
mào zi (hat)	mouse	mào jīn (towel)	flower
lán qiú (basketball)	lantern	lán bǎo shí (sapphire)	pot
sháo zi (spoon)	saw	shào zi (whistle)	toaster
bēi zi (cup)	baby carriage	bèi zi (quilt)	umbrella
bào zi (leopard)	ball	bào zhǐ (newspaper)	rabbit
miàn bāo (bread)	meat	miàn tiáo (noodles)	carrot
qì chē (car)	cheese	qí zi (flag)	onion
dì tú (map)	deer	diàn shì (television)	lion
xīn (heart)	ship	xīng (star)	scissors
lǐ zi (plum)	leash	lǐ wù (gift)	corn
shū (book)	shoe	shù (tree)	knife
tāng (soup)	taco	táng (candy)	grapes
wá wa (doll)	watch	wà zi (sock)	toothbrush
shǒu tào (glove)	soda	shǒu jī (cellphone)	kite
kǒng què (peacock)	coal	kǒng lóng (dinosaur)	drum
dēng pào (lightbulb)	duck	dèng zi (stool)	ant

B.2 Auditory stimuli

I saw the bee near the table.

He noticed the tulip on the floor.

They talked about the mountain while in the car.

She was curious about the lamp on the table.

We remarked on the monkey outside the house.

I was confused about the artichoke on the counter.

They bought the diamond from the store.

He took the leaf from the tree.

We watched the goat from a distance.

They were interested in the story about the shark.

I heard the boy talk about the beetle.

We used the camera to photograph the bus.

She was upset that the woman didn't have the coat.

I questioned whether the man had the pipe.

He glanced at the picture of the cherry.

They saw the man put down the bomb.

We needed the man to find us a phone.

She saw a picture of the tiger.

I saw the píng zi (bottle) in the backyard.

We found the xī hóng shì (tomato) in the truck.

We saw the mào zi (hat) in the tree.

He brought the lán qiú (basketball) to the team.

I moved the sháo zi (spoon) to the side.

She bought the bēi zi (cup) for her sister.

They noticed the bào zi (leopard) in the enclosure.

We prepared the miàn bāo (bread) for dinner.

I took the qì chē (car) to the garage.

I knew that the story was not about a dì tú (map).

They looked for the lady with a xīn (heart).

He explained that the container was not for the lǐ zi (plum).

He placed the wallet near the shū (book).

They wanted the meal without the tāng (soup).

I bought the other item as well as the wá wa (doll).

She needed the neighbor to show her the shǒu tào (glove).

We knew that the movie did not feature any kǒng què (peacock).

He found the room that had the dēng pào (lightbulb).

C GCA

C.1 Model: Looks to the target picture, as a function of Position, Language, and Splice

(1) *PropTargetLooks ~ (ot1+ot2+ot3)*Language*Position*Splice + (ot1+ot2+ot3 |Subject)*

	Estimate	Std. Error	t value	p
(Intercept)	0.62780855	0.01633827	38.4256547	0.000000e+00
ot1	0.59875248	0.05129641	11.6724063	0.000000e+00
ot2	-0.19800860	0.04173335	-4.7446132	2.089051e-06
ot3	-0.15185439	0.03997467	-3.7987658	1.454184e-04
Position - medial	-0.18487754	0.01721096	-10.7418522	0.000000e+00
Language - codeswitched	-0.07687375	0.02005847	-3.8324824	1.268567e-04
Spliced - yes	-0.08339592	0.01593271	-5.2342582	1.656488e-07
ot1:Position - medial	0.02776906	0.05952328	0.4665244	6.408402e-01
ot2:Position - medial	0.17060677	0.05925644	2.8791260	3.987790e-03
ot3:Position - medial	0.06529215	0.05897598	1.1070973	2.682518e-01
ot1:Language - cs	0.02346384	0.06910122	0.3395575	7.341898e-01
ot2:Language - cs	-0.02572853	0.06807464	-0.3779459	7.054708e-01
ot3:Language - cs	-0.01502193	0.06716852	-0.2236454	8.230332e-01
Position - medial :Language - cs	0.10226705	0.02974471	3.4381594	5.856828e-04
ot1:Spliced - yes	-0.10657118	0.05519253	-1.9308985	5.349560e-02
ot2:Spliced - yes	0.09326702	0.05519253	1.6898487	9.105691e-02
ot3:Spliced - yes	0.06182829	0.05519253	1.1202293	2.626160e-01
Position - medial:Spliced - yes	0.13955310	0.02529131	5.5178274	3.432162e-08
Language - cs:Spliced - yes	0.04892233	0.02962913	1.6511566	9.870661e-02
ot1:Position - medial:Language - cs	0.10473401	0.10224215	1.0243721	3.056595e-01
ot2:Pos - med:Lang - cs	0.18603671	0.10008350	1.8588151	6.305335e-02
ot3:Pos - med:Lang - cs	-0.10291132	0.09806850	-1.0493821	2.940023e-01
ot1:Pos - med:Spliced - yes	0.11564362	0.08728235	1.3249370	1.851920e-01
ot2:Pos - med:Spliced - yes	-0.06748056	0.08639913	-0.7810328	4.347832e-01
ot3:Pos - med:Spliced - yes	-0.15508816	0.08559729	-1.8118349	7.001171e-02
ot1:Lang - cs:Spliced - yes	0.18680655	0.10154479	1.8396468	6.582011e-02
ot2:Lang - cs:Spliced - yes	0.05300838	0.09858773	0.5376773	5.907999e-01
ot3:Lang - cs:Spliced - yes	-0.05945902	0.09594027	-0.6197504	5.354222e-01
Pos - med:Lang - cs:Spliced - yes	-0.13277256	0.04378415	-3.0324341	2.425901e-03
ot1:Pos - med:Lang - cs:Spliced - yes	-0.17514820	0.14985596	-1.1687770	2.424935e-01
ot2:Pos - med:Lang - cs:Spliced - yes	-0.12151861	0.14489443	-0.8386700	4.016545e-01
ot3:Pos - med:Lang - cs:Spliced - yes	0.08543771	0.14021148	0.6093489	5.422932e-01

C.2 Model: Looks to the Mandarin competitor picture, as a function of Language and Splice

(2) *PropMandLooks ˜ (ot1+ot2+ot3)*Splice*Language + (ot1+ot2+ot3 |Subject) + (ot1+ot2+ot3 |Subject:Splice) + (ot1+ot2+ot3 |Subject:Language)*

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.117382729	0.01141701	10.28139351	0.000000e+00
ot1	-0.099893177	0.03350701	-2.98126168	2.870634e-03
ot2	0.057189346	0.02409614	2.37338157	1.762604e-02
ot3	0.064075527	0.02079931	3.08065623	2.065450e-03
Language - code-switched	0.064075435	0.01178351	5.43772063	5.396650e-08
Splice-yes	0.015327563	0.01336816	1.14657268	2.515583e-01
ot1:Language - code-switched	-0.103481186	0.03746142	-2.76234047	5.738860e-03
ot2:Language - code-switched	-0.111375691	0.03204348	-3.47576733	5.093940e-04
ot3:Language - code-switched	-0.001137048	0.03009908	-0.03777682	9.698656e-01
ot1:Splice-yes	-0.044271149	0.04073970	-1.08668337	2.771768e-01
ot2:Splice-yes	0.044654950	0.03098545	1.44115883	1.495398e-01
ot3:Splice-yes	-0.069688346	0.02789126	-2.49857333	1.246943e-02
Language-cs:Splice-yes	-0.023217492	0.01173349	-1.97873655	4.784568e-02
ot1:Language-cs:Splice-yes	0.049749049	0.04060108	1.22531356	2.204571e-01
ot2:Language-cs:Splice-yes	-0.045465310	0.04042338	-1.12472812	2.607043e-01
ot3:Language-cs:Splice-yes	0.070580889	0.04031654	1.75066843	8.000304e-02

C.3 Model: Looks to the English competitor picture, as a function of Language and Splice

(3) *PropEnglishLooks ~ (ot1+ot2+ot3)*Language*Splice + (ot1+ot2+ot3 |Subject) + (ot1+ot2+ot3 |Subject:Language) + (ot1+ot2+ot3 |Subject:Splice)*

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.1698001875	0.01589975	10.67942216	0.000000e+00
ot1	-0.2088790763	0.04270698	-4.89098177	1.003343e-06
ot2	-0.0177217014	0.02833834	-0.62536134	5.317339e-01
ot3	0.0388566188	0.02557619	1.51924988	1.286996e-01
Language - code-switched	0.0009590451	0.01738997	0.05514931	9.560195e-01
Splice-yes	0.0354600650	0.01818940	1.94949097	5.123682e-02
ot1:Language - code-switched	-0.0565018650	0.04974300	-1.13587561	2.560086e-01
ot2:Language - code-switched	0.0717891438	0.04268123	1.68198395	9.257195e-02
ot3:Language - code-switched	0.0455677567	0.03927761	1.16014572	2.459895e-01
ot1:Splice-yes	-0.0169180366	0.05193557	-0.32575049	7.446131e-01
ot2:Splice-yes	0.0076128979	0.03591379	0.21197700	8.321250e-01
ot3:Splice-yes	0.0198265538	0.03548797	0.55868388	5.763775e-01
Language-cs:Splice-yes	-0.0227289064	0.01583682	-1.43519421	1.512318e-01
ot1:Language-cs:Splice-yes	0.0005622502	0.05472382	0.01027432	9.918024e-01
ot2:Language-cs:Splice-yes	-0.0433114556	0.05444590	-0.79549529	4.263254e-01
ot3:Language-cs:Splice-yes	0.0026256058	0.05428864	0.04836381	9.614263e-01