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Identifying bilingual talkers after a language switch: Language experience matters^{a)}

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^{a)} Portions of this work were presented at the 172nd Meeting of the Acoustical Society of America, Honolulu, HI, USA

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ABSTRACT

The current study investigates the role of language experience in generalizing indexical information across languages within bilingual speech. Participants ($n = 48$) learned to identify bilingual talkers speaking in one of their languages and were then tested on their ability to identify the same talker when speaking the same language and when speaking their other language. Both monolingual and bilingual participants showed above chance performance in identifying the talkers in both language contexts. However, bilingual participants outperformed monolinguals in generalizing knowledge about the speaker's voice across their two familiar languages, which may be driven by their experience with language mixing.

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Keywords: Talker identification, Bilingualism, Speech perception, Language mixing

1. Introduction

Many individuals around the world speak and hear more than one language daily. There is growing research on how bilingual listeners process speech sounds from individual languages (see Ingvalson et al., 2014 for a review). However, it is not as clear how listeners process bilingual speech produced by the same speaker. Even within the same discourse, bilingual speakers sometimes engage in code-switching (Heredia & Altarriba, 2001). Do listeners treat bilingual speech from the same speaker as if they are two independent language streams? Or can listeners make use of information from one language stream to aid in their perception of the second language stream? In the current study, we investigated how listeners might use *indexical information* (i.e., cues to speaker identity) across languages when hearing bilingual speech, and how language experience might play a role in this process.

To date, there is limited evidence on what aspects of indexical information in bilinguals' speech is similar or different across their two languages. Ryabov and colleagues (2016) found that Russian-English bilinguals perceived their own speech characteristics (e.g., voice quality, pitch) to be similar in both of their languages. Depending on the language pair, some studies do show that the fundamental frequency (F_0) and F_0 variability can change when switching from one language to another (e.g., Papangelou, 2011). For example, Altenberg and Ferrand (2006) found that, while the mean F_0 of English-Cantonese speakers did not change across languages, English-Russian bilinguals consistently had a higher mean F_0 in Russian than in English. Similarly, a recent study by Bradlow and colleagues (2017) showed that for bilingual speakers, speaking rate in the first language predicts speaking rate in the second language. These studies suggest that, while there are some changes in indexical cues across languages, these changes are consistent enough to facilitate indexical processing of bilingual speech.

In a direct examination of this question, Winters and colleagues (2008) examined how monolingual listeners processed indexical information across languages in bilingual speech. In their study, monolingual English listeners were trained to identify the voices of English-German bilingual talkers from speech in one language (English or German). Then, they were tested on their ability to discriminate and identify those same talkers from speech in both languages (English and German). Those who were trained with German were able to identify the English counterparts as well as the German, while those who were trained with English performed worse for German compared to English. The authors concluded that, when trained in an unfamiliar language, listeners were encoding language-independent indexical information that they could generalize to the bilingual speaker's other language. However, when trained in a familiar language, listeners were encoding language-dependent cues that did not generalize to bilingual speaker's other language. However, even those trained with the English voices were able to identify the same speakers when they were speaking German above chance levels, indicating that listeners were able to generalize some language-independent cues for talker identification.

In the current study, we sought to replicate and extend the findings from Winters and colleagues (2008) with a different set of languages (English and French). Specifically, we tested whether listeners would focus on language-dependent cues when hearing a familiar language and thus show decreased performance in talker identification when hearing the same speaker speak a different language. Further, we examined whether language experience (monolingual versus bilingual, and experience with language mixing) would influence one's ability to recognize talkers in bilingual speech.

Here, we recruited one group of monolingual (English) listeners and one group of bilingual (English-French) listeners to be trained on bilingual voices speaking English and then tested on

the same bilingual voices speaking both English and French. To account for potential language dominance and stimuli effects, we also recruited another group of (English-French) bilingual listeners who were trained on the bilingual voices speaking French and tested on the same bilingual voices speaking both English and French. If monolingual listeners do focus on language-dependent cues when hearing speech in their familiar language (English), then they should show a decrease in performance when hearing the same voice in an unfamiliar language (French).

By the same reasoning, if bilingual listeners also only focus on language-dependent cues when hearing speech in one language, then they should also show a decrease in performance when hearing the same voice in another familiar language. However, if bilingual listeners are more sensitive to cues that generalize across languages in bilingual speech, then they should show more equivalent performance across the two languages at test. We also examined whether bilingual participants' experience with language mixing would also mediate their performance in the task. Given that language mixing involves the experience of communicating in two languages with the same interlocutor, it is possible that experience with language mixing would support the generalization of indexical information across languages in bilingual speech.

2. Methods

2.1 Participants

One group of monolingual English speakers were recruited for the study ($n = 16$; 13 females, 3 males; *mean age* = 22 years, *range* = 18 – 28 years). In addition, two groups of bilingual participants were recruited: the English-trained group [$n = 16$; 12 females, 4 males; *mean age* = 22 years, *range* = 18 – 29 years], and the French-trained group [$n = 16$; 14 females, 2 males; *mean age* = 22 years, *range* = 18 – 29 years]. The three groups were matched on age [one-way ANOVA: $F(2,45) = .05, p = .96$] and sex [Fisher's exact test: $p = .56$].

Group assignment was determined via self-report measures of language ability, and confirmed by the Language Exposure and Proficiency Questionnaire (LEAP; Marian et al., 2007). To be included in the monolingual group, participants had to have rated their knowledge of English with a 7 in a scale from 1 to 7, where 1 represents no ability and 7 represents native-like ability. Further, they had to have rated their knowledge of French and any other known languages with a maximum of 3 ($M = 2.3$; $SD = 0.7$). Importantly, none of the monolingual participants understood a complete sentence in our French stimuli set, as confirmed by debriefing after the study. To be included in the bilingual groups, participants had to have rated their knowledge of English *and* French with a minimum of 5 on a scale from 1 to 7, and their knowledge of any other known languages with a maximum of 3. Our two groups of bilingual participants rated their knowledge of English and French similarly (English-trained: $M_{English} = 7.0$, $SD_{English} = 0.0$ and $M_{French} = 5.8$, $SD_{French} = 0.8$; French-trained: $M_{English} = 6.8$, $SD_{English} = 0.5$ and $M_{French} = 6.0$, $SD_{French} = 0.9$). To compare participants' hearing abilities, we administered the Hearing in Noise Test (HINT; Nilsson et al., 1994) in English for all three listener groups and also in French for the bilingual listener groups. The test assesses participants' speech reception thresholds in noisy contexts. There was no significant difference in participants' English HINT scores across all three groups [$F(2,45) = 0.83$, $p = 0.44$], suggesting that the groups are well matched on hearing ability and English proficiency. Further, a two-way ANOVA revealed no main effect or interaction between bilingual group (English-trained vs. French-trained) and language (English vs. French) on HINT scores [$p \geq 0.73$ in all cases].

However, self-report responses on questionnaires show a trend for both groups of bilingual participants to be more English-dominant. A two-way ANOVA on age of acquisition for each language showed a main effect of Language [$F(1,30) = 4.09$, $p = .05$], such that participants were

exposed to English [English-trained: $M = 0.8$, $SD = 2.2$; French-trained: $M = 1.9$, $SD = 3.0$] earlier in life than French [English-trained: $M = 3.1$, $SD = 3.2$; French-trained: $M = 3.3$, $SD = 2.5$]; there was no main effect of Group nor an interaction between Language and Group [$p \geq 0.14$], indicating that the age of acquisition to each of their languages were matched across the two groups. Further, both groups of bilingual participants were more English-dominant based on the Bilingual Dominance Scale (BDS; Dunn & Fox Tree, 2009, where -30 represents dominance in French, and $+30$ represents dominance in English; English-trained: $M = +14.3$, $SD = 7.8$; French-trained: $M = +12.1$, $SD = 12.1$); there was no significant difference in BDS scores between the two bilingual groups [$p = .56$].

Bilingual participants also completed the Bilingual Switching Questionnaire (BSQ; Rodriguez-Fornells et al., 2012), which characterizes individual patterns of language mixing into four constructs: i) *L1-switch*: the tendency to switch from English to French; (ii) *L2-switch*: the tendency to switch from French to English; (iii) *contextual switch*, which measures the frequency of switches that are triggered by certain contexts, and (iv) *unintended switch*, which measures the lack of intention and awareness of the language switches [English-trained: $M = 33.8$, $SD = 5.3$; French-trained: $M = 35.4$, $SD = 4.3$]. Critically, there was no significant differences in BSQ scores between the two bilingual groups, indicating that they were well matched for language use [$p = .27$].

2.3 Stimuli

Four female native speakers of English and French were recorded producing 10 sentences in English and 10 sentences in French. The sentence lists in both languages were taken from Orena, and colleagues (2015), which were chosen due to the similar number of words and syllables across languages. All speakers were simultaneous English-French bilinguals from Montréal who rated

their knowledge of both English and French as 7 out of 7. Five English sentences from each speaker were used in the training phase for the English-trained groups; the training sentences were the same across all participants for the English-trained groups. Likewise, five French sentences from each speaker were used in the training phase for the French-trained group. The remaining five English sentences and five French sentences were used for the test phase; the test sentences were the same across all participants from the three groups.

Table 1 shows that the acoustic characteristics (duration and mean pitch) of these stimuli. For both duration and mean pitch, we computed a linear mixed-effects model, with Language (English vs. French) as a fixed effect, and Speaker and Item as random intercepts. Although the number of syllables per sentence was matched across languages, mean duration was slightly longer for the French than the English stimuli ($\hat{\beta} = 0.20$, $SE = 0.06$, $t = 3.29$, $p = 0.004$). Further, mean pitch (F_0) was also slightly higher for the French stimuli than the English stimuli ($\hat{\beta} = 4.23$, $SE = 1.55$, $t = 2.55$, $p = 0.02$). Importantly, the degree of duration and pitch variability was consistent across the two languages as reflected by the variation ratio [$p > .05$ for both] calculated according to the procedure in Johnson et al. (2011). Since the stimuli across languages were spoken by the same speakers, we hypothesized that the stimuli would be equally easy to learn across languages.

Table 1. Mean duration (in seconds) and fundamental frequency (mean F_0 , in Hz) for English and French stimuli for the four bilingual speakers separately and in aggregate. Standard deviation is shown in parentheses.

Speaker	Duration (s)		Mean F_0 (Hz)	
	English	French	English	French
1	3.6 (0.3)	3.9 (0.3)	206.5 (11.5)	229.1 (14.4)
2	3.7 (0.3)	4.3 (0.3)	216.6 (8.2)	219.3 (4.2)
3	3.3 (0.4)	3.8 (0.2)	205.2 (14.7)	210.5 (13.4)
4	3.3 (0.3)	3.5 (0.3)	200.9 (11.4)	204.2 (7.9)
All	3.5 (0.4)	3.9 (0.4)	207.3 (12.7)	215.8 (14.1)

2.4 Procedure

Similar to previous studies on talker identification (e.g., Orena et al., 2015), the current experiment consisted of a training and a test phase. During training, listeners learned to identify the voices of the four bilingual speakers when they spoke in one language (in English for the Monolingual and English-trained bilingual groups, or in French for the French-trained bilingual group). The training phase was presented in blocks of 60 randomized trials (4 talkers x 5 sentences x 3 repetitions). On each trial, participants saw an array of four cartoon avatars presented in a single row, and they heard a sentence spoken by one of the speakers. Participants were asked to identify the speaker of that sentence by pressing one of four labeled buttons. They received feedback on each trial, with the word “Correct” or “Incorrect” appearing on the screen with the correct avatar. The next trial began after a 2000 ms pause. Participants remained in the training phase until they met a learning criterion of 85% correct within a single block (60 trials), or the completion of eight training blocks.

Participants from all groups received the same test phase. In the test phase, participants saw an array of the same four cartoon avatars. During each trial, they heard either an English or French sentence spoken by the same four speakers heard during training and were asked to identify the speaker of that sentence. However, no feedback was provided to participants at test. There were 120 test trials (4 talkers x 5 sentences x 2 languages x 3 repetitions), presented in random order.

3. Results

We analyzed performance during the training and test phase using R (R Development Core Team, 2017). Mean performance for the listener groups is shown in Table 2 and also in Figure 1A for training and Figure 1B for test. First, we examined participants’ performances during the training phase. Recall that the monolingual group was trained with the voices speaking English,

while the bilingual groups were trained either in English or in French. A one-way ANOVA with group as a between-subjects factor showed no difference in the number of training blocks to reach the 85% accuracy criterion between the three groups [$F(2,45) = 0.31, p = 0.74, \eta_g^2 = 0.01$]. Further, participants across the three groups showed no difference in the training accuracy in the first block [$F(2,45) = 0.83, p = 0.44, \eta_g^2 = 0.04$], or in the training accuracy in the last block before the test phase [$F(2,45) = 0.39, p = 0.68, \eta_g^2 = 0.02$]. These analyses show that the three listeners groups learned the voices at the same learning rate and to the same degree, confirming that the voices in the two languages were equivalently easy to learn.

Table 2. Mean performance for the three listener groups at training and test. For the Blocks measure, performance reflects number of training blocks to reach the learning criterion. For all other measures, performance reflects talker identification accuracy (percent correct). “First block” refers to training accuracy in the first training block, while “Last block” refers to the training accuracy in the last block before the test phase. Values in parentheses indicate standard error of the mean.

Phase	Measure	Monolinguals	Bilinguals	
			English-trained	French-trained
Training	Blocks	2.2 (0.2)	2.0 (0.1)	2.06 (0.2)
	First block	73.7 (3.4)	72.9 (3.5)	78.2 (2.3)
	Last block	91.0 (1.3)	92.4 (1.1)	92.1 (0.1)
Test	Trained	88.9 (1.0)	90.0 (1.0)	87.7 (1.1)
	Novel	77.1 (1.4)	85.2 (1.2)	82.2 (1.2)

We analyzed performance at test with a general linear mixed-effects model (gLMM) with the binomial response family as implemented with the lme4 package (Bates et al., 2015). A gLMM was fitted to trial-level data during the test phase (correct = 1, incorrect = 0) with Group, Language Type, and their interaction as fixed effects. Group was entered into the model treatment-coded as two contrasts with the (English-trained) monolinguals as the reference level. Language Type was contrast-coded (trained = 1, novel = -1). The model also included random intercepts by participant and talker. There was no main effect of Group for either the English-trained bilinguals vs.

monolinguals contrast ($\hat{\beta} = 0.518, SE = 0.369, z = 1.408, p = 0.159$) or the French-trained bilinguals vs. monolinguals contrast ($\hat{\beta} = 0.287, SE = 0.366, z = 0.782, p = 0.434$) contrast. There was a main effect of Language Type ($\hat{\beta} = 0.473, SE = 0.067, z = 7.092, p < 0.001$), with increased accuracy for the trained compared to the novel language. There was also a significant interaction between Group and Language Type for both the English-trained bilinguals vs. monolinguals contrast ($\hat{\beta} = -0.022, SE = 0.010, z = -2.203, p = 0.027$) and the French-trained bilinguals vs. monolinguals contrast ($\hat{\beta} = -0.205, SE = 0.010, z = -2.102, p = 0.036$).

Figure 1. Panel (a) shows performance during training for the three language groups in terms of number of training blocks to reach criterion (left) and talker identification accuracy during the first and last training block (center and right, respectively). Panel (b) shows mean talker identification accuracy for the three language groups for each language type. Error bars indicate standard error of the mean.

To examine these interactions, separate follow-up models were constructed to compare performance between each bilingual group and the monolingual group. The structure of these models was identical to the full model except that Group was now contrast-coded given two group levels in each model (English-trained and French-trained bilinguals = 1 in their respective model, monolinguals = -1 in both models). For the English-trained bilinguals and monolinguals model, the interaction between Group and Language Type was confirmed ($\hat{\beta} = -0.111$, $SE = 0.049$, $z = -2.216$, $p = 0.027$). Analysis of the simple effect of Group at each Language Type showed equivalent performance between the two groups for the trained language ($\hat{\beta} = 0.145$, $SE = 0.183$, $z = 0.792$, $p = 0.428$) and increased performance for bilinguals compared to the monolinguals for the novel language ($\hat{\beta} = 0.366$, $SE = 0.176$, $z = 2.074$, $p = 0.038$). For the French-trained bilinguals and monolinguals model, the interaction between Group and Language Type was again confirmed ($\hat{\beta} = -0.103$, $SE = 0.049$, $z = -2.110$, $p = 0.035$). However, analysis of the simple effect of Group at each Language Type showed equivalent performance between the two groups for both the trained language ($\hat{\beta} = 0.039$, $SE = 0.186$, $z = 0.211$, $p = 0.833$) and the novel language ($\hat{\beta} = 0.245$, $SE = 0.180$, $z = 1.364$, $p = 0.173$). The direction of the significant interaction suggests that the change from trained to novel items was less for the French-trained bilinguals compared to the monolinguals, but the simple effects analysis does not provide strong evidence that the two groups reliably differed for either the trained or novel language. One final model was constructed to directly compare the two bilingual groups with the same model structure; Group was contrast-coded (English-trained bilinguals = 1, French-trained bilinguals = -1). There was no main effect of Group ($\hat{\beta} = 0.119$, $SE = 0.204$, $z = 0.584$, $p = 0.559$) nor an interaction between Group and Language Type ($\hat{\beta} = -0.007$, $SE = 0.051$, $z = -0.150$, $p = 0.881$),

indicating equivalent performance between the two bilinguals groups for the trained and novel languages, regardless of which language was presented during training.

Finally, we examined whether experience with language mixing would affect the ability to process speech across languages. That is, listeners who have more experience with language-mixed speech might have more implicit knowledge about how indexical information generalizes across languages within the same speaker. To examine this prediction, we constructed a gLMM for the bilingual participants with trial-level accuracy as the dependent variable (0 = incorrect, 1 = correct) with Language Type and the four constructs of the Bilingual Switching Questionnaire as fixed effects, in addition to the interactions between each construct and language type. Language Type was contrast-coded (trained = 1, novel = -1); all language switching constructs were entered as continuous variables scaled and centered around the mean. The model also included random intercepts by subject and talker. As expected, there was a main effect of Language Type ($\hat{\beta} = 0.269$, $SE = 0.053$, $z = 5.075$, $p < 0.001$), but there was no main effect for any of the language mixing constructs ($p \geq 0.367$ in all cases). However, there was an interaction between Language Type and the L1-Switch construct (i.e., the tendency to switch from English to French) ($\hat{\beta} = -0.299$, $SE = 0.119$, $z = -2.507$, $p = 0.012$). No other interaction was reliable ($p \geq 0.387$ in all cases).

Figure 2. The difference between talker identification accuracy for trained and novel languages across bilingual participants as a function of L1-Switch scores (Bilingual Switching Questionnaire; Rodriguez-Fornells et al., 2011). The solid line represents the best-fitting regression line, and the shaded region represents the 95% confidence interval.

In interpreting the L1-Switch construct, it is important to note that our bilingual sample is English-dominant as a whole; as such, the L1-switch construct represents a tendency to switch from their more dominant to their less dominant language. The interaction between L1-Switch scores and language type can be viewed in Figure 2, which plots the difference in talker identification accuracy between the trained and novel language for bilingual participants on the y-axis. Figure 2 shows that participants with higher L1-Switch scores (i.e., higher tendency to switch from English to French) had lower difference scores compared to those with lower L1-Switch scores. These results suggest that participants who reported more experience with language mixing showed more similar performance across French and English in the test phase, indicating that they are better at generalizing indexical properties across languages in bilingual speech.

4. Discussion

Prior work has shown that listeners focus on the language-dependent indexical characteristics when processing speech in a familiar language, and thus show decreased talker

identification skills when the same speaker switches languages (Winters et al., 2008). This pattern was observed in the current experiment for the monolingual participants who were better at identifying a bilingual talker when hearing them speak the same language compared to when they spoke their other language. However, bilingual listeners showed a smaller decrease in talker identification after the language switch. This cannot be attributed to a language-dominance bias during training, as we found similar patterns of learning for bilinguals regardless of the order of the language switch (i.e., English to French, or French to English). These findings reveal that bilingual listeners show an advantage in generalizing indexical information across familiar languages.

Our findings also suggest that specific types of language experience play a role in this process, including one's experience with language mixing in speech production. Interestingly, the construct that was associated with the increased ability to generalize indexical properties across languages was not one's overall language mixing habits, but rather one's frequency of switching to the second, non-dominant language – which is a task that requires more processing effort than the reverse (i.e., switching to the more-dominant language; Liao & Chan, 2016). It would then follow that bilinguals who have more experience producing language switches would also encode and process indexical properties from bilingual speech with more ease. However, one limitation of the analysis here is that it did not directly examine participants' receptive experience with language mixing. Future studies are needed to confirm the association between language mixing and bilingual talker processing, and to dissociate the role of one's production/perception of language mixing on indexical processing.

Why might French-English bilinguals show an advantage in this task over English monolinguals? Given one study which showed no general bilingual advantage for talker

identification in adulthood (Theodore & Flanagan, 2019), we propose three non-mutually exclusive possibilities for the results of the current study, which examined bilinguals' ability to generalize information across two known languages. First, it is possible that there are systematic changes in *indexical information* across bilingual speech, and that bilingual listeners are more sensitive to these systematic differences than monolingual listeners. As described previously, some studies show that certain indexical properties of speech shift in the same direction for a given language pair (e.g., Papangelou, 2011). Given that bilingual listeners have more experience with bilingual speech (both in terms of production and in exposure), they would have more opportunities than monolingual listeners to learn about these systematic changes across bilingual speech. This interpretation is in line with our finding that individuals who had a greater tendency to switch from their English to French are better at processing bilingual speech.

Similarly, a second possibility is that there are systematic consistencies in *linguistic information* across bilingual speech, and that bilingual listeners of these languages are more sensitive to these types of linguistic information than monolingual listeners. As a group, simultaneous bilinguals do produce some speech sounds differently than monolinguals, including certain consonants (e.g., Sundara et al., 2006) and vowels (e.g., Danielson et al., 2014). Given that monolingual adults show talker-specific realizations of certain phonetic properties of speech (e.g., voice-onset-time), it may also be the case that bilingual adults show talker-specific consistency in linguistic properties across their two languages. Specifically, in the same way that some monolingual adults produce consistently longer word-initial voice-onset-times (VOT) for different stops in their single language (Theodore et al., 2009), it is possible that bilingual adults who consistently produce longer word-initial VOTs in their first language would also produce longer word-initial VOTs in their second language. Monolingual adults show sensitivity to talker-specific

phonetic variation (including VOT) in the neural systems associated with talker processing (Myers & Theodore, 2017). Thus, it is possible that listeners might also be able to use these talker-specific phonetic cues to generalize across bilinguals' speech in their two languages.

Finally, it is also possible that bilinguals outperformed monolinguals in this task because they were familiar with both languages at the test phase, while the monolinguals were only familiar with the one of the two languages. Indeed, a recent study has shown that lexical access can improve the encoding and retrieval of indexical information (McLaughlin et al., 2015). It would be of interest to examine how bilinguals would perform in this task if they were not familiar with the language pair of the bilingual speakers. Taken together, our results support the finding that monolingual listeners focus on language-dependent cues when hearing a familiar language. Further, our study suggests that bilingual listeners have further access to transferrable indexical cues in bilingual speech that monolingual listeners do not have access to. Future studies should examine how bilingual listeners can use one language stream to help in the comprehension of a second language stream.

Acknowledgements

This research was supported by a Social Sciences and Humanities Research Council of Canada (SSHRC) Insight Grant to L. Polka and the Acoustical Society of America (Raymond H. Stetson Scholarship) to A. Orena. We thank C. Ossowski, P. Noriega and J. Srouji for their assistance with various parts of the project.

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Figure captions

Figure 1. Panel (a) shows performance during training for the three language groups in terms of number of training blocks to reach criterion (left) and talker identification accuracy during the first training block (right). Panel (b) shows mean talker identification accuracy for the three language groups for each language type. Error bars indicate standard error of the mean.

Figure 2. The difference between talker identification accuracy for trained and novel languages across participants as a function of L1-Switch scores (Bilingual Switching Questionnaire; Rodriguez-Fornells et al., 2011). The solid line represents the best-fitting regression line, and the shaded region represents the 95% confidence interval.