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# Hemispheric Differences in Indexical Specificity Effects in Spoken Word Recognition

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Variability in talker identity, one type of indexical variation, has demonstrable effects on the speed and accuracy of spoken word recognition. Furthermore, neuropsychological evidence suggests that indexical and linguistic information may be represented and processed differently in the 2 cerebral hemispheres, and is consistent with findings from the visual domain. For example, in visual word recognition, changes in font affect processing differently depending on which hemisphere initially processes the input. The present study examined whether hemispheric differences exist in spoken language as well. In 4 long-term repetition-priming experiments, the authors examined responses to stimuli that were primed by stimuli that matched or mismatched in talker identity. The results demonstrate that indexical variability can affect participants' perception of spoken words differently in the 2 hemispheres.

*Keywords:* hemisphere asymmetries, specificity effects, indexical information, spoken word recognition

Both written and spoken forms of language are communicated over a highly variable signal. For example, in written language the letters composing words can appear in different cases (UPPERCASE and lowercase) and different fonts (e.g., Chicago and Times). In spoken language, the identity of the talker and speaking rate represent two different sources of variability. Nonetheless, despite such variations, people typically process written and spoken language quickly and accurately.

Research using the long-term repetition-priming paradigm suggests that certain variations may in fact affect the efficiency with which listeners perceive language. The standard long-term repetition-priming effect refers to any facilitation in the processing of a stimulus as a consequence of encoding the same (or a highly related) stimulus in an earlier episode (Bowers, 1999). In this paradigm, participants are presented with a block of stimuli to which they must respond (the study phase). After a short distractor task, participants are presented with another block of stimuli (the test phase). In this second block, some of the stimuli from the first block are repeated. Typically, performance for repeated stimuli is better than performance for new (i.e., nonrepeated) stimuli. For example, in the lexical decision task, participants are typically faster and more accurate in categorizing letter strings as words when they were studied in an earlier phase of the experiment. In the stem-completion task, participants are more likely to complete a word stem (e.g., BEA____) as a previously studied word (e.g., *BEACON*) as compared with an unstudied word (e.g., *BEAGLE*). However, if the first and second presentations (*prime* and *target*, respectively) mismatch on some dimension (e.g., letter case in visual words; talker identity in spoken words), the priming effect may be attenuated. This attenuation in priming is referred to as *specificity* (or a *specificity effect*).

In the auditory domain, research has revealed specificity effects on spoken word processing and recognition (see Luce & McLennan, 2005, for a review). In particular, indexical variability affects the speed and accuracy of spoken word recognition.[1] *Indexical variation* arises from differences in speaking rate, differences among talkers, differences in affective states, and so on (Abercrombie, 1967; Pisoni, 1997). Previous research has demonstrated that surface details associated with indexical variability (e.g., talker identity) are preserved in some form in memory and have consequences for subsequent perception (see Goldinger, 1996, 1998; Pisoni, 1997, for reviews). From a theoretical point of view, representation and processing effects of indexical variation are a serious challenge to current real-time processing models of

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[1] Allophonic variation has also been shown to have consequences for spoken word processing (see, e.g., McLennan et al., 2003); however, the present investigation is limited to talker variability, one type of indexical variation.

spoken word recognition, all of which essentially ignore surface variability (see Luce & McLennan, 2005).[2]

Much of the representational work on indexical variability has been conducted using the long-term repetition-priming paradigm. Church and Schacter (1994) and Schacter and Church (1992) found talker effects in implicit tasks such as stem completion and identification of low-pass filtered words. Performance in both tasks was better when stimuli were repeated by the same talker (see also Goldinger, 1996). Luce and Lyons (1998) observed significant talker effects in an explicit recognition memory experiment but not in an implicit priming experiment, demonstrating that repetition priming for spoken words might not always be sensitive to changes in the surface characteristics of the stimuli. Luce, McLennan, and Charles-Luce (2003) have proposed that the failure of Luce and Lyons to obtain specificity effects may have been due, at least in part, to the rapidity of the response. McLennan and Luce (2005) recently obtained results in support of their time-course hypothesis, which predicts that specificity effects take time to develop. In three long-term repetition-priming experiments, the authors manipulated the speed with which participants processed the stimuli and observed that indexical variability affects spoken word recognition only when processing is relatively slow and effortful.

In summary, within the auditory domain there is important evidence of specificity effects on word processing. In addition to the studies just discussed, a number of other studies have also obtained specificity effects with other paradigms (Bradlow, Nygaard, & Pisoni, 1999; Fujimoto, 2003) and specific populations (Houston & Jusczyk, 2000, in infants; Sommers, 1996, in elderly adults). However, no published study to date has explored whether hemispheric presentation affects the likelihood of obtaining indexical specificity effects in spoken word processing.[3] Nevertheless, neuropsychological and functional imaging studies provide compelling reasons to believe that hemispheric differences may exist in the auditory domain in general and in spoken language processing in particular. Research studies using cognitive neuroscience techniques, including functional MRI (fMRI), magnetoencephalography (MEG), positron-emission tomography (PET), and investigations of populations with various disorders provide evidence that indexical and linguistic information may be represented and processed differently in the two cerebral hemispheres.

Shestakova et al. (2002) conducted an MEG investigation of speech perception across different speakers and found evidence for more abstract (phoneme) representations in the left hemisphere (LH; more specifically, in the left temporal cortex). Furthermore, patients with right hemisphere (RH) damage perform worse than patients with LH damage in voice discrimination tasks (Van Lancker & Canter, 1982). Moreover, there appears to be more activity in the RH than in the LH when participants are attempting to recognize a talker's voice (Von Kriegstein, Eger, Kleinschmidt, & Giraud, 2003). These findings suggest that the RH is more reliant on the representation and processing of indexical information associated with talker identity than the LH. Indeed, there is now converging evidence in the cognitive neuroscience literature that the RH plays an important role in processing information associated with talker identity (see, e.g., Belin, Fecteau, & Bédard, 2004). Finally, Stevens (2004) recently obtained evidence in an fMRI study that memory for voices is primarily lateralized in the RH and that memory for words is primarily lateralized in the LH.

There are a number of proposals attempting to account for hemispheric differences in language processing. For example, a PET study by Zatorre and Belin (2001) provides evidence to support their hypothesis that the LH is specialized for temporal processing and the RH is specialized for spectral processing. However, Boemio, Fromm, Braun, and Poeppel (2005) argued that both the LH and the RH are sensitive to temporal structure and that auditory signals are analyzed over multiple timescales (25–50 ms and 200–300 ms). Boemio et al. presented data from an fMRI study that were consistent with an asymmetric sampling in time hypothesis (see Poeppel, 2003), in which the LH is primarily responsible for processing on the shorter timescale and the RH is primarily responsible for processing on longer timescales. Therefore, at least one potential explanation for hemispheric differences in language processing is that the LH is particularly sensitive to rapid acoustic changes, precisely the types of changes involved in linguistic processing (e.g., making phonemic distinctions), and the RH is particularly sensitive to acoustic changes over longer timescales (and/or spectral changes), the types of changes that could help in the process of talker identification.

Although none of the neuropsychological evidence speaks directly to hemispheric differences in indexical specificity effects during online spoken word recognition, the results of these studies are certainly consistent with the possibility that such differences may exist, especially with respect to talker-specific indexical information. Moreover, examining the role of the two hemispheres during spoken word recognition has the consequence of gaining insight into the different processing styles of the hemispheres, particularly if the pattern that emerges is consistent with results obtained in vision.

In the visual domain, Marsolek and colleagues (Marsolek, 1999; Marsolek, Kosslyn, & Squire, 1992) have argued that two relatively independent subsystems support the ability to recognize abstract and specific aspects of the input, and that these subsystems operate more efficiently in the LH and RH, respectively. Indeed, recent evidence is consistent with the claims that dissociable neural subsystems underlie abstract and specific recognition of objects (Burgund & Marsolek, 2000; Marsolek, 1999; Marsolek & Burgund, 2003), word forms (Marsolek, 2004; Marsolek et al., 1992; Marsolek, Schacter, & Nicholas, 1996; Marsolek, Squire, Kosslyn, & Lulenski, 1994; but see Koivisto, 1995), pseudoword forms (Burgund & Marsolek, 1997), and letterlike forms (Marsolek, 1995).

[2] Note that nothing in the architectures of these models prohibits the necessary modifications: Models could add representations designed to capture indexical variability (e.g., representations associated with talker identity). However, the challenge is to identify exactly how various indexical properties should be implemented into a real-time processing model of spoken word recognition.

[3] However, Schacter and Church (1992) referred to an unpublished study that examined hemispheric differences in the auditory domain: "In fact, we have initiated experiments on auditory stem completion using a dichotic listening procedure, and we have observed preliminary evidence that the right hemisphere is more impaired by study-to-test voice changes than is the left hemisphere (Schacter, Aminoff & Church, 1992)" (p. 927).

The strongest support for the two-systems hypothesis comes from studies using the long-term repetition-priming paradigm. Marsolek and colleagues have reported qualitatively distinct patterns of visual long-term priming in the two cerebral hemispheres. Using the stem-completion task, these authors observed that long-term priming for words is insensitive to study-to-test changes in letter case (i.e., UPPER and lower) when stems are presented to the LH (the right visual field) and sensitive to these changes when presented to the RH (the left visual field) (Burgund & Marsolek, 1997; Marsolek, 2004; Marsolek et al., 1992, 1994).

A similar pattern of priming has been obtained for object identification. In Marsolek's (1999) study, participants named objects (e.g., *piano*) presented in either the left or the right visual field during a test phase after having viewed same-exemplar and different-exemplar objects during an initial encoding phase. The authors obtained equivalent priming between different exemplars (e.g., two different exemplars of a piano) when test objects were presented to the LH but found reduced priming between different exemplars when the stimuli were presented to the RH.

In the present investigation, we examined the role of talker-specific information in spoken word recognition in the left and right hemispheres. To this end, we conducted four long-term repetition-priming experiments using two tasks that are widely used in research on specificity effects: stem completion (see, e.g., Church & Schacter, 1994) and auditory lexical decision (see, e.g., McLennan & Luce, 2005). In Experiments 1 and 2, ear of stimulus presentation was manipulated in both the study and test phases. The majority of projections are contralateral, and thus a stimulus presented to the right ear should be processed more quickly and more efficiently in the LH, and vice versa.

Note that in the studies by Marsolek and colleagues discussed earlier, hemisphere of stimulus presentation was manipulated only during the test phase. We chose to manipulate ear (hemisphere) of presentation during both the study and test phases in order to maximize our ability to obtain hemispheric differences in indexical specificity effects. We hypothesized that the right ear at study, right ear at test condition should maximize the role of the LH, and the left ear at study, left ear at test condition should maximize the role of the RH. The remaining two conditions (the right ear at study, left ear at test condition and the left ear at study, right ear at test condition) should allow us to evaluate whether the ear (hemisphere) of presentation manipulation is more effective at study or test. In Experiments 3 and 4, ear of stimulus presentation was manipulated only during the test phase.

The main hypothesis under examination was that the indexical information in speech, including talker-specific details, is represented and processed differently in the two cerebral hemispheres. More specifically, we predict that processing in the RH (when stimuli are presented to the left ear) will be facilitated when indexical information at study and test match. Furthermore, when stimuli are presented to the right ear (the LH), we predict that it will not matter whether the indexical information at study and test match or mismatch, because in both cases the input is simply mapped onto representations that are devoid of the surface information associated with indexical variability.

## Experiment 1: Stem Completion

We used the long-term repetition-priming paradigm and the stem-completion task (test phase) to examine potential hemispheric differences associated with indexical specificity effects in spoken word recognition.

### Method

*Participants.* Forty-eight participants were recruited from the University Jaume I of Castellón (Spain). They were paid 6 euros (approximately $8) or received partial credit for a course requirement. Participants were right-handed native speakers of Spanish with no reported history of speech or hearing disorders.

*Materials.* The stimuli consisted of (a) 48 bisyllabic spoken experimental items; (b) 48 bisyllabic spoken filler items; and (c) 32 bisyllabic control items. All stimuli were Spanish words with an accent on the first syllable and were selected from the LEXESP corpus (Sebastián-Gallés, Marti, Carreiras, & Cuetos, 2000). The mean word frequency of occurrence for the experimental items was 201 per five million (mean log frequency = 1.93) according to the LEXESP corpus, and all items had first syllables that allowed at least three Spanish word completions. See the Appendix for a complete list of the stimuli used in all of the experiments.

The stimuli were recorded in a sound-attenuated room by both a male (Julio González [J.G.]) and a female (Lola Albert [L.A.]) talker, were low-pass filtered at 10 kHz, and were digitized at a sampling rate of 20 kHz using a 16-bit analog-to-digital converter. All stimuli were edited into individual sound files and stored on computer disk for later playback. Audio files were equated in root-mean-square (RMS) amplitude. Auditory stems were created by digitally truncating each word so that only the first syllable was preserved.

*Design.* The experiment involved four separate sessions. In each session, two blocks of stimuli were presented. The first consisted of the *primes* (words) and the second the *targets* (auditory stems). The stimuli spoken by talkers J.G. and L.A. served as both primes and targets. For both the primes and the targets, half of the stimuli were spoken by talker J.G. and half were spoken by talker L.A. Primes *matched*, *mismatched*, or were *unrelated* to the targets. Matched primes and targets were identical on the talker dimension (e.g., $foca_{\mathrm{J.G.}}$ [seal]–$fo_{\mathrm{J.G.}}$; $foca_{\mathrm{L.A.}}$–$fo_{\mathrm{L.A.}}$). Mismatched primes and targets differed on the talker dimension (e.g., $foca_{\mathrm{J.G.}}$–$fo_{\mathrm{L.A.}}$; $foca_{\mathrm{L.A.}}$–$fo_{\mathrm{J.G.}}$). In each session, the prime and target blocks both consisted of 24 stimuli. The prime block consisted of 8 experimental words, 8 filler words, and 8 unrelated (i.e., control) words. The target block consisted of 24 auditory stems, 12 of which were derived from experimental words and 12 of which were derived from filler words. Moreover, 8 of the auditory stems matched (i.e., they were produced by the same talker who produced the corresponding words during the study phase), 8 mismatched (i.e., they were produced by the other talker), and 8 were controls (i.e., the words on which the stems were derived were not presented during the study phase).

Orthogonal combination of the three levels of prime (match, mismatch, and control), two levels of target (talker J.G., talker L.A.), two levels of ear of stimulus presentation at prime block (left, right), and two levels of ear of stimulus presentation at target block (left, right) resulted in 24 conditions. The combination of ear of stimulus presentation at prime and target blocks resulted in four separate sessions. Across participants, each item was assigned to every possible condition. However, no single participant heard more than one version of a given word within a block during any of the four sessions. For example, if a participant heard the word *foca* (or stem *fo*) in one of the blocks, he or she did not hear the same word (or stem) again in the same block. For each participant, every word (or stem) appeared in only one of the four sessions.

*Procedure.* Each participant took part in four independent sessions separated by at least 30 min. Each session corresponded to one combination of ear of stimulus presentation during the prime and target blocks. Within each block, the stimuli were presented to the same ear in random order (i.e., within each block, ear of stimulus presentation was blocked). The order of the sessions was balanced across participants.

Participants were tested individually in a quiet room and were not told at the beginning of the experimental session that there would be two blocks of trials. The experiment was controlled by computer (Inquisit 1.33 [2003] software in a PC Pentium). In both the prime and target blocks, the stimuli were presented monaurally over calibrated headphones AKG-K55 at 70 dB.

In the first (prime) block, participants performed a single-word shadowing task in which they attempted to repeat (or shadow) the stimulus word as quickly and accurately as possible. The shadowing task has been used in previous investigations in which specificity effects were obtained (e.g., McLennan et al., 2003). Before moving on to the second block, participants were given a distractor task (mental arithmetic) to work on for approximately 3–4 min. In the second (target) block, participants performed the stem-completion task. They were told that a series of syllables would be spoken over the headphones and that their task was to respond to each one with the first word that came to mind. It was emphasized that there was no correct response on the completion task. A red square was illuminated on the computer screen to indicate the beginning of each trial. There were 6 s between the presentation of stems, during which participants entered their response using the keyboard. Responses were stored in the computer.

## Results

Any participant whose overall mean of target words reported fell two standard deviations below the grand mean was excluded from the analyses, resulting in the elimination of 2 participants.

A Prime (match, mismatch, control) × Target (talker J.G., talker L.A.) × Ear of Stimulus Presentation at Prime Block (left, right) × Ear of Stimulus Presentation at Target Block (left, right) analysis of variance (ANOVA) was performed on proportion of target words reported.[4] Mean proportions of target words reported, along with their respective standard error bars, are illustrated in Figure 1.

We observed a significant main effect of prime, $F(2, 90) = 87.22$, $p < .001$, $MSE = 0.13$. Planned comparisons based on the main effect of prime revealed a significant difference between the match and control conditions, $F(1, 45) = 117.25$, $p < .001$, $MSE = 0.14$, and between the mismatch and control conditions, $F(1, 45) = 110.67$, $p < .001$, $MSE = 0.15$. Crucially, the difference between the match and mismatch conditions (also referred to as the magnitude of specificity, or MOS) was not significant ($F < 1$). Indeed, the MOS was nearly 0 in both ears at the target block.

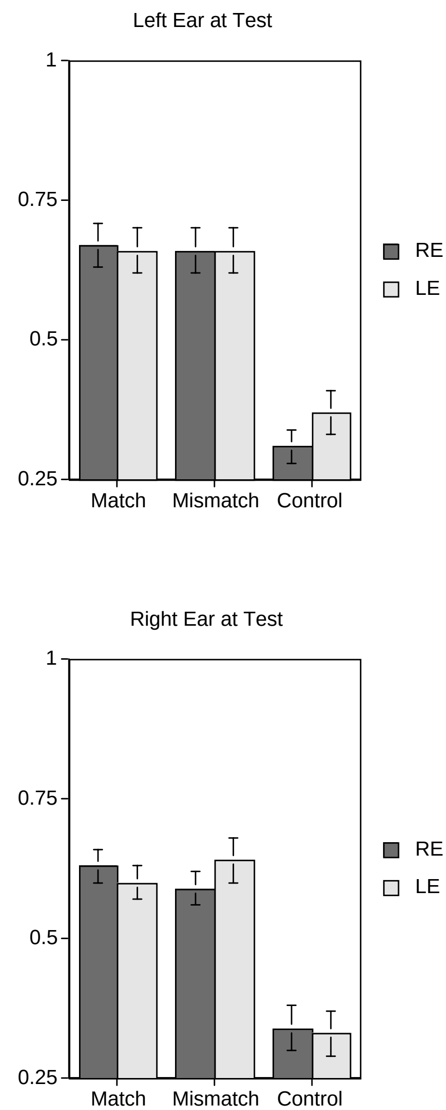


*Figure 1.* Mean proportion of target words reported (with error bars representing plus or minus one standard error of the mean) as a function of prime type for the left ear (upper panel) and right ear (lower panel) presentation conditions at test for Experiment 1. RE = right ear at study; LE = left ear at study.

Furthermore, we observed a significant two-way interaction of Ear of Presentation at Target Block × Target, $F(1, 45) = 7.33$, $p <$

[4] Item analyses are not appropriate for the current experiments and thus were not performed. First, because we used a completely counterbalanced design, each item appeared in every condition and, consequently, served as its own control. In such a design the treatment effect can be tested directly without the need to perform an item analysis (Raaijmakers, 2003; Raaijmakers, Schrijnemakers, & Gremmen, 1999). Second, the number of items in each condition (24) was small owing to the large number of conditions. Thus, the statistical power of an item analysis would have been unacceptably low. Finally, the items for Experiment 1 were not chosen randomly. Rather, they were selected with first syllables that allowed at least three Spanish word completions.

.05, $MSE = 0.08$, and a significant three-way interaction of Ear of Presentation at Target Block $\times$ Ear of Presentation at Prime Block $\times$ Target, $F(1, 45) = 8.70$, $p < .01$, $MSE = 0.06$. These two significant effects, both interactions involving target, reflect the observation that for talker J.G. only, a greater number of target words were reported when the stimuli were presented to the left ear, particularly in the left ear at study and left ear at test condition.

No other main effects or interactions approached significance, including the crucial Ear of Presentation at Target Block $\times$ Prime interaction ($F < 1.0$, $p = .65$).

### Discussion

As expected, a clear repetition-priming effect was obtained in this experiment. Both matched and mismatched primes produced a significantly greater proportion of target words reported on the auditory stem-completion test than the control condition. However, matched primes facilitated responses to targets as much as mismatched primes. Thus, in contrast to the results of Schacter and Church (1992) and Church and Schacter (1994), no specificity effects were obtained. Because we failed to obtain specificity effects, we did not have an opportunity to assess the role of talker-specific information in relation to the left and right hemispheres.

The discrepancy between our data and those of Schacter and Church may be due, at least in part, to two main differences between the present experiment and their experiments. First, the encoding tasks used at the study phase were quite different. In the Schacter and Church (1992) study, participants performed one of two encoding tasks: a semantic task that required participants to judge the pleasantness of each word or a nonsemantic task in which participants made pitch judgments about the voices. In the Church and Schacter (1994) study, participants were asked to rate the speaker's clarity of enunciation. Both nonsemantic tasks focused participants' attention on the acoustic properties of the speaker's voice. In contrast, the encoding task used in the present experiment simply required participants to repeat each word aloud (shadowing or naming).

Second, in Schacter and Church's experiments, all stimuli were presented binaurally during the study phase, and in the present experiment the stimuli were presented monaurally during the study phase. If specificity effects are relatively difficult to obtain in the stem-completion task, then it is possible that an encoding task that merely requires participants to repeat words received through a single channel (ear) is insufficient for producing talker effects in the test phase. In fact, this is one instance of a more general comment regarding specificity effects. That is, despite the apparent plethora of evidence in support of highly detailed representations, years of work in the laboratory of the second author, Conor T. McLennan (and, we suspect, the laboratories of many other researchers as well), demonstrate that specificity effects are actually relatively difficult to obtain. Whereas repetition-priming effects are robust and observed under a wide variety of conditions, specificity effects are typically relatively weak and observed only under certain conditions.

In sum, in the present experiment using the stem-completion task, we obtained a significant priming effect but no evidence of specificity. Regarding whether the ear of presentation affects the likelihood of obtaining indexical specificity effects in spoken word processing, two hypotheses exist according to our present results. First, there may be no difference between the hemispheres with respect to the representation and processing of talker information during the perception of spoken words. Alternatively, such hemispheric differences may exist, but obtaining specificity effects in general could depend on a variety of factors (e.g., task). Thus, perhaps under other circumstances, such as the use of a more online task (e.g., auditory lexical decision), specificity effects will be more likely to emerge and we will be in a better position to evaluate the predicted hemispheric differences in specificity effects.

## Experiment 2: Auditory Lexical Decision

In this experiment, we once again used the long-term repetition-priming paradigm to examine potential hemispheric differences associated with indexical specificity effects in spoken word recognition. However, three important changes were made from Experiment 1 in an attempt to maximize the likelihood of obtaining indexical specificity effects, a necessary condition for evaluating hemispheric differences in indexical specificity effects. First, in the current experiment we replaced the stem-completion task with an auditory lexical decision task, a task in which Conor T. McLennan has had success in obtaining indexical specificity effects (see, e.g., McLennan & Luce, 2005). Owing to the nature of the stem-completion task, participants may have noticed some overlap between the initial list (during the study phase) and the subsequent task, which in turn could have encouraged the participants to remember the prime words explicitly. Consequently, it may have been the use of explicit strategies that eliminated hemispheric differences. In the lexical decision task, participants simply respond *word* or *nonword* and are not required to generate words as responses, making the use of such explicit strategies unlikely. Moreover, the present experiment was designed to produce a relatively difficult discrimination between the real words and the nonwords in the experiment (by using low-frequency words and wordlike nonwords). According to the time-course hypothesis (Luce et al., 2003; McLennan & Luce, 2005), the difficult discrimination should result in relatively slow processing during the lexical decision task, thus providing a greater opportunity to observe indexical specificity effects with this task.

Second, we now used the same task during both the study and test phases of the experiment. Doing so could potentially increase the likelihood of obtaining specificity effects because of transfer appropriate processing (see, e.g., Franks, Bilbrey, Lien, & McNamara, 2000).

Third, in an attempt to minimize the involvement of the same hemisphere as the ear receiving the words and nonwords (via ipsilateral projections), we now presented noise to the ear opposite the one presented the spoken word or nonword item. The presentation of noise in the opposite ear should increase competition between the hemispheres (by presenting information to both hemispheres simultaneously) and increase the likelihood of observing hemispheric asymmetries (Fecteau, Enns, & Kingstone, 2000; Kimura, 1961).

### Method

*Participants.* Forty-eight new participants were recruited from the University Jaume I of Castellón (Spain). They received partial credit for a course requirement. Participants were right-handed native speakers of Spanish with no reported history of speech or hearing disorders.

*Materials.* The stimuli consisted of (a) 48 bisyllabic spoken experimental items; (b) 48 bisyllabic spoken nonword filler items; and (c) 32 bisyllabic spoken control items (half of the control items were words, half were nonwords). All word stimuli were Spanish words with an accent on the first syllable and were selected from the LEXESP corpus (Sebastián-Gallés et al., 2000). To make the word–nonword lexical discrimination task difficult, all nonwords were created by changing one phoneme from the second syllable of the real-word stimuli so that they became wordlike nonwords (see McLennan & Luce, 2005).

The stimuli were recorded in a sound-attenuated room by both a male (J.G.) and a female (L.A.) talker, were low-pass filtered at 10 kHz, and were digitized at a sampling rate of 20 kHz using a 16-bit analog-to-digital converter. All stimuli were edited into individual sound files and stored on computer disk for later playback. Audio files were equated in RMS amplitude.

An 800-ms audio file was created containing pink noise. The noise was also low-pass filtered at 10 kHz and digitized at a sampling rate of 20 kHz. Finally, RMS amplitude was equated to the same level as the speech files. Pink noise has a spectral frequency of 1/f and is found mostly in nature. It was chosen because its spectral level decreases with increasing frequency, as occurs in speech signals, and thus it serves as an effective intelligibility masker (and is also less annoying than white noise).

The mean word frequency of occurrence for the word stimuli was 8.4 per five million (mean log frequency = 0.91) according to the LEXESP corpus. The mean durations for the experimental stimuli produced by talkers J.G. and L.A. were 637 ms and 760 ms, respectively. This difference in duration reflects the difference in the talkers' natural speaking rates; no attempt was made to equate the durations of the stimuli produced by talkers J.G. and L.A.

*Design.* The design was the same as that used in Experiment 1.

*Procedure.* The procedure was the same as that used in Experiment 1, with the following exceptions: In both the prime and the target blocks, participants performed a lexical decision task in which they were instructed to decide as quickly and accurately as possible whether each item they heard was a real Spanish word or a nonword. They indicated their decision by pressing one of two appropriately labeled keys on the computer keyboard (*word* on the right and *nonword* on the left), using their dominant (right) hand to make all *word* responses.

Each trial proceeded as follows: A red square was illuminated on the computer screen to indicate the beginning of each trial. The participant was then presented with a speech stimulus monaurally over the headphones and simultaneously with the noise in the opposite ear. The participant was instructed to make a lexical decision as quickly and accurately as possible. Reaction times (RTs) were measured from the offset of the presentation of the stimulus to the onset of the participant's keypress response.[5] After the participant responded, the next trial was initiated 2 s later. If the maximum reaction time (5 s) expired, the computer automatically recorded an incorrect response and presented the next trial.

## Results

Any participant whose overall mean RT fell two standard deviations beyond the grand mean was excluded from the analyses, resulting in the elimination of 2 participants. Moreover, for each condition, any mean RT that fell two standard deviations beyond the overall mean for that condition was removed and subsequently replaced with the new overall mean for that condition, resulting in the replacement of 4% of the mean RTs.

Prime (match, mismatch, control) × Target (talker J.G., talker L.A.) × Ear of Stimulus Presentation at Prime Block (left, right) × Ear of Stimulus Presentation at Target Block (left, right) participant ANOVAs were performed on mean RTs for correct responses and percentages correct for the experimental stimuli. Note that the experimental stimuli were all real words; no analyses were performed on the nonword filler items. Accuracy to experimental stimuli was greater than 93% overall. We observed a significant main effect of prime on accuracy, $F(1, 45) = 11.67$, $p < .01$, $MSE = 0.37$, which was driven entirely by lower accuracy in the control condition.

Mean RTs, along with their respective standard error bars, are illustrated in Figure 2. We obtained a significant main effect of prime, $F(2, 90) = 59.00$, $p < .001$, $MSE = 18{,}079.52$. Planned comparisons based on the main effect of prime revealed a significant difference between the match and control conditions, $F(1, 45) = 78.13$, $p < .001$, $MSE = 21{,}274.62$, and between the mismatch and control conditions, $F(1, 45) = 64.39$, $p < .001$, $MSE = 23{,}847.33$, but not between the match and mismatch conditions ($F < 1.0$).

The two-way interaction of Ear at Prime Block × Prime did not approach significance ($F < 1.0$, $p = .42$). Crucially, we obtained the significant two-way interaction of Ear of Presentation at Target Block × Prime, $F(2, 90) = 3.00$, $p < .05$, $MSE = 15{,}586.57$. We were primarily interested in the difference between the match and mismatch talker conditions in the two ears at target block. To examine this crucial interaction more closely, we performed two additional analyses.

In the first additional analysis, we investigated the consequences of the two-way interaction of Ear at Target Block × Prime with the control condition removed, to ensure that any difference between the control conditions was not carrying the effect. Fortunately, even with the control condition removed we obtained the significant two-way interaction of Ear of Presentation at Target Block × Prime, $F(1, 45) = 5.22$, $p < .05$, $MSE = 10{,}566.68$, demonstrating that the difference between the match and mismatch conditions varied as a function of ear of presentation during the target block.

In the second additional analysis, we attempted to investigate the locus of this effect more directly by performing an analysis on

[5] Following the procedure in Fujimoto (2003), RTs were measured from the offset of the auditory stimulus, rather than the onset, in order to account for the fact that participants often have to wait until the end of the stimulus to determine its lexical status and make their lexical decision response, particularly because the discrimination was difficult and the nonwords were wordlike. Other researchers have followed this procedure for other tasks that would similarly require processing the entire stimulus, such as word spotting (see, e.g., Norris, McQueen, Cutler, & Butterfield, 1997; see also Onishi, Chambers, & Fisher, 2002). Finally, the data pattern was the same when RTs from onset were examined.

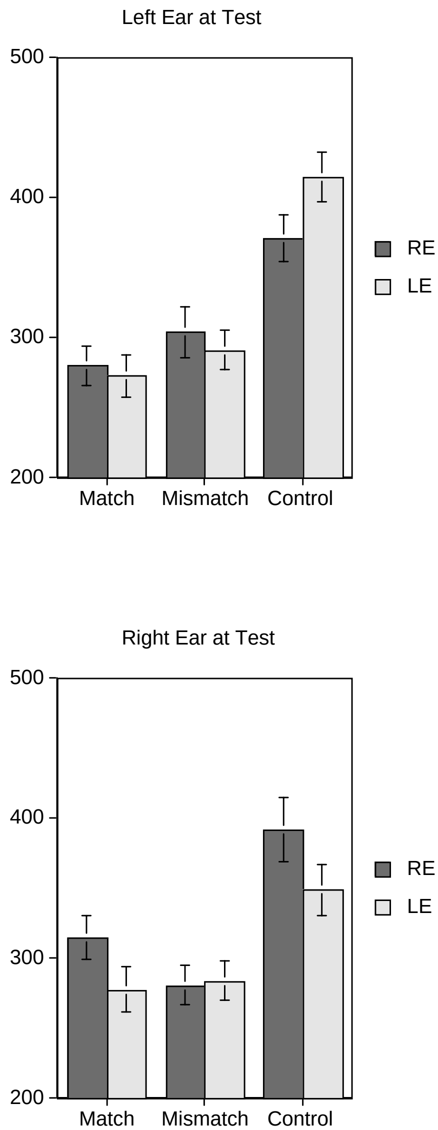


*Figure 2.* Mean reaction times (in milliseconds, with error bars representing plus or minus one standard error of the mean) as a function of prime type for the left ear (upper panel) and right ear (lower panel) presentation conditions at test for Experiment 2. RE = right ear at study; LE = left ear at study.

the MOS in the two ear-of-presentation conditions at test. Recall that the MOS, or magnitude of specificity, is simply the difference between the match and mismatch conditions. In the MOS analysis, the main effect of ear at target block was significant, $F(1, 45) = 5.22$, $p < .05$, $MSE = 21{,}133.35$, providing support for the idea that talker-specific information is playing a different role in the two hemispheres at test. The mean MOS in the left ear was –21, indicating that participants were 21 ms faster when the talker matched than when the talker mismatched and thus talker-specific information facilitated processing of spoken words in this condition. This was not the case in the right ear. In the right ear, the mean was 13.6, demonstrating that participants' recognition of the spoken target words was no faster when the talker matched than when the talker mismatched.[6]

Furthermore, we obtained a significant main effect of target, $F(1, 45) = 36.42$, $p < .001$, $MSE = 12{,}680.64$, presumably because of the differences in stimulus duration due to the talkers' different speaking rates. We also obtained a significant two-way interaction of Ear of Presentation at Target Block × Ear of Presentation at Prime Block, $F(1, 45) = 5.08$, $p < .05$, $MSE = 14{,}677.27$, indicating that switching the ear of presentation between the prime and target blocks led to shorter mean RTs compared with when the ear of presentation was the same during both the prime and target blocks. (This interaction is discussed further in the General Discussion.) Finally, the three-way interaction of Ear of Presentation at Target Block × Ear of Presentation at Prime Block × Prime was significant, $F(2, 90) = 4.42$, $p < .05$, $MSE = 13{,}705.27$. This relatively complex interaction may be indicative of asymmetrical interhemispheric repetition-priming effects (see Weems & Zaidel, 2005) and is discussed further in the General Discussion.

No other main effects or interactions approached significance except for interactions involving target (talker). Moreover, because all effects involving target simply reflect differences in stimulus duration, due to the different speaking rates of the two talkers, effects involving target are theoretically uninteresting and thus are not discussed further.

### *Discussion*

Once again, as expected, a clear repetition-priming effect was obtained. Both matched and mismatched primes produced facilitative effects on lexical decision responses, relative to the control condition. However, unlike in Experiment 1, we found that the difference between matched and mismatched primes was different depending on the ear of presentation at test. In the left ear, but not in the right ear, matched primes served as more effective primes than mismatched primes. This suggests that talker-specific information is represented and processed differently in the two hemispheres. Therefore, with respect to the two possibilities laid out in the discussion of Experiment 1 regarding potential hemispheric differences in specificity effects in spoken word processing, the first hypothesis can clearly be ruled out. Our current results suggest that there is indeed a difference between how the two hemispheres represent and process talker-specific information, at least under some conditions, consistent with the second hypothesis. In particular, matching on the talker dimension facilitates the perception of spoken language when stimuli are presented to the left ear during test but not to the right ear. This finding is crucial because (a) it is consistent with our predictions at the outset of this study; (b) it is consistent with the cognitive neuropsychological evidence discussed earlier; (c) it parallels findings from visual word recognition (e.g., Marsolek, 2004); and (d) perhaps most important, it is, to our knowledge, the first such finding involving spoken word recognition.

[6] Indeed, the effect was in the opposite direction in the LH. That is, when stimuli were presented to the RE at test, participants were actually slower to make their lexical decision responses to target stimuli spoken by the same talker than to target stimuli spoken by the different talker. This pattern is discussed further in the General Discussion.

In sum, in the present experiment using the hard discrimination lexical decision task, we obtained a significant priming effect and an effect of talker-specific information. However, the role that the talker-specific information played differed depending on which ear was presented with the stimuli during the test block. When the stimuli were presented to the left ear during test, the matching of talker identity facilitated perception. On the other hand, when the stimuli were presented to the right ear during test, the mismatching of talker identity facilitated perception. This latter finding is inconsistent with the prediction made at the outset of this study, namely, that matched and mismatched stimuli would serve as equally effective primes when stimuli were presented to the right ear. This prediction was based on the hypothesis that talker variability is irrelevant in the LH. However, if talker variability were truly irrelevant in the LH (because regardless of changes in the identity of the talker, abstract linguistic information dominated), then there should have been no difference between the matched and mismatched prime types. Before rejecting this hypothesis, we considered that there may be aspects of our experimental design that led to (or at least contributed to) this unanticipated effect. In particular, manipulating the ear of presentation at both study and test could have unnecessarily complicated our ability to evaluate potential hemispheric differences in specificity effects. Therefore, we conducted two additional experiments in which we manipulated the ear of presentation at test only (and presented the stimuli binaurally at study), as has been done in the visual domain.

Finally, because we made a number of changes between Experiments 1 and 2 in an attempt to maximize the likelihood of obtaining indexical specificity effects, it is difficult to pinpoint the locus of the different pattern of results between the two experiments. Therefore, Experiments 3 and 4 were also conducted in order to shed light on the precise conditions that lead to indexical specificity effects.

## Experiment 3: Stem Completion II

In this experiment, as in Experiment 1, we used the long-term repetition-priming paradigm and the stem-completion task (test phase) to examine potential hemispheric differences associated with indexical specificity effects in spoken word recognition. However, in order to maximize the likelihood of obtaining indexical specificity effects in the stem-completion task, three important changes were made from Experiment 1.

First, we replaced the shadowing task during the study phase with a pleasantness-rating task (as in Schacter & Church, 1992). It is possible that (at least part of) the reason we did not obtain indexical specificity effects in Experiment 1 is due to the shadowing response, which allowed participants to hear their responses binaurally. Although indexical specificity effects have been obtained using the shadowing task (e.g., McLennan & Luce, 2005), this task may not be ideal when stimuli are presented monaurally and the goal is to evaluate hemispheric differences (particularly when ear of presentation is blocked). Alternatively, it may not be the shadowing task per se that is responsible for our failure to obtain specificity effects in Experiment 1. Rather, it is possible that using the same task at study and test, as was done in Experiment 2 but not in Experiment 1, was (at least part of) the reason for the different pattern of results in Experiments 1 and 2. Therefore, being able to obtain the same pattern of results as in Experiment 2 in a new stem-completion experiment in which the task differed between study and test would allow us to rule out using the same task at study and test as an explanation for our different pattern of results in Experiments 1 and 2, and would provide stronger support for our hemispheric differences hypothesis.

Second, we now present the stimuli binaurally during the study phase and only manipulate ear (hemisphere) of presentation during the test phase. Third, our ear of presentation manipulation is no longer blocked and counterbalanced over multiple sessions. Rather, ear of presentation varies throughout the course of the experiment, which now consists of only a single session. Reducing the experiment to one session also allows us to minimize the likelihood that participants are able to adopt explicit strategies to solve the stem completions.

### Method

*Participants.* Sixty participants were recruited from the University Jaume I of Castellón (Spain). They received partial credit for a course requirement. Participants were right-handed native speakers of Spanish with no reported history of speech or hearing disorders. Handedness was assessed by the short form of the Edinburgh Handedness Inventory (Oldfield, 1971). Laterality quotients of this instrument range from –100 (full left-handed) to 100 (full right-handed). Mean laterality quotient of participants was 85.7.

*Materials.* Because stimulus presentation was manipulated only during the test phase, only half as many items were necessary in this experiment as compared with the previous experiments, in which stimulus presentation was also manipulated during the study phase. The stimuli were a subset of the stimuli used in Experiment 1 and consisted of (a) 24 bisyllabic spoken experimental items; (b) 24 bisyllabic spoken filler items; and (c) 16 bisyllabic control items. The mean word frequency of occurrence for the experimental items was 149 per five million (mean log frequency = 1.80) according to the LEXESP corpus (Sebastián-Gallés et al., 2000).

*Design.* The design was the same as that used in Experiment 1, with the following exceptions: The experiment involved only one session, and ear (hemisphere) of stimulus presentation during the study phase was not manipulated. Orthogonal combination of the three levels of prime (match, mismatch, and control), two levels of target (talker J.G., talker L.A.), and two levels of ear of stimulus presentation at target block (left, right) resulted in 12 conditions.

*Procedure.* The procedure was the same as that used in Experiment 1, with the following exceptions: First, during the study block, the stimuli were presented binaurally. Second, a pleasantness-rating task was used in which participants heard a spoken word and were instructed to rate each word for "pleasantness" on a scale from 1 to 4 (1 = *unpleasant*, 2 = *moderately unpleasant*, 3 = *moderately pleasant*, 4 = *pleasant*) (Schacter & Church, 1992). Third, during the target block, the stimuli were presented monaurally in random order, and ear of stimulus presentation was not blocked. That is, on half of the trials the stimuli were presented to the left ear and on the other half of the trials the stimuli were presented to the right ear, and ear of stimulus presentation was random across all trials.

### Results

Any participant whose overall mean of target words reported fell two standard deviations below the grand mean was excluded from the analyses, resulting in the elimination of 2 participants.

A Prime (match, mismatch, control) × Target (talker J.G., talker L.A.) × Ear of Stimulus Presentation at Target Block (left, right) ANOVA was performed on proportion of target words reported. Mean proportions of target words reported, along with their respective standard error bars, are illustrated in Figure 3.

We observed a significant main effect of prime, $F(2, 114) = 40.49$, $p < .001$, $MSE = 0.14$. Planned comparisons based on the main effect of prime revealed a significant difference between the match and control conditions, $F(1, 57) = 66.02$, $p < .001$, $MSE = 0.15$, and between the mismatch and control conditions, $F(1, 57) = 32.53$, $p < .001$, $MSE = 0.14$, but not between the match and mismatch conditions, $F(1, 57) = 1.63$, $p = .206$, $MSE = 0.15$. No other main effects or interactions approached significance.

We performed an additional analysis in order to investigate the difference between the match and mismatch conditions separately for each ear of stimulus presentation. Crucially, this difference (match = .595 vs. mismatch = .496) was statistically significant in the left ear (RH), $F(1, 57) = 3.25$, $p = .076$, $MSE = 0.17$ ($p = .038$, for a one-tailed test), but this difference (match = .560 vs. mismatch = .569) was not significant in the right ear (LH), $F < 1$.

### Discussion

Once again, as expected, a clear repetition-priming effect was obtained. Both matched and mismatched primes produced a significantly greater proportion of target words reported on the auditory stem-completion test than the control condition. However, unlike in Experiment 1, we found that the difference between matched and mismatched primes was different depending on the ear of presentation at test. In the left ear, but not in the right ear, matched primes served as more effective primes than mismatched primes. This finding provides further evidence that talker-specific information is represented and processed differently in the two hemispheres.

Furthermore, the changes in experimental procedure from Experiment 1—namely, the use of the pleasantness-rating task during study, bilateral stimulus presentation during study, and presenting the two ear-of-presentation conditions at test randomly during a single phase (rather than blocked over multiple phases)—proved successful in producing hemispheric differences in specificity effects. Also, because different tasks were used during the study (pleasantness-rating) and test (stem-completion) phases, we can now rule out the use of the same task at study and test, as well as the use of the lexical decision task, as necessary criteria for obtaining indexical specificity effects and hemispheric differences.

Finally, unlike Experiment 2, stimuli mismatching in indexical information did not facilitate responding in the current experiment. Consequently, it is not clear whether the use of the auditory lexical decision task, the manipulation of ear of presentation at both study and test, or both led to this unanticipated result in Experiment 2. Therefore, we conducted Experiment 4 in order to investigate the locus of this effect.

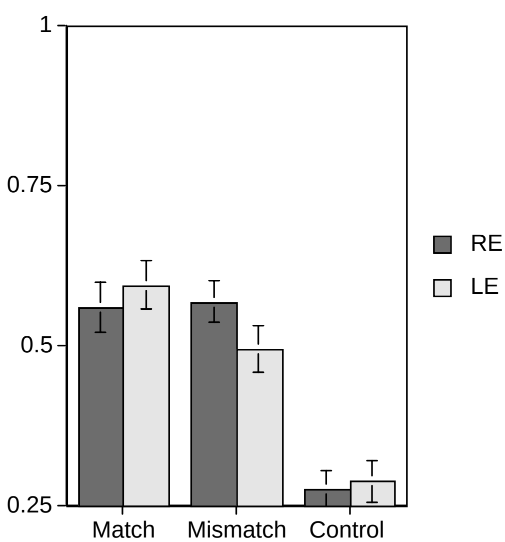


*Figure 3.* Mean proportion of target words reported (with error bars representing plus or minus one standard error of the mean) as a function of prime type for the left ear and right ear presentation conditions at test for Experiment 3. RE = right ear at test; LE = left ear at test.

## Experiment 4: Auditory Lexical Decision II

In this experiment, as in Experiment 2, we used the long-term repetition-priming paradigm and the auditory lexical decision task (test phase) to examine potential hemispheric differences associated with indexical specificity effects in spoken word recognition. However, during the study phase, stimuli were presented binaurally and the lexical decision task was replaced with a pleasantness-rating task. Furthermore, the spatial locations of participants' manual responses (*word* and *nonword*) during the test phase were counterbalanced, rather than participants always responding *word* with their right hand (as is Experiment 2). All other aspects of the current design and procedure were the same as in Experiment 3.

### Method

*Participants.* Sixty participants were recruited from the University Jaume I of Castellón (Spain). They received partial credit for a course requirement, and all were right-handed native speakers of Spanish with no reported history of speech or hearing disorders. Mean laterality quotient in the Edinburgh Handedness Inventory (Oldfield, 1971) was 89.2.

*Materials.* Because stimulus presentation was manipulated only during the test phase, only half as many items were necessary in this experiment as compared with the previous experiments, in which stimulus presentation was also manipulated during the study phase. The stimuli were a subset of those used in Experiment 2 and consisted of (a) 24 bisyllabic spoken experimental items; (b) 24 bisyllabic spoken nonword filler items; and (c) 16 bisyllabic spoken control items (half of the control items were words, half were nonwords). The mean word frequency of occurrence for the word stimuli was 7 per five million (mean log frequency = 0.81) according to the LEXESP corpus (Sebastián-Gallés et al., 2000).

*Design.* The design was the same as that used in Experiment 2, with the following exceptions: The experiment involved only one session, and ear (hemisphere) of stimulus presentation during the study phase was not manipulated. Orthogonal combination of the three levels of prime (match, mismatch, and control), two levels of target (talker J.G., talker L.A.), and two levels of ear of stimulus presentation at target block (left, right) resulted in 12 conditions.

*Procedure.* The procedure was the same as that used in Experiment 2, with the following exceptions: First, during the study block, the stimuli were presented binaurally. Second, as in Experiment 3, a pleasantness-rating task was used during the study block. Third, during the target block, the stimuli were presented monaurally in random order and ear of stimulus presentation was not blocked. That is, on half of the trials the stimuli were presented to the left ear, and on the other half of the trials the stimuli were presented to the right ear, and ear of stimulus presentation was random across trials.

### Results

Any participant whose overall mean RT fell two standard deviations beyond the grand mean was excluded from the analyses, resulting in the elimination of 3 participants. Moreover, for each condition, any mean RT that fell two standard deviations beyond the overall mean for that condition was removed and subsequently replaced with the new overall mean for that condition, resulting in the replacement of 5.7% of the mean RTs.

Prime (match, mismatch, control) × Target (talker J.G., talker L.A.) × Ear of Stimulus Presentation at Target Block (left, right) participant ANOVAs were performed on mean RTs for correct responses and percentages correct for the experimental stimuli. Note that the experimental stimuli were all real words; no analyses were performed on the nonword filler items. Accuracy to experimental stimuli was greater than 92% overall. We observed a significant main effect of prime on accuracy, $F(2, 112) = 17.31$, $p < .001$, $MSE = 0.03$, which was driven by lower accuracy in the control condition. No other main effects or interactions were significant.

However, when control stimuli were removed from the analysis, a significant two-way interaction emerged for Ear of Stimulus Presentation at Target Block (left, right) × Prime (match, mismatch), $F(1, 56) = 7.49$, $p < .01$, $MSE = 0.02$. This interaction reflects the observation that for the left ear only, accuracy in the match condition was significantly greater than in the mismatch condition (0.98 vs. 0.94), $F(1, 56) = 4.53$, $p < .05$, $MSE = 0.02$, whereas for the right ear, accuracy in the match condition was nominally lower than in the mismatch condition (0.93 vs. 0.97), $F(1, 56) = 3.01$, $p = .09$, $MSE = 0.02$.

Mean RTs, along with their respective standard error bars, are illustrated in Figure 4. We obtained a significant main effect of prime, $F(2, 112) = 10.76$, $p < .001$, $MSE = 18{,}620.39$. Planned comparisons based on the main effect of prime revealed a significant difference between the match and control conditions, $F(1, 56) = 24.85$, $p < .001$, $MSE = 14{,}969.63$, and between the mismatch and control conditions, $F(1, 56) = 10.51$, $p < .01$, $MSE = 19{,}395.17$, but not between the match and mismatch conditions, $F(1, 56) = 1.17$, $p = .284$, $MSE = 21{,}496.37$. We also obtained a significant main effect of target, $F(1, 56) = 51.92$, $p < .001$, $MSE = 28{,}510.65$, presumably because of the differences in stimulus duration due to the talkers' different speaking rates. No other main effects or interactions approached significance.

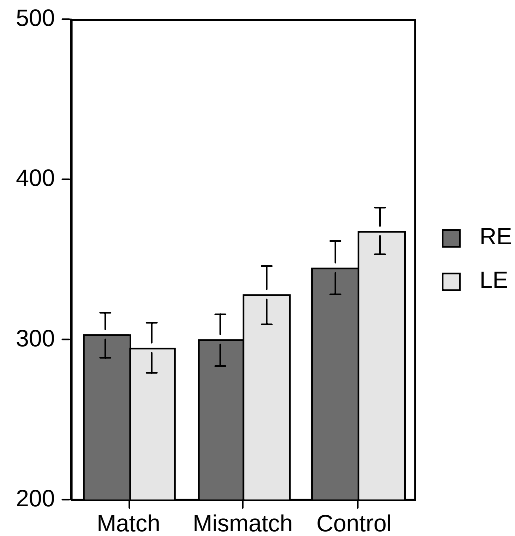


*Figure 4.* Mean reaction times (in milliseconds, with error bars representing plus or minus one standard error of the mean) as a function of prime type for the left ear and right ear presentation conditions at test for Experiment 4. RE = right ear at test; LE = left ear at test.

We were primarily interested in the RT differences between the match and mismatch talker conditions in the two ears at target block. To examine this question, we performed an additional analysis within each ear condition. Crucially, for the left ear (RH), the mean RT in the match condition (295 ms) was significantly shorter than in the mismatch condition (328 ms), $F(1, 56) = 2.97$, $p = .090$, $MSE = 10{,}263.90$ ($p = .045$, for a one-tailed test). However, there was no difference between the match ($M = 303$ ms) and mismatch ($M = 300$ ms) conditions in the right ear (LH).

Overall, we obtained relatively weak specificity effects. However, crucially, our data also show that there is a clear difference between the two hemispheres with respect to specificity effects. Therefore, to gain more power in our analyses, we performed an ANOVA on the RTs in the match and mismatch conditions from Experiments 2 and 4 combined. This combined ANOVA revealed a significant interaction of Ear of Stimulus Presentation at Target Block (left, right) × Prime (match, mismatch), $F(1, 101) = 6.63$, $p = .011$, $MSE = 9{,}362.40$. This interaction reflects the observation that for the left ear only, RTs in the match condition were significantly shorter than in the mismatch condition, $F(1, 101) = 5.18$, $p = .025$, $MSE = 14{,}051.71$; there was no difference between the RTs in the match and mismatch conditions for the right ear ($F < 1$).

### Discussion

Once again, as expected, a clear repetition-priming effect was obtained. Both matched and mismatched primes produced facilitative effects on lexical decision responses relative to the control condition. Furthermore, we found that the difference between matched and mismatched primes was different depending on the ear of presentation at test. However, unlike in Experiment 2, stimuli mismatching in indexical information did not facilitate responding in the current experiment. Consequently, it does not appear that the use of the auditory lexical decision task led to this unanticipated result in Experiment 2. Rather, the manipulation of ear of presentation at both study and test was likely responsible for producing this effect, possibly owing to asymmetrical transfer between the hemispheres (discussed further in the General Discussion).

## General Discussion

The main hypothesis under examination was that indexical information in speech, such as talker-specific details, is represented and processed differently in the two cerebral hemispheres. Consequently, we predicted that we would observe a different pattern of priming in the two hemispheres. More specifically, we predicted an interaction between ear of presentation (at study and/or test) and prime type.

In Experiment 1, we used the shadowing task during the prime block and the stem-completion task during the target block. Unfortunately, we failed to obtain specificity effects under these experimental conditions. Although other researchers have obtained specificity effects using the stem-completion task (e.g., Schacter & Church, 1992), our study is not the first to have failed to do so using this task (see Pilotti, Bergman, Gallo, Sommers, & Roediger, 2000). Because we were unable to obtain specificity effects under these conditions, we switched tasks and changed some aspects of our experimental conditions in an attempt to maximize the likelihood of our obtaining specificity effects, and thus provide us with an opportunity to evaluate any potential hemispheric differences in specificity effects.

In Experiment 2, we used the auditory lexical decision task during both the prime and target blocks. Using the same task during both blocks should have increased our ability to obtain specificity effects (Franks et al., 2000). Moreover, the speeded-shadowing task used during the study phase in Experiment 1 may not have been the ideal task for obtaining specificity effects, particularly when investigating hemispheric differences. Although the stimuli were presented monaurally, the participants were able to hear their own voice responses binaurally, and thus this task may not have been conducive for obtaining indexical specificity effects associated with changes in talkers. Consequently, the choice of task during the study phase could have been (at least partially) responsible for our failure to obtain specificity effects in Experiment 1. Also, in Experiment 2, unlike in Experiment 1, noise was presented to one ear while the spoken word or nonword was simultaneously presented to the opposite ear. The presentation of noise in this manner should have minimized any processing of the spoken stimulus via ipsilateral projections. Finally, we used a hard discrimination lexical decision task by employing low-frequency words and wordlike nonwords, which should have resulted in relatively slow processing in the lexical decision task and, according to McLennan and Luce's (2005) time-course hypothesis, maximized our likelihood of obtaining indexical specificity effects in this task.

Unlike in Experiment 1, we were successful in obtaining specificity effects in Experiment 2, a necessary criterion for evaluating whether any hemispheric differences exist with respect to specificity effects. Moreover, we obtained a different pattern of results when we collapsed over the two ear-of-presentation conditions at study and evaluated the pattern of results in the two ear-of-presentation conditions at test. In particular, we obtained a significantly different MOS effect in the left ear than in the right ear during test, consistent with our predictions at the outset of this project, with findings reported in the visual domain (Marsolek, 2004), and with the neuropsychological evidence discussed earlier.

Three aspects of our data from Experiment 2 merit further discussion: First, we observed a *reverse* specificity effect in the LH. The three-way interaction between ears of presentation at target and prime blocks and prime indicates that this *reverse* specificity effect was carried by the right-ear/right-ear condition. Recall that in the LH (right ear), the mean RT in the mismatch condition was not only no greater but actually less than the mean RT in the match condition. This pattern is inconsistent with the prediction we made at the outset of the study, according to which it would not matter whether the indexical information at study and test matched or mismatched when stimuli were presented to the right ear because in both cases the input is simply mapped onto representations that are devoid of the indexical information appearing on the surface. Instead, this finding suggests that, at least under the current circumstances, more specific indexical information may play opposite roles in the two hemispheres, such that matches in indexical information facilitate perception in the RH whereas mismatches in indexical information facilitate perception in the LH. However, the results of Experiments 3 and 4, in which ear of presentation was manipulated at test only, suggest that this reverse specificity effect was likely due to the manipulation of stimulus presentation at both study and test.

Second, switching the ear of presentation between the prime and target blocks led to shorter mean RTs compared with when the ear of presentation was the same during both the prime and target blocks. In other words, presenting stimuli to the same ear during both the prime block and the subsequent target block appears to slow processing, particularly for nonrepeated (i.e., control) stimuli. Although it is currently unclear what led to this pattern of results, it is possible that it is due, at least in part, to attentional factors. For example, participants may have been expecting the stimuli to be presented to the same ear at study and test, and when the stimuli were presented to the opposite ear at test, they may have paid more attention to the stimuli, which in turn facilitated their ability to respond to the stimuli.

Third, although a reasonable prediction at the outset of this study would have been that the left-ear/left-ear condition would produce the greatest MOS, this was not the case. Rather, the right-ear/left-ear condition produced a similar MOS as the left-ear/left-ear condition. However, this may have been due, at least in part, to potential asymmetrical interhemispheric repetition-priming effects. Weems and Zaidel (2005) recently examined repetition priming within and between the hemispheres and found greater relative left-to-right interhemispheric transfer. According to this account, comparable magnitudes of specificity would be predicted in the left ear at test, regardless of which ear the stimuli had been presented to during the study phase. When stimuli are presented to the left ear during study, the RH should process the stimuli and specificity effects should emerge. When stimuli are presented to the right ear during study, the LH should initially process the stimuli. However, owing to the greater left-to-right interhemispheric transfer, the input should also be subjected to processing by the RH, providing an opportunity for specificity effects to emerge. Indeed, this account is consistent with the current pattern of results: The MOS was comparable in the right-ear/left-ear (–24) and left-ear/left-ear (–18) conditions.

However, there are two major differences from the current study that strongly encourage one to be cautious when interpreting our data in terms of Weems and Zaidel's (2005) findings. First, their study was conducted in the visual domain, and it is not at all clear at this point how similar (or different) such interhemispheric asymmetries may be in the auditory and visual domains. Second, hemisphere of presentation was not blocked in their study, as it was in ours. Nevertheless, manipulating the ear of presentation at both study *and* test may have unnecessarily complicated our ability to evaluate potential hemispheric differences in specificity effects. Therefore, we conducted Experiments 3 and 4, in which ear of presentation was manipulated at test only, as Marsolek and colleagues have done in the visual domain (Marsolek, 1999, 2004; Marsolek et al., 1992, 1994, 1996).

In Experiment 3, we again used the stem-completion task during the target block. However, rather than using the shadowing task during the prime block, as had been done in Experiment 1, we used a pleasantness-rating task during the prime block. Moreover, the stimuli were presented binaurally during the study phase, and the two ear-of-presentation conditions at test were randomly presented during a single phase (rather than being blocked over multiple phases). Unlike in Experiment 1, we now obtained specificity effects using the stem-completion task, which allowed us to evaluate potential hemispheric differences. Consistent with our predictions at the outset of the study, we obtained significant specificity effects when stimuli were presented to the left ear but not when stimuli were presented to the right ear. Furthermore, because different tasks were used during the study (pleasantness-rating) and test (stem-completion) phases, the results of Experiment 3 demonstrate that both indexical specificity effects and hemispheric differences can be obtained in the stem-completion task and when different tasks are used during the study and test phases of the experiment.

In Experiment 4, we again used the auditory lexical decision task during the target block. However, rather than using the same task during the prime block, as had been done in Experiment 2, we used a pleasantness-rating task during the prime block. Moreover, the stimuli were presented binaurally during the study phase, and the two ear-of-presentation conditions at test were randomly presented during a single phase (rather than being blocked over multiple phases). Consistent with our predictions at the outset of the study, we obtained significant specificity effects when stimuli were presented to the left ear but not when stimuli were presented to the right ear. Furthermore, we no longer obtained the unanticipated reverse specificity effect obtained in Experiment 2. Consequently, it does not appear that the use of the auditory lexical decision task led to this unanticipated result. Rather, the manipulation of ear of presentation at both study and test was likely responsible for producing this effect, possibly due to asymmetrical transfer between the hemispheres.

The current work has provided important new findings consistent with the idea that mismatching surface information affects perception of spoken language differently in the RH and LH. In particular, it appears that the RH, but not the LH, benefits from matches in indexical information. Nevertheless, future investigations of hemispheric differences that use different tasks and experimental methods should provide new insights regarding the particular conditions that lead to the types of hemispheric differences obtained in the current study, and to the precise nature of hemispheric differences in specificity effects.[7] Furthermore, the current study focused on talker variability. Although talker variability is the most frequently studied source of indexical variability, and thus was particularly well suited for this initial investigation of hemispheric differences, future studies examining other sources of indexical variability (e.g., differences in articulation style) will provide a more complete picture of the nature of hemispheric differences in indexical specificity effects.

Finally, the present results have important implications for theories and models of spoken word recognition. No current major processing model includes representations designed to capture indexical information and thus is able to account for indexical specificity effects, much less hemispheric differences in specificity effects (see footnote 2). Nonetheless, the present results indicate that the hemisphere that initially processes the information will mediate the role that indexical information plays during spoken word recognition. These findings should ultimately lead to the development of better theories and models of spoken word recognition.

[7] Although we have not speculated as to why the RH and LH come to process linguistic and indexical information differently, a recent study suggests that it may stem from the way the cochlea processes different types of sounds (Sininger & Cone-Wesson, 2004). Apparently, early in development the cochlea of infants tends to amplify different types of sounds differently, thus mimicking the hemispheric differences observed later in development.

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## Appendix

## Experimental Stimuli

All of the following stimuli were used in Experiment 1; those marked with an asterisk were used in Experiment 3. English translations appear in parentheses.

### *Experimental Items*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| alto | (tall) | foca* | (seal) | llama | (flame) | pulga | (flea) |
| angel | (angel) | freno | (brake) | loco | (mad) | rasgo | (feature) |
| broma* | (joke) | gato | (cat) | muela | (back tooth) | riña* | (quarrel) |
| calma* | (calm) | gorra* | (cap) | nazi* | (Nazi) | rojo* | (red) |
| carne | (meat) | grado | (degree) | nota* | (note) | ruedo* | (arena) |
| chico* | (boy) | gripe | (influenza) | nudo | (knot) | salsa | (sauce) |
| clavo* | (nail) | guasa* | (teasing) | pelo | (hair) | salto* | (jump) |
| cuerda* | (rope) | guiño* | (wink) | percha | (hanger) | silla | (chair) |
| dato | (data) | hiena* | (hyena) | plaza | (square) | traje* | (suit) |
| duda | (doubt) | hueso* | (bone) | postre | (dessert) | verso* | (verse) |
| faja | (girdle) | jarra* | (jug) | precio* | (price) | vino* | (wine) |
| fecha* | (date) | liquen* | (lichen) | prisa | (hurry) | zona | (area) |

### *Filler Items*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| asno* | (donkey) | hambre | (hunger) | monte | (mountain) | techo | (ceiling) |
| beca* | (scholarship) | jefe | (boss) | mulo | (mule) | tienda* | (shop) |
| blando | (soft) | joya* | (jewel) | niebla | (fog) | tinta* | (ink) |
| bote | (boat) | juerga* | (binge) | olmo | (elm) | toro | (bull) |
| brazo* | (arm) | lanza | (lance) | once* | (eleven) | túnel* | (tunnel) |
| cepo | (trap) | leche* | (milk) | parto* | (birth) | urna* | (urn) |
| choza* | (hut) | liebre | (hare) | piedra* | (stone) | vaca | (cow) |
| crimen* | (crime) | lluvia | (rain) | renta* | (income) | vasco | (Basque) |
| droga | (drug) | mancha* | (stain) | selva | (jungle) | veto | (veto) |
| fibra | (fiber) | marca | (mark) | suelo* | (ground) | vuelo* | (flight) |
| frasco* | (bottle) | mesa* | (table) | surco* | (furrow) | zanja | (ditch) |
| guerra | (war) | miedo* | (fear) | talco | (talc) | zurdo* | (left-handed) |

### *Control Items*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Acto | (act) | flecha* | (arrow) | laca | (lacquer) | sierra | (saw) |
| baile* | (dancing) | fuerza | (strength) | lucha* | (fight) | sombra* | (shadow) |
| barco* | (ship) | funda | (cover) | menta | (mint) | trueno* | (thunder) |
| cine | (cinema) | fútbol | (football) | orca* | (killer whale) | uva* | (grape) |
| circo* | (circus) | gesta | (heroic deed) | padre | (father) | voto* | (vote) |
| cola | (tail) | globo* | (balloon) | palma | (palm) | yate | (yacht) |
| disco | (record) | golfo* | (gulf) | raya* | (line) | yema | (yolk) |
| eco | (echo) | kilo* | (kilo) | reina* | (queen) | yerno* | (son-in-law) |

All of the following stimuli were used in Experiment 2; those marked with an asterisk were used in Experiment 4. English translations appear in parentheses.

### *Experimental Items*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| arpa* | (harp) | cuña* | (wedge) | menta | (mint) | rima | (rhyme) |
| brocha | (brush) | dique | (dike) | mirlo* | (blackbird) | rosca | (thread) |
| bucle | (curl) | fémur* | (femur) | nácar | (nacre) | salmo* | (psalm) |
| carpa | (carp) | fósil | (fossil) | necia* | (foolish) | sebo | (grease) |
| caspa* | (dandruff) | furcia* | (tart) | noria* | (big wheel) | sidra | (cider) |
| cebra* | (zebra) | gaita | (bagpipes) | oca | (goose) | talco | (talc) |
| chándal* | (tracksuit) | galgo* | (greyhound) | ogro | (ogre) | teja* | (tile) |
| ciervo | (deer) | grillo* | (cricket) | ostra* | (oyster) | termo* | (thermos) |
| cofre | (coffer) | jota* | (Spanish dance) | parra* | (grapevine) | teta* | (breast) |
| cráter* | (crater) | lancha | (launch) | pinza | (hairgrip) | traba* | (obstacle) |
| cromo | (picture card) | lince* | (lynx) | prisma | (prism) | trucha* | (trout) |
| croquis* | (sketch) | lira | (lyre) | pulpo | (octopus) | viña | (vine) |

(*Appendix continues*)

### Nonword Filler Items

| | | | |
|---|---|---|---|
| arpu* | cuma* | mento | rida |
| brocho | dica | mirco* | rosta |
| bucla | fémar* | nácor* | salma* |
| carpe | fópil | nemia* | sebi |
| caspo* | furcie* | nosia* | sidri |
| cebre | gaito | oco | talca |
| chándol* | galpo* | opre | tepa |
| ciermo | grille* | ostro* | termu* |
| cofra | joca* | parre* | teti* |
| cráper* | lancho | pinga | trala* |
| crolis | linje* | prismo | truche* |
| croques* | liro | pulpe | viñe |

### Control Word and Nonword Items

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| brindis | (toast) | faja* | (girdle) | ingle* | (groin) | neutro | (neuter) |
| buda* | (Buddha) | fresa | (strawberry) | lirio* | (iris) | remo* | (oar) |
| burra | (donkey) | gramo* | (gram) | malva | (mallow) | soja* | (soy) |
| charca* | (pond) | horca | (gallows) | molde | (mold) | tarro | (pot) |
| brindos | | fapa* | | ingla* | | neulo | |
| budo* | | freca | | limio* | | reso* | |
| burre | | graco* | | malvo | | soje* | |
| charta* | | horco | | molda | | tarra | |

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