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Examining potential hemispheric differences in talker effects in spoken word recognition

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Abstract

Variability in talker identity, one type of indexical variation, has demonstrable effects on the speed and accuracy of spoken word recognition. Furthermore, variability in visual word recognition, such as changes in font, appears to affect processing differently, depending on which cerebral hemisphere initially processes the input. The present study examined whether such hemispheric differences exist in spoken language as well. In two long-term repetition-priming experiments, the authors examined responses to targets that were primed by stimuli that matched or mismatched on the indexical variable of interest, talker identity. The results demonstrate that indexical variability can, under some circumstances, be shown to affect participants' perception of spoken words differently in the two cerebral hemispheres.

Both written and spoken forms of language are communicated over a highly variable signal. For example, in written language the letters comprising 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.

In the visual domain, Marsolek and colleagues (Marsolek, 1999; Marsolek, Kosslyn, & Squire, 1992) have argued that two relatively independent subsystems support our ability to recognize abstract and specific aspects of the input, and that these subsystems operate more efficiently in the left and right hemispheres, respectively. According to this view, an abstract-category subsystem, which uses a *feature-based* processing strategy, subserves category recognition and operates more effectively in the left cerebral hemisphere (LH). A specific-exemplar subsystem, which uses a more *holistically-based* processing strategy, subserves exemplar recognition and operates more effectively in the right cerebral hemisphere (RH). 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 letter-like forms (Marsolek, 1995).

The strongest support for this two-systems hypothesis comes from studies employing the long-term repetition-priming paradigm. 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 distracter 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., non-repeated) 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) compared to 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*).

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; Marsolek et al., 1994). That is, the magnitude of the repetition priming effect is greater when the stems presented during the test phase appear in the same letter-case in which the words from which the stems were derived had appeared in the earlier phase of the experiment. However, this specificity effect is only obtained when the stems are presented to the RH.

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

In the auditory domain, research has revealed specificity effects on spoken word processing and recognition (see Luce & McLennan, 2005, for 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 spoken word recognition, all of which essentially ignore surface variability (see Luce & McLennan, 2005).

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 effects of talker variation 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. Goldinger (1996) observed talker effects in both implicit (perceptual identification) and explicit (recognition) tasks and found that talker effects varied with level of processing (with the strongest effects at the lowest levels). 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. According to their time-course hypothesis, specificity effects may take time to develop. McLennan and Luce (2005) recently obtained results in support of their time-course hypothesis. 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, 2003, in infants; Sommers, 1996, in elderly adults). However, unlike in the visual domain, no published study to date has explored whether hemispheric presentation affects the likelihood of obtaining indexical specificity effects in spoken word processing.[2] Nevertheless, the motivation for the present study is not limited to an attempt to obtain hemispheric differences in specificity effects that would parallel findings in the visual domain. Rather, independent evidence provides compelling reasons to believe that such hemispheric differences potentially exist in the auditory domain as well, and in spoken language processing in particular. More specifically, research studies using cognitive neuroscience techniques, including fMRI, ERP, 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 ERP investigation of speech perception across different speakers and found a greater mismatch negativity (MMN) effect in the LH than in the RH, providing evidence for more abstract (phoneme) representations in the LH (more specifically, in the left temporal cortex). Furthermore, patients with 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. Finally, in a recent fMRI study Stevens (2004) obtained evidence that memory for voices is primarily lateralized in the RH and that memory for words is primarily lateralized in the RH.

Although none of the neuropsychological evidence speaks directly to potential hemispheric differences in indexical specificity effects during on-line spoken word recognition, they are certainly consistent with the possibility that such differences may exist, especially with respect to talker-specific indexical information. Therefore, 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 two long-term repetition priming experiments using two implicit tasks that are both widely used in research on specificity effects, stem-completion and auditory lexical decision. In both experiments, ear of stimulus presentation was manipulated both in the study and test phases. Moreover, because the majority of projections are contralateral, a stimulus presented to the right ear should be processed more quickly and more dominantly by the left hemisphere, and vice versa.

The main hypothesis under examination was that the indexical information in speech, such as talker-specific details, is represented and processed differently in the two cerebral hemispheres. Consequently, we predict that we will obtain a different pattern of priming in the two hemispheres. In other words, if there are hemispheric differences in indexical specificity effects during on-line spoken word recognition, then we should obtain a different pattern of priming, depending on whether the stimuli are presented to the right ear (RE) or the left ear (LE). Thus, we predict an interaction between ear of presentation (at study and/or test) and prime type. More specifically, we make the following predictions: Processing in the RH (when stimuli are presented to the LE) will be facilitated when indexical information at study and test match. Furthermore, at least two distinct predictions can be made with respect to the role that indexical information will play in the LH (when stimuli are presented to the RE). Both predictions are based on the assumption that the LH is primarily responsible for representing and processing relatively abstract linguistic information. The first prediction is 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. The second prediction is that processing in the LH will be facilitated when indexical information at study and test *mismatch* because it should be easier to map input onto abstract information in more variable contexts. In other words, the process of mapping input to abstract representations should be easier when the abstract information - but not the indexical information - repeats from study to test. Again, both predictions are based on the assumption that the LH is primarily responsible for representing and processing relatively abstract linguistic information. However, only the second, perhaps more sophisticated, prediction takes into account the process of mapping input to representation.

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 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 (1) 48 bisyllabic spoken experimental items; (2) 48 bisyllabic spoken filler items; and (3) 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, Cuetos, & Carreiras, 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 had first syllables that allowed at least three Spanish word completions. See the Appendix for a complete list of the stimuli used in both experiments.

The stimuli were recorded in a sound-attenuated room by both a male (JG) and female (LA) talker, low-pass filtered at 10 kHz, and 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. 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 JG and LA served as both primes and targets. For both the primes and targets, half of the stimuli were spoken by talker JG and half were spoken by talker LA. Primes *matched*, *mismatched*, or were *unrelated* to the targets. Matched primes and targets were identical on the talker dimension (e.g., $foca_{JG}$[seal]-fo_{JG}; $foca_{LA}$-fo_{LA}). Mismatched primes and targets differed on the talker dimension (e.g., $foca_{JG}$[seal]-fo_{LA}; $foca_{LA}$-fo_{JG}). In each session, the prime and target blocks both consisted of 24 stimuli. The composition of the prime block was as follows: Eight experimental words, eight filler words, and eight unrelated (i.e. control) words. The composition of the target block was as follows: 12 auditory stems derived from experimental words and 12 derived from filler words. In the target block, eight auditory stems matched, eight mismatched, and eight were controls, relative to what was presented in the earlier prime block.

Orthogonal combination of the three levels of prime (match, mismatch, and control), two levels of target (talker JG, talker LA), 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 (stem) appeared in only one of the four sessions.

Procedure. Each participant participated 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 Millisecond 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. Before moving on to the second block, participants were given a distracter 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 beyond the grand mean was excluded from the analyses, resulting in the elimination of two participants.

A Prime (match, mismatch, control) X Target (talker JG, talker LA) X Ear of Stimulus Presentation at Prime Block (left, right) X Ear of Stimulus Presentation at Target Block (left, right) ANOVA was performed on proportion of target words reported.[3] Mean proportion 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 = .13, a significant two-way interaction between the Ear of Presentation at Target Block X Target, F (1, 45) = 7.33, $p < .05$, MSE = .08, and a significant three-way interaction between the Ear of Presentation at Target Block X Ear of Presentation at Prime Block X Target, F (1, 45) = 8.70, $p < .01$, MSE = .06. No other main effects or interactions approached significance, including the crucial Ear of Presentation at Target Block X Prime interaction.

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 = .14, and between the mismatch and control conditions, F (1, 45) = 110.67, $p < .001$, *MSE* = .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.

The other two significant effects, both interactions involving target, reflect the observation that for talker JG only, a greater number of target words were reported when the stimuli were presented to the LE, particularly in the LE at study and LE at test condition.

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 non-semantic 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 non-semantic 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 second author's laboratory (and, we suspect, the laboratories of many other researchers as well) demonstrate that specificity effects are actually relatively difficult to obtain. Although repetition-priming effects are robust and observed under a wide variety of conditions, specificity effects, on the other hand, are typically relatively weak and only observed 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 on-line 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. First, in the current experiment we replaced the stem-completion task with an auditory lexical decision task. According to McLennan & Luce's (2005) results and the time-course hypothesis (Luce et al., 2003; McLennan & Luce, 2005), the present experiment was designed to increase the difficulty of the discrimination between the real words and the nonwords in the experiment (by using low-frequency words and word-like nonwords). The difficult discrimination should result in relatively slow processing, thus providing a greater opportunity to observe indexical specificity effects. Second, we now used the same task during both the study and test phases of the experiment, which could potentially increase the likelihood of obtaining specificity effects because of transfer appropriate processing or TAP (see e.g., Franks, Bilbrey, Lien, & McNamara, 2000). Finally, 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 opposite ear as the one to which we presented the spoken word or nonword item.

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 (1) 48 bisyllabic spoken experimental items; (2) 48 bisyllabic spoken nonword filler items; and (3) 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, Marti, Cuetos, & Carreiras, 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 word-like nonwords (see McLennan & Luce, 2005).

The stimuli were recorded in a sound-attenuated room by both a male (JG) and female (LA) talker, low-pass filtered at 10 kHz, and 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 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 JG and LA 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 JG and LA.

Design. The design was that 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 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 labelled 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 key press response.[4] 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 greater than 2 SD above or less than 2 SD below 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) X Target (talker JG, talker LA) X Ear of Stimulus Presentation at Prime Block (left, right) X Ear of Stimulus Presentation at Target Block (left, right) participant analyses of variance (ANOVA) were performed on mean RTs for correct responses and percentages correct for the experimental stimuli. Accuracy to experimental stimuli was greater than 93% overall. We observed a significant main effect of prime on accuracy, $F(1, 45) = 11.67$, $p < .01$, $MSE = .37$, 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 = 18079.52 and a significant main effect of target, F (1, 45) = 36.42, $p < .001$, MSE = 12680.64, presumably because of the differences in stimulus duration due to the talkers' different speaking rates. We also obtained a significant two-way interaction between the Ear of Presentation at Target Block X Ear of Presentation at Prime Block, F (1, 45) = 5.08, $p < .05$, MSE = 14677.27; and, crucially, a significant two-way interaction between the Ear of Presentation at Target Block X Prime, F (2, 90) = 3.00, $p < .05$, MSE = 15586.57. Finally, the three-way interaction between the Ear of Presentation at Target Block X Ear of Presentation at Prime Block X Prime was significant, F (2, 90) = 4.42, $p < .05$, MSE = 13705.27. 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 will not be discussed further.

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 = 21274.62, and between the mismatch and control conditions, F (1, 45) = 64.39, $p < .001$, MSE = 23847.33, but not between the match and mismatch conditions, $F < 1.0$.

The interaction of ear of presentation at target block by ear of presentation at prime block reveals that switching the ear of presentation between the prime and target blocks led to shorter mean RTs compared to when the ear of presentation was the same during both the prime and target blocks. (This interaction will be discussed further in the General Discussion.)

The three-way interaction involving ear of presentation at target block by ear of presentation at prime block by prime type appears to reflect the two-way interaction just discussed (i.e., shorter RTs when ear of presentation was switched between the prime and target blocks), and also demonstrating that the greatest difference occurs in the control level of prime type. In particular, the longer RTs in the same ear at study and test conditions (i.e., RE-RE and LE-LE), relative to the different ear conditions (i.e., RE-LE and LE-RE) seem to be carried primarily by the LE-LE control condition. This relatively complex interaction may be indicative of asymmetric interhemispheric repetition priming effects (see Weems & Zaidel, 2005). (See General Discussion.)

We were primarily interested in the difference between the match and mismatch talker conditions in the two ears at target block, which was obtained in the 2-way interaction between the Ear at Target Block X Prime. (Note that the 2-way interaction between the Ear at Prime Block X Prime did not approach significance). In order to examine this crucial interaction more closely, we performed additional analyses on the MOS in the two ear of presentation conditions at test.

In the MOS analysis, the main effect of ear at target block was significant, $F(1, 45) = 5.22$, $p < .05$, $MSE = 21133.35$, providing support for the idea that talker-specific information is playing a different role in the two hemispheres at test, as illustrated in Figure 3. The mean MOS in the LE 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 RE. In the RE, 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.[5]

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 Experiment 1, we found that the difference between matched and mismatched primes was different depending on the ear of presentation at test. In the LE, but not in the RE, 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 LE during test but not to the RE. This finding is crucial because: (1) it is consistent with our predictions at the outset of this study; (2) it is consistent with the cognitive neuropsychological evidence discussed earlier; (3) it parallels findings from visual word recognition (e.g., Marsolek, 2004); and (4) perhaps most importantly, it is, to our knowledge, the first such finding involving spoken word recognition.

Furthermore, because we expected abstract linguistic information to dominate processing in the LH, one of the predictions at the outset of this study was that matched and mismatched stimuli might serve as equally effective primes when stimuli were presented to the RE. This was clearly not the case. Rather, mismatched primes served as more effective primes than matched primes when stimuli were presented to the RE at test. This finding is inconsistent with the claim that talker variability is irrelevant in the LH. If talker variability were truly irrelevant in the LH (because regardless of talker variation, abstract linguistic information dominated), then there should have been no difference between the matched and mismatched prime types. Instead, the present results are consistent with the second prediction made at the outset of this study, namely that the mismatching, rather than the matching, of talker-specific information would facilitate the perception of spoken words that are presented to the RE because input is more easily mapped onto abstract representations in more variable contexts (in this case, when the talkers at study and test differ). We will discuss the potential implications of this finding 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 LE during test, the matching of talker identity facilitated perception. On the other hand, when the stimuli were presented to the RE during test, the mismatching of talker identity facilitated perception.

General Discussion

The main hypothesis under examination was that the 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 that has failed to obtain specificity effects using this task (see Pilotti et al., 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 increase our ability to obtain specificity effects (Franks, et al., 2000). 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 minimize any processing of the spoken stimulus via ipsilateral projections. Finally, we used a hard discrimination lexical decision task by employing low frequency words and word-like nonwords, which should slow processing and, according to McLennan & Luce's (2005) time-course hypothesis, maximize our likelihood of obtaining indexical specificity effects.

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. When we collapsed over the two ear of presentation conditions at test, the pattern of results in the two ear of presentation conditions at study was remarkably similar (and statistically equivalent). However, this was clearly not the case 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 LE than in the RE 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 (particularly in the RE–RE condition). Recall that in the LH (RE), the mean RT in the mismatch condition was not only no greater, but it was actually less, than the mean RT in the match condition. This effect helps to distinguish between the two alternative hypotheses laid out in the Introduction.

This pattern is inconsistent with the first hypothesis, which assumed that it would not matter whether the indexical information at study and test matched or mismatched when stimuli were presented to the RE because in both cases the input is simply mapped onto representations that are devoid of the indexical information appearing on the surface. However, this pattern is consistent with the idea that an abstract subsystem operates more efficiently in the LH than in the RH, consistent with findings in the visual domain (Marsolek, 1995). Moreover, this pattern is also consistent with the second hypothesis, which predicted that when stimuli were presented to the RE, abstract information would resonate with the input more easily in more variable contexts (see McLennan, in press). Nevertheless, this pattern clearly contradicts a more extreme claim that surface information plays no role when stimuli are presented to the RE at both study and test. 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 while mismatches in indexical information facilitate perception in the LH.

Second, switching the ear of presentation between the prime and target blocks led to shorter mean RTs compared to when the ear of presentation was the same during both the prime and target blocks. The three-way interaction between ear of presentations at target and prime blocks and prime indicates that this finding was primarily carried by the LE-LE control condition. 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 non-repeated (i.e., control) stimuli in LE-LE condition.

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 LE-LE condition would produce the greatest MOS, this was not the case. More generally, the ear of presentation at prime played little or no role with respect to the observed degree of specificity. However, this may be due, at least in part, to potential asymmetric interhemispheric repetition priming effects. Weems and Zaidel (2005) recently examined repetition priming within and between the hemispheres. They found that the LH at test appears to be more influenced by the hemisphere of prior presentation than does the RH. They explained this finding by a greater relative left-to-right interhemisperic transfer. In other words, when stimuli are presented to the LH at study, the information is transferred to the RH relatively more efficiently than the reverse condition. That is, when the stimuli are presented to the RH at study, the information is not transferred to the LH as efficiently.

The potential implications of this interhemispheric asymmetry account are as follows: The RE-LE condition should potentially result in a comparable magnitude of specificity as the LE-LE condition, because the information presented to the RE at prime should transfer to the RH relatively efficiently, at least by the time stimuli are presented during the target block. Moreover, the LE-LE and LE-RE conditions should be relatively unaffected by the presentation at prime block, because the information presented to the LE at prime should not transfer to the LH as efficiently. Indeed, this account is consistent with the current pattern of results; the MOS was comparable in the RE-LE (-24) and LE-LE (-18) conditions. Furthermore, the LE-LE condition still produced specificity (MOS = -18) and the LE-RE still produced a relatively abstract pattern (MOS = -6), neither of which would have been predicted had the information transferred more efficiently from the RH to the LH during the presentation at the prime block, thus indicating that the hemisphere at prime is less important when it is the RH than when it is the LH.

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 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.

Note that interhemispheric asymmetry could also be responsible, at least in part, for the relatively complex (and unanticipated) interactions obtained in the current study (including the reverse specificity effect in the RE-RE condition). In short, manipulating the ear of presentation at both study *and* test could unnecessarily complicate the ability to evaluate potential hemispheric differences in specificity effects. Therefore, although 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, future investigations of hemispheric differences in which the ear of presentation is manipulated at test only (and stimuli are presented binaurally at study) should shed new light on the specific conditions that lead to the types of hemispheric differences obtained in the current study and on the precise nature of hemispheric differences in specificity effects. [6] Furthermore, the current study focused on talker variability. Although talker variability is the most frequently studied source of indexical variability, and thus particularly well-suited for initial investigations 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 (particularly those of Experiment 2) have important implications for theories and models of spoken word recognition. No current major processing model currently includes representations designed to capture indexical information, and thus is able to account for indexical specificity effects, much less hemispheric differences in specificity effects. 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.

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Appendix

Experiment 1 Stimuli (with their English translations):

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)

Experiment 2 Stimuli (with their English translations):

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)

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
crome	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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Footnotes

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

[2]However, Schacter & Church (1992) refer 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)."

[3]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, and Gremmen, 1999). Second, the number of items in each condition (24) was small due to the large number of conditions. Thus, the statistical power of an item analysis would be 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.

[4]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 word-like. Other researchers have also followed this procedure for other tasks that would similarly require processing the entire stimulus, such as word spotting (e.g., see Norris, McQueen, Cutler, & Butterfield, 1997; see also Onishi, Chambers, & Fisher, 2002). Finally, the data pattern was the same when RTs from onset were examined.

[5]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 consistent with one of the hypotheses laid out in the Introduction and will be discussed further in the General Discussion.

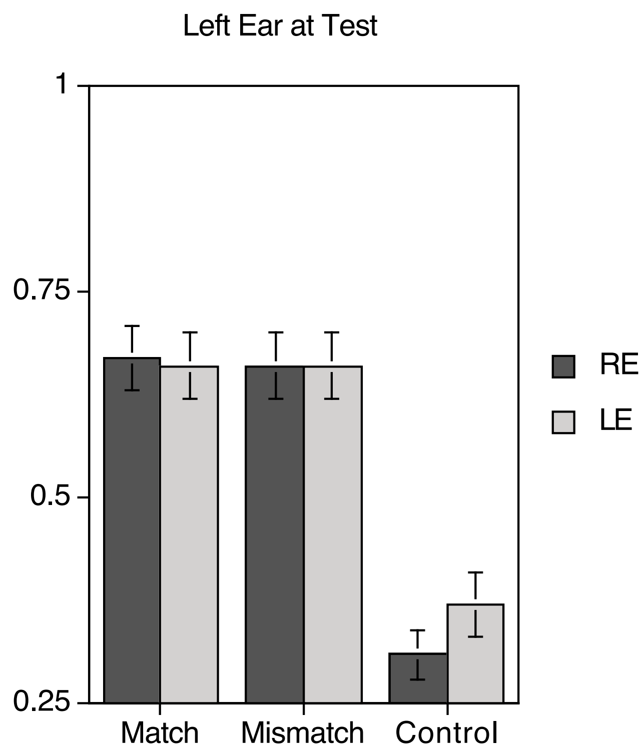
[6]Although we have not speculated as to why the RH and LH come to process linguistic and indexical information differently, a recent study suggests that it may stem from the way the cochlea processes different types of sounds (Sininger & Cone-Wesson, 2004). Apparently early in development the cochlea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

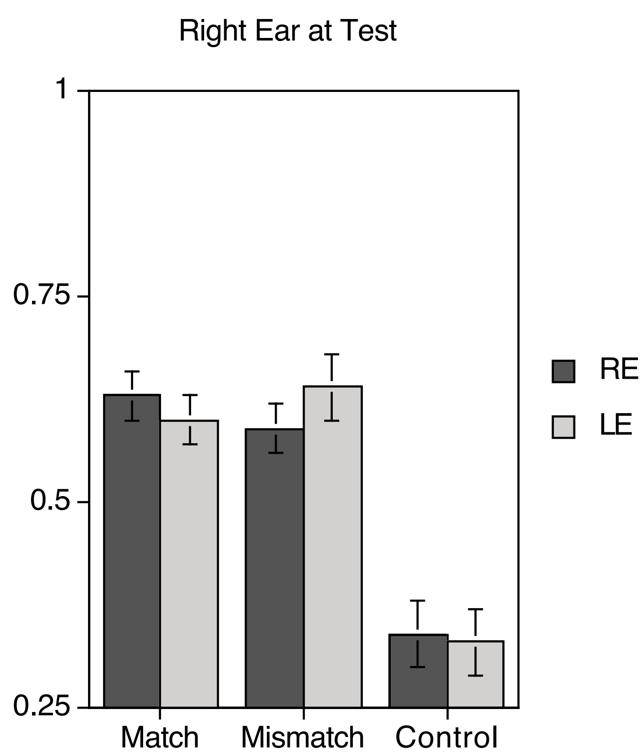
Figure Captions

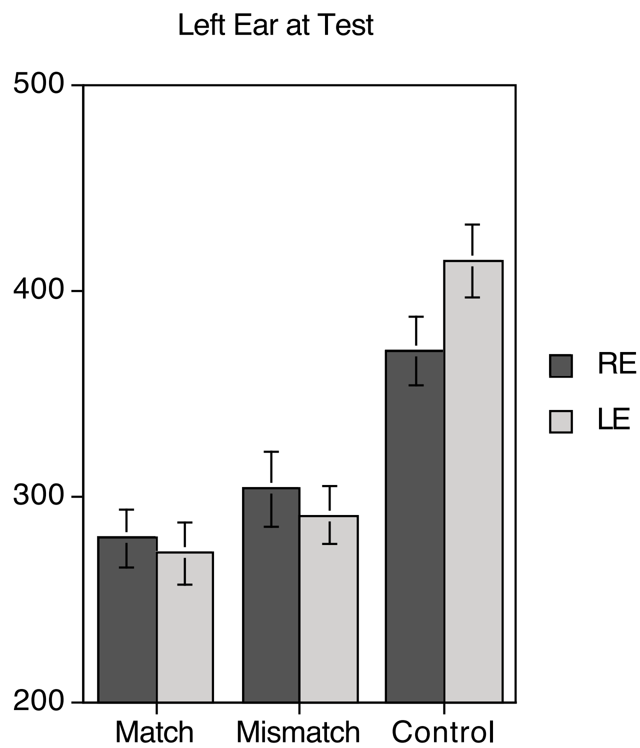
Figure 1. Mean proportion of target words reported (with standard error bars) as a function of prime type for the left ear (upper panel) and right ear (lower panel) presentation conditions at test for Experiment 1. Note RE = Right Ear at study; LE = Left Ear at study.

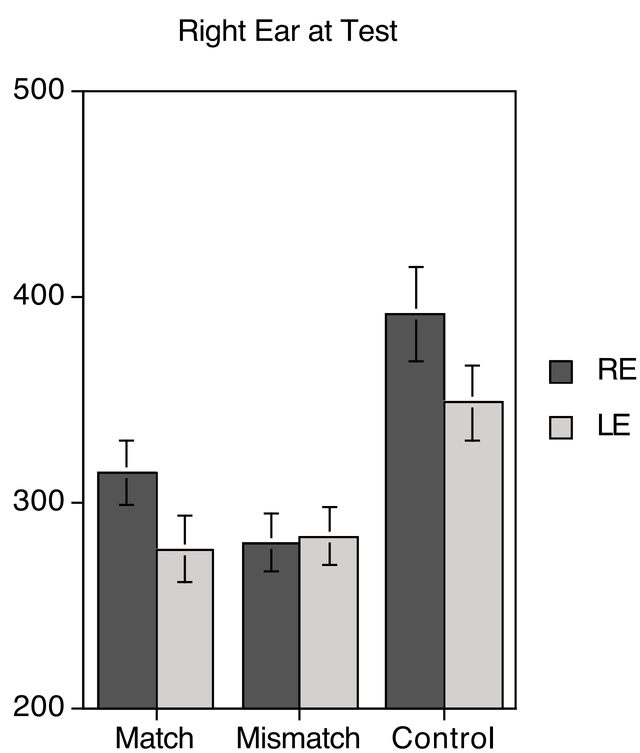
Figure 2. Mean reaction times (ms) (with standard error bars) as a function of prime type for the left ear (upper panel) and right ear (lower panel) presentation conditions at test for Experiment 2. Note RE = Right Ear at study; LE = Left Ear at study.

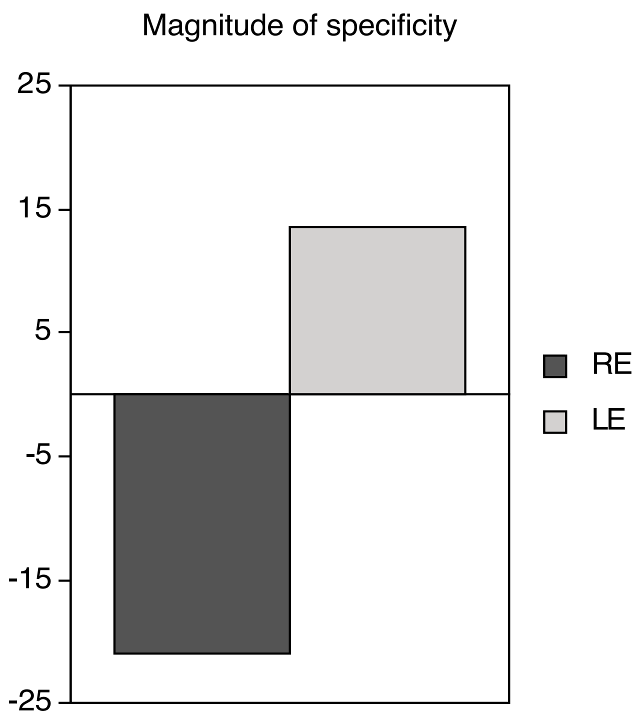
Figure 3. Magnitude of specificity (the difference between the match and mismatch conditions) for the left and right ear presentation conditions at test for Experiment 2. Note RE = Right Ear at study; LE = Left Ear at study.


Left Ear at Test
1
0.75
0.5
0.25
Match
Mismatch
Control
RE
LE


Right Ear at Test
1
0.75
0.5
0.25
Match
Mismatch
Control
RE
LE


Left Ear at Test
500
400
300
200
Match
Mismatch
Control
RE
LE


Right Ear at Test
500
400
300
200
Match
Mismatch
Control
RE
LE


Magnitude of specificity
25
15
5
-5
-15
-25
RE
LE