

# An ERP investigation of dichotic repetition priming with temporally overlapping stimuli

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**Abstract** In the present study, we used event-related potentials (ERPs) to examine the effects of prime–target repetition using a dichotic priming paradigm. Participants monitored a stream of target words in the right, attended ear for occasional animal names, and ERPs were recorded to nonanimal words that were either unrelated to or a repetition of prime words presented to the left ear. The prime words were spoken in a different voice and had a lower intensity than did the target words, and the prime word onset occurred 50 ms before target word onset. Repetition-priming effects were observed in the ERPs starting around 150 ms post-target-onset and continued to influence processing for the duration of the target stimuli. These priming effects provide further evidence in favor of parallel processing of overlapping dichotic stimuli, at least up to the level of some form of sublexical phonological representation, a likely locus for the integration of the two sources of information.

**Keywords** Spoken word recognition · Dichotic priming · Repetition priming · ERPs

## Introduction

The vast majority of auditory priming studies investigating spoken word recognition have involved prime stimuli presented prior to target stimuli in close temporal proximity, but with no overlap between the two (see Dufour, 2008, for a review). Although interesting patterns of behavioral priming have been observed and have been used to constrain current models of spoken word recognition, one might nevertheless question the sensitivity of this paradigm for revealing online processes related to speech perception, particularly with respect to early perceptual processes. More precisely, the sequential-priming paradigm might be useful for understanding processes involving time-invariant phonological representations (sublexical or lexical) that enable the integration of information within words prior to word identification, and this is clearly an important goal for research. However, the technique may be less suited for the study of processing linked to lower-level, time-specific phonological representations—that is, to phonemes coded for their position in time rather than their position in a word. Given that one of the key questions for current research on spoken word recognition is precisely just how such time-specific phonological information makes contact with time-invariant, word-centered phonological representations (Hannagan, Magnuson, & Grainger, 2013), the need for a more appropriate methodology becomes obvious.

The present study provides an initial exploration of one possible methodology for examining such early processes in spoken word recognition. The three essential ingredients of the paradigm are (1) the dichotic presentation of prime and target stimuli—targets in the attended ear, primes in the other ear; (2) temporal overlap across the primes and targets; and (3) the use of millisecond-by-millisecond measures of priming effects using event-related potentials (ERPs). Whereas earlier studies had demonstrated behavioral repetition priming using a

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dichotic listening procedure, the goal of the present study was to use ERPs to determine how quickly priming effects arise with temporally overlapping primes and targets. One seminal behavioral study is that of Dupoux, Kouider, and Mehler (2003), who were the first to use a “dichotic priming” paradigm to examine the type of information that can be obtained from the unattended ear in a dichotic listening situation. Dupoux et al. presented prime stimuli to the unattended ear and simultaneously presented target stimuli to the attended ear. Primes were presented at a reduced intensity and could be either surrounded by silence or embedded in a carrier sentence of the same spectral and energy levels as the prime. Participants made lexical decisions to targets in the attended ear, and robust interaural repetition priming was found only when primes were presented in isolation. Dupoux et al. argued that primes presented in isolation capture attention, enabling processing of the prime stimuli in the unattended ear, and giving rise to priming effects as well as to the conscious identification of primes. When primes were embedded in carrier sentences, no attentional capture occurred, primes were not consciously identified, and there was no priming.

However, more recent work has shown that behavioral repetition priming can be obtained with unattended words presented in a continuous speech stream when the voice changes across the prime and target (Rivenez, Darwin, & Guillaume, 2006). This might be due to the change in voice facilitating the tracking of distinct sound sources over time (Darwin, Brungart, & Simpson, 2003). In any case, the thorny issue of whether or not dichotic priming can be obtained in the absence of awareness of the stimuli presented to the unattended ear (Holender, 1986) is orthogonal to the present enterprise. We are specifically interested in the kind of priming effects reported by Dupoux et al. (2003) in their Experiment 1, with isolated primes that were presented simultaneously with targets. The prime stimuli were temporally compressed, such that phonemes in the prime and target were not perfectly aligned, although they were spoken in the same voice. Even if prime stimuli were identified in these conditions, the priming effects that were found still require an explanation. According to Dupoux et al., in these specific conditions, attention might have rapidly switched to the unattended channel in order to enable lexical processing of the primes. However, they did not specify how processing of the target stimuli would then proceed in the absence of attention, under the assumption that only one channel can be attended at a time. As was pointed out by Treisman (1971), it is not obvious how two simultaneously presented dichotic stimuli can be processed together, given the evidence that switching attention between the ears is difficult and takes time.

A number of studies have used ERPs to examine various kinds of effects in dichotic listening paradigms (e.g., Bentin,

Kutas, & Hillyard, 1995; Hillyard, Hink, Schwent, & Picton, 1973), but to our knowledge the only prior study to investigate repetition-priming effects was the one by Okita and Jibu (1998). These authors found a significant reduction in the N400 ERP component in the repetition condition, but only when primes were attended to. However, the primes and targets were presented sequentially in that study. This is therefore further evidence for limited processing of unattended stimuli, but it does not speak to the issue of how this limited processing can influence the simultaneous processing of attended stimuli. In the present study, participants were presented with a spoken prime word in the left, “unattended” ear, and 50 ms later with a spoken target word in the right, “attended” ear.<sup>1</sup> The 50-ms SOA was designed to mimic the head start for prime processing in standard masked priming with visual stimuli (e.g., Holcomb & Grainger, 2006). The targets were either a repetition of the prime word (e.g., fire–FIRE, mouth–MOUTH), a completely unrelated word (e.g., mouth–FIRE or fire–MOUTH), or, occasionally, “probe” words from a specific semantic category (animals). Participants were instructed to attend all target words presented in the right, attended ear and to press a button whenever such an item was an animal name. The ERP recording was time-locked to the onset of all nonprobe target words in the attended ear (i.e., target words to which participants made no behavioral response, referred to here as “critical” targets).

The timing of the dichotic repetition-priming effects to be investigated in the present study will provide important constraints on possible mechanisms driving such effects. Effects arising relatively early in the ERP signal would suggest that attentional switches are an improbable cause of dichotic repetition priming with temporally overlapping stimuli. According to attention-switch accounts of dichotic repetition-priming effects, attention would be automatically attracted to the unattended ear upon prime presentation (an exogenous shift of attention), and would then rapidly switch back to the attended ear in order to respect the task instructions (an endogenous shift of attention). Information from the unattended ear could then be integrated with ongoing processing of target stimuli presented to the attended ear, hence generating priming effects. Given that the lowest estimates of the timing of shifts of attention are around 50 ms for an exogenous shift, and 150 ms for an endogenous shift (Lachter, Forster, & Ruthruff, 2004), plus a minimum amount of time spent processing prime stimuli, one might not expect to see priming effects prior to the N400 time window.

<sup>1</sup> Given the evidence for a right-ear advantage in prior research on dichotic listening (e.g., Kimura, 1961), we presented to-be-attended stimuli to that ear in order to further bias processing toward the attended stimuli.

## Method

### Participants

A group of 36 volunteers (25 female, 11 male; mean age = 19.9 years,  $SD=1.6$ ), who were all undergraduate students at Tufts University, were paid \$25 to participate in this experiment. All were right-handed native speakers of English.

### Stimuli

The *critical* stimuli for this experiment were 150 pairs of monosyllabic English words digitized at 22 kHz and edited for precise word onset (Cooledit 2000 k) and overall duration (prime mean duration = 411 ms, target mean duration = 412 ms). The noncritical *probe* stimulus pairs were formed by combining 25 monosyllabic animal names with 25 unrelated monosyllabic words using the same recording parameters. For both the critical and probe items, the first member of each pair was referred to as the *prime*, and the second member as the *target*. Stimulus lists consisted of 125 trials, each containing a prime–target pair of items. In addition to ear of presentation, primes and targets were differentiated by intensity and speaker gender, in order to minimize the physical similarity between repeated items and to enhance attentional separation. Targets were presented in the right ear at a normal conversational listening level (~60 dB SPL) in a female voice. Primes were presented in the left ear at a lower intensity level (–6 dB) and were spoken in a male voice. On 50 of the critical trials, the target was a repetition of the prime (e.g., fire–FIRE), and on the other 50 critical trials, the target was unrelated to the prime (e.g., mouth–FIRE). Across two lists, critical target words appeared once in each of the two conditions, but within lists each target stimulus was presented once. For the 25 noncritical probe trials, five contained animal names in the unattended, prime ear and filler words in the attended, target ear, whereas another 20 trials contained unrelated filler words in the unattended, prime ear and animal names in the attended, target ear.

### Procedure

Spoken words were presented via headphones (Sennheiser Model PC131) at normal listening levels (attended ear = 60 dB, unattended ear = 54 dB). Each trial began with the onset of the prime word, spoken by a male speaker in the unattended ear, and was rapidly followed 50 ms later by the onset of a target word, spoken by a female speaker in the attended ear (i.e.,  $SOA=50$  ms). In order to keep the attentional demands of the task high, trials occurred in rapid succession, with an average interval of prime onsets

between trials of 1 s. Every 30–35 trials, participants were provided a short (2-min) rest break (see Fig. 1 for a schematic of typical trials). Participants were asked to refrain from blinking and from moving their eyes except during breaks. Animal names served as the *probe* items in a go/no-go semantic categorization task in which participants were instructed to attend the right ear and to rapidly press a single button whenever they detected an animal name, but to passively listen to all other stimuli (i.e., critical stimuli did not require an overt response). They were not told about the possible occurrence of animal names in the unattended, left ear. A practice session was administered before the main experiment, to familiarize the participant with the procedure.

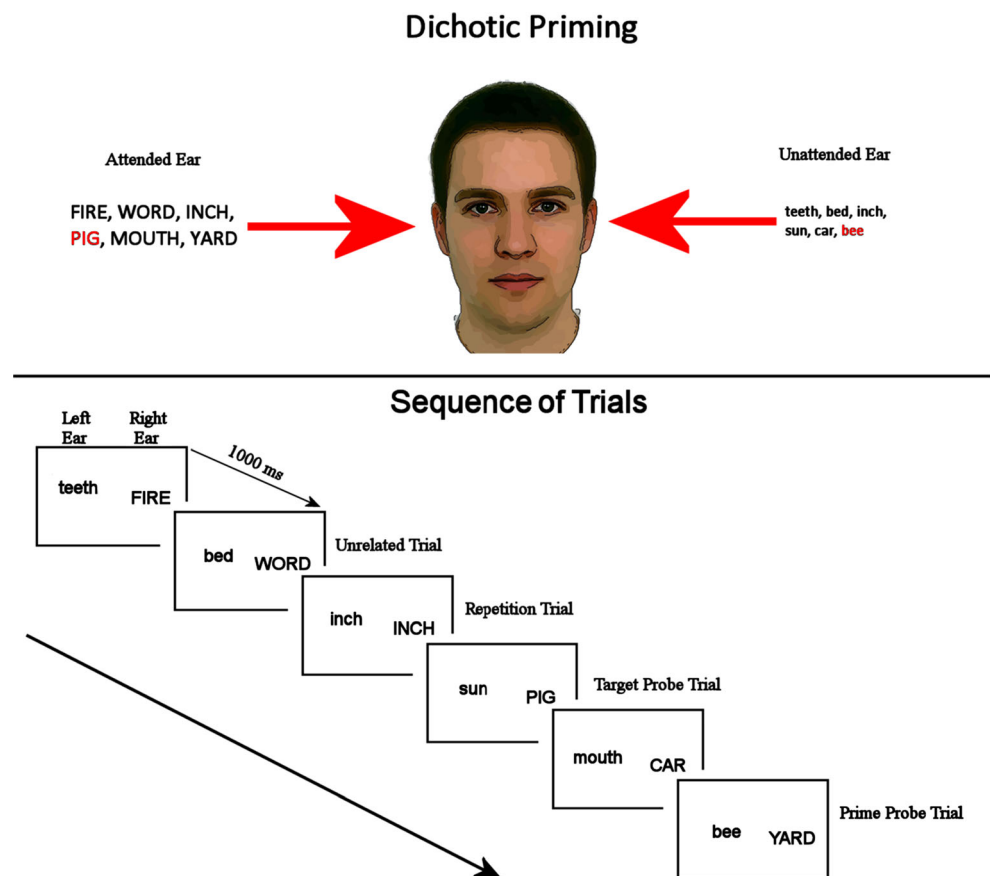
### Electroencephalogram (EEG) recording procedure

Participants were seated in a comfortable chair in a sound-attenuated, darkened room. The EEG was recorded from 29 active tin electrodes held in place on the scalp by an elastic cap (Electrode-Cap International; see Fig. 2). In addition to the 29 scalp sites, additional electrodes were attached below the left eye (to monitor for vertical eye movements/blinks), to the right of the right eye (to monitor for horizontal eye movements), over the left mastoid bone (reference), and over the right mastoid bone (recorded actively to monitor for differential mastoid activity). All EEG electrode impedances were maintained below 5 k  $\Omega$  (the impedance for eye electrodes was less than 10 k $\Omega$ ). The EEG was amplified by an SA Bioamplifier with a bandpass from 0.01 to 40 Hz, and the EEG was continuously sampled at a rate of 250 Hz throughout the experiment.

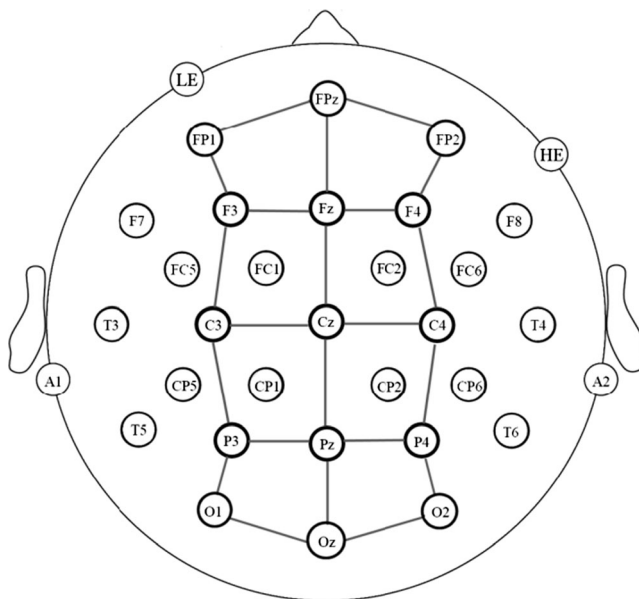
### Data analysis

Averaged ERPs were formed offline from trials free of ocular and muscular artifacts (artifacts disqualified less than 10 % of trials). ERPs were calculated by averaging the EEG time-locked to a point 50 ms pre-target-onset and lasting until 800 ms post-target-onset. The 50-ms pretarget period was used as the baseline. Separate ERPs were formed for the two target conditions (targets that were repetitions of their prime words and targets that were unrelated to their prime words). In order to carefully quantify the time course of repetition effects, mean amplitudes in three contiguous post-target-onset latency windows were measured: 150–300 ms (pre-N400), 300–600 ms (N400), and 600–900 ms (post-N400). Repeated measures analyses of variance (ANOVAs) were used to analyze the data from 15 electrode sites (see Fig. 2) in each epoch separately. Each ANOVA included a Repetition factor (repetition vs. unrelated) and two distributional factors: Laterality (left vs. midline vs. right) and

**Fig. 1** Dichotic priming paradigm (top) and a sequence of six trials (bottom). Lowercase is used to represent the lower intensity of stimuli presented to the unattended (left) ear, and the slightly higher location of these stimuli represents their earlier (by 50 ms) onset, as compared with the stimuli in the attended (right) ear. In the top panel, the animal name probe words are shown in color (in the right, attended ear, these were the to-be-responded-to items).



Anterior–Posterior (FP vs. F vs. C vs. P vs. O). We have used this analysis scheme in several previous ERP masked-



**Fig. 2** Electrode montage and sites used in the analyses (darker circles).

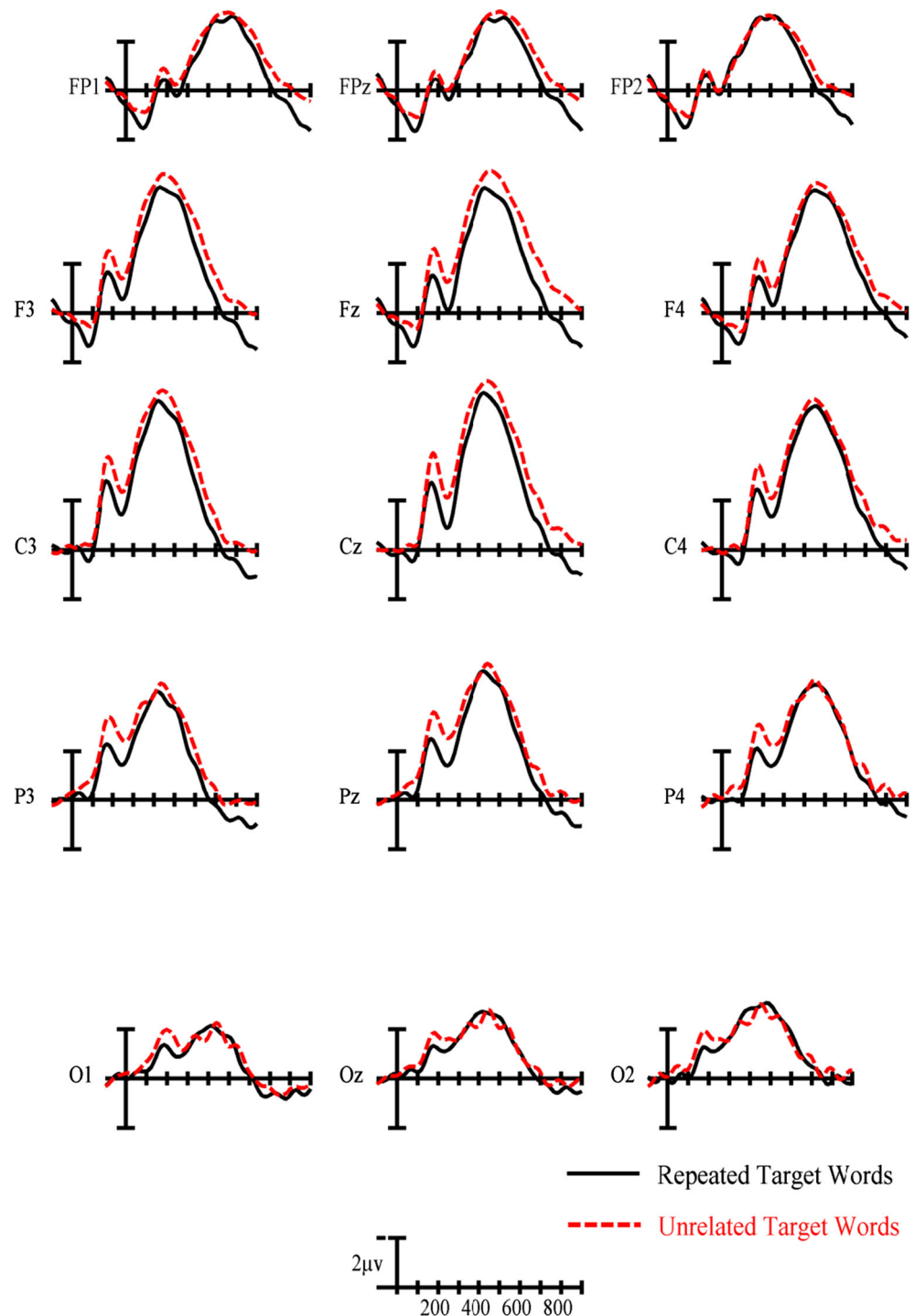
priming studies, and it has been shown to provide the best balance between a thorough analysis of the time course and scalp distribution of priming effects and a simple, straightforward presentation of the results (e.g., Grainger, Lopez, Eddy, Dufau, & Holcomb, 2012). Greenhouse–Geisser correction was applied to all effects with more than one degree of freedom in the numerator.

## Results

### Electrophysiological data

*150- to 300-ms epoch* In the first epoch, we found a main effect of repetition [ $F(1, 35)=10.97, p=.0022$ ], with targets following unrelated primes producing more negative-going waves than targets following repeated primes. This effect was widespread across the scalp (with the exception of the most frontal sites), as can be seen in Fig. 3 and the left panel of Fig. 4.

**Fig. 3** Grand average event-related potential waveforms from the 15 scalp sites used in the analyses of the data. The  $x$ -axis represents milliseconds from target word onset, and negative values are plotted up on the  $y$ -axis.

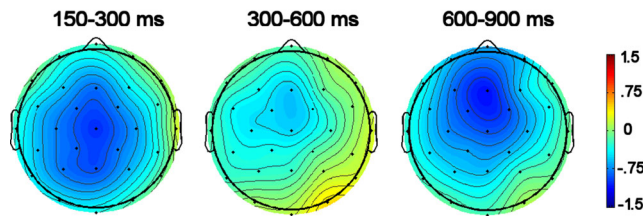


**300- to 600-ms epoch (N400)** In the second analysis time window, a main effect of repetition was no longer apparent ( $p > .46$ ), although we did observe a Laterality  $\times$  Repetition interaction [ $F(2, 70) = 4.98$ ,  $p < .0129$ ], indicating a central-leftward distribution of the priming effect (see Fig. 4, middle).

**600- to 900-ms epoch** In the final analysis window, a marginal main effect of repetition emerged [ $F(1, 35) = 3.1$ ,  $p = .087$ ] and a Laterality  $\times$  Repetition interaction [ $F(2, 70) = 6.09$ ,  $p = .0073$ ]. As during the previous epoch, the priming effect was somewhat left-lateralized (see Figs. 3 and 4).



## Priming Effect in 3 Epochs



**Fig. 4** Topographic maps showing average voltage differences (unrelated condition minus repetition condition) across all electrode sites for the three analysis epochs. The color bar is a microvolt scale.

*Time-course analysis* In order to more precisely characterize the temporal properties of repetition priming, we also ran a series of analyses on the contiguous 50-ms mean amplitude epochs from 100 to 900 ms. These results are presented in Table 1.

### Behavioral data

Postexperiment debriefing of participants revealed that they were aware of words occurring in the unattended ear, but none reported that they had noticed the presence of animal words in this ear. These informal reports are backed up by the animal detection task results: Participants detected an average of 90 % ( $SD=7.6$ ) of the animal name probe words in the right, attended ear. However, no participant pressed to any of the animal names in the left, unattended ear.

### Discussion

In the present study, we presented participants with clearly audible target words in the right (attended) ear and asked them to press a response button as soon as they heard an animal name. At 50 ms before each word presented to the right ear, a prime word was presented to the left (unattended) ear, at a lower intensity and spoken in a different voice. Prime words could be the same as the targets or totally different words. Animal names were also presented to the unattended ear, and

although participants were aware of words being presented to the unattended ear, they never responded to the presence of an animal name in that ear. Our results showed a robust repetition-priming effect that emerged about 150 ms post-target-onset, and that was present for the entire duration of the target word, although the spatial distribution of priming effects did change slightly over time, becoming more left-lateralized in later time windows. This clearly suggests that phonological information was obtained from the unattended ear and influenced the online processing of target words in the attended ear. Most importantly, the relatively early onset of these priming effects, prior to the N400 component, suggests that they are unlikely to be due to attention switches enabling the sequential processing of primes and targets.

It is interesting to compare the present findings with those found previously in more traditional dichotic listening experiments with simultaneous presentation of stimuli to each ear, and in particular with respect to the phenomenon known as “phonological fusion” (Cutting, 1976; Sexton & Geffen, 1981). This phenomenon refers to the kinds of errors participants make in a dichotic listening paradigm with simultaneous presentation, such as reporting hearing “black” upon presentation of “back” and “lack.” Cutting observed that phonological fusion is sensitive to phonetic characteristics but is relatively insensitive to nonlinguistic acoustic factors, and therefore he concluded that fusion involves the combination of phonemes from both ears into a unitary percept. Later work by Kolinsky, Morais, and Cluytens (1995) provided further support for a relatively high-level locus of such phonological fusions. Kolinsky et al. presented pseudoword stimuli simultaneously to both ears and asked their participants to indicate whenever they heard a word. A large number of illusory words were reported when the word was formed as a recombination of the syllables of the pseudowords, such as reporting “cotton” when hearing “collan” and “bitton.” Kolinsky et al. argued that their results pointed to syllables as the key representations involved in interaural integration (see Mattys & Melhorn, 2005, for further evidence).

What might be the mechanism(s) behind dichotic priming and phonological fusion effects? Dupoux et al. (2003) suggested that attention switches might have driven the dichotic priming effects that they observed, with attention directed to the prime being a necessary condition for obtaining these

**Table 1** All  $p$  values from a time-course analysis showing main effects of repetition and interactions of this factor (R) with the Laterality (L) and Anterior–Posterior (AP) distributional factors, at consecutive 50-ms epochs from 100 to 900 ms post-target-onset

	100– 150	150– 200	200– 250	250– 300	300– 350	350– 400	400– 450	450– 500	500– 550	550– 600	600– 650	650– 700	700– 750	750– 800	800– 850	850– 900
Repetition	.350	.002	.006	.090	.280	.690	.950	.530	.880	.280	.250	.150	.300	.130	.070	.008
R×L	.260	.500	.044	.080	.037	.150	.190	.027	.036	.003	.003	.080	.004	.130	.030	.120
R×AP	.760	.250	.100	.320	.310	.120	.530	.210	.400	.360	.100	.570	.110	.660	.060	.120

effects. However, the timing of the dichotic repetition-priming effects found in the present study points to attention switches being an unlikely locus of these effects, even when applying the lowest estimates of the timing of such switches. Treisman (1971) had already nicely summarized the key issue here, in reference to research described in Treisman (1970, 1971) and earlier work on dichotic listening: “If switching between the ears with alternating stimuli is difficult, as the present experiments suggest, how can it lead to so many spontaneous, apparently unavoidable errors in experiments with simultaneous presentation?” (Treisman, 1971, p. 166). Today, many would agree that the answer lies in the quite extensive processing that is performed on information arriving in the unattended ear, and the way that this information can be integrated with simultaneously processed information in the attended ear. Here, we tentatively propose a straightforward extension of a recent model of spoken word recognition, the TISK model (Hannagan et al., 2013), as a possible solution to Treisman’s paradox, and as an account of the present findings.<sup>2</sup>

The backbone of our tentative explanation is the work performed by low-level speech analyzers that receive the auditory signal as input and generate output representations (probably phonemes) that are both *time-specific* (as postulated in TISK) and *source-specific* (an extension of TISK). Thus, a given phoneme /p/ is tagged for its temporal location in echoic memory (/p/ at time slot *t* in the memory loop) and for the source that generated the input (/p/ from source *x*). The source-specific nature of such analyzers would enable parallel processing of different speech inputs at a cocktail party. Attention then determines how much this information will be used for conscious identification of the speech signal, by modulating the relative weights assigned to the different sources as time-specific and source-specific phonemes are mapped onto higher-order, time-invariant and source-invariant, sublexical phonological representations that code for the order of phonemes in a word, rather than for their position in time or the location of their source. It is at this higher level of representation that phonological fusions arise, and that processing of target words in the attended ear in the present study was influenced by phonological information extracted from the unattended ear.

In conclusion, we examined repetition-priming effects in a dichotic priming paradigm in which prime stimuli were presented to the unattended ear, at lower intensity, spoken in a

different voice, and 50 ms prior to target stimuli presented to the attended ear. We found an early priming effect starting at around 150 ms post-target-onset, as well as prolonged effects of repetition priming on the N400 component. The early effect of prime–target relatedness suggests that sublexical phonological information is extracted from the unattended ear and either integrated with sublexical phonological information extracted from the attended ear or, at the very least, used to determine whether or not these two sources of information match. One obvious next step would be to examine the effects of different types of prime–target overlap (e.g., onset vs. rime overlap) in the dichotic priming paradigm. In general, we expect this future work to provide valuable insights with respect to describing the mechanisms that enable speech information that is initially represented in time, to make contact with time-invariant phonological representations.

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## References

- Bentin, S., Kutas, M., & Hillyard, S. A. (1995). Semantic processing and memory for attended and unattended words in dichotic listening: Behavioral and electrophysiological evidence. *Journal of Experimental Psychology: Human Perception and Performance*, 21, 54–67. doi:10.1037/0096-1523.21.1.54
- Cutting, J. E. (1976). Auditory and linguistic processes in speech perception: Inferences from six fusions in dichotic listening. *Psychological Review*, 83, 114–140. doi:10.1037/0033-295X.83.2.114
- Darwin, C. J., Brungart, D. S., & Simpson, D. B. (2003). Effects of fundamental frequency and vocal-tract length on attention to one of two simultaneous talkers. *Journal of the Acoustical Society of America*, 114, 2913–2922.
- Dufour, S. (2008). Phonological priming in auditory word recognition: When both controlled and automatic processes are responsible for the effects. *Canadian Journal of Experimental Psychology*, 62, 33–41. doi:10.1037/1196-1961.62.1.33
- Dupoux, E., Kouider, S., & Mehler, J. (2003). Lexical access without attention? Explorations using dichotic priming. *Journal of Experimental Psychology: Human Perception and Performance*, 29, 172–184.
- Grainger, J., Lopez, D., Eddy, M., Dufau, S., & Holcomb, P. J. (2012). How word frequency modulates masked repetition priming: An ERP investigation. *Psychophysiology*, 49, 604–616. doi:10.1111/j.1469-8986.2011.01337.x
- Hannagan, T., Magnuson, J., & Grainger, J. (2013). Spoken word recognition without a TRACE. *Frontiers in Language Sciences*, 4, 563.
- Hillyard, S. A., Hink, R. F., Schwent, V. L., & Picton, T. W. (1973). Electric signs of selective attention in the human brain. *Science*, 182, 177–179.
- Holcomb, P. J., & Grainger, J. (2006). On the time course of visual word recognition: An event-related potential investigation using masked repetition priming. *Journal of Cognitive Neuroscience*, 18, 1631–1643. doi:10.1162/jocn.2006.18.10.1631
- Holender, D. (1986). Semantic activation without conscious identification in dichotic listening, parafoveal vision, and visual masking: A

<sup>2</sup> It has not gone unnoticed that the early dichotic repetition-priming effect found in the present work resembles the mismatch negativity (MMN) effect found in ERP studies using the so-called “oddball” paradigm (e.g., Näätänen, 2001), in terms of both the timing and the spatial distribution of these effects. The MMN is thought to require habituation to a standard (i.e., massively repeated) stimulus, prior to presentation of the deviant stimulus that generates an increased negativity. Clearly, this was not the case in the present study, in which repeated and different stimuli were equiprobable.

- survey and appraisal. *Behavioral and Brain Sciences*, 9, 1–23. doi: [10.1017/S0140525X00021269](https://doi.org/10.1017/S0140525X00021269). disc. 23–66.
- Kimura, D. (1961). Cerebral dominance and the perception of verbal stimuli. *Canadian Journal of Psychology*, 15, 166–171.
- Kolinsky, R., Morais, J., & Cluytens, M. (1995). Intermediate representations in spoken word recognition: Evidence from word illusions. *Journal of Memory and Language*, 34, 19–40.
- Lachter, J., Forster, K. I., & Ruthruff, E. (2004). Forty-five years after Broadbent (1958): Still no identification without attention. *Psychological Review*, 111, 880–913. doi:[10.1037/0033-295X.111.4.880](https://doi.org/10.1037/0033-295X.111.4.880)
- Mattys, S., & Melhorn, J. F. (2005). How do syllables contribute to the perception of spoken English? Insight from the migration paradigm. *Language and Speech*, 48, 223–253.
- Näätänen, R. (2001). The perception of speech sounds by the human brain as reflected by the mismatch negativity (MMN) and its magnetic equivalent (MMNm). *Psychophysiology*, 38, 1–21. doi: [10.1111/1469-8986.3810001](https://doi.org/10.1111/1469-8986.3810001)
- Okita, T., & Jibu, T. (1998). Selective attention and N400 attenuation with spoken word repetition. *Psychophysiology*, 35, 260–271.
- Rivenez, M., Darwin, C. J., & Guillaume, A. (2006). Processing unattended speech. *Journal of the Acoustical Society of America*, 119, 4027–4040.
- Sexton, M. A., & Geffen, G. (1981). Phonological fusion in dichotic monitoring. *Journal of Experimental Psychology: Human Perception and Performance*, 7, 422–429. doi:[10.1037/0096-1523.7.2.422](https://doi.org/10.1037/0096-1523.7.2.422)
- Treisman, A. M. (1970). Perception and recall of simultaneous speech stimuli. *Acta Psychologica*, 33, 132–148.
- Treisman, A. M. (1971). Shifting attention between the ears. *Quarterly Journal of Experimental Psychology*, 23, 157–167. doi:[10.1080/14640747108400236](https://doi.org/10.1080/14640747108400236)