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# Auditory Semantic Priming and the Dichotic Right Ear Advantage

Daniel Voyer and Natalie Hearn

Department of Psychology, University of New Brunswick

Address correspondence to Daniel Voyer, Department of Psychology, University of New Brunswick, PO Box 4400, Fredericton, NB, Canada, E3B 5A3. Phone: 1-506-453-4974; E-mail: voyer@unb.ca.

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Abstract

The current study presents two experiments that aimed to explore the effects of auditory semantic priming on the dichotic right ear advantage. In Experiment 1, a classic fused dichotic words task was modified with the addition of auditory associative primes with three levels of relatedness (right, left, or neither ear). In Experiment 2, a new dichotic listening task was developed based on a binaural task used in a published auditory priming study. In both experiments, we expected that priming would produce a large right ear advantage when related to the right ear target but that the magnitude of this advantage would decrease for left ear related targets. Although evidence of priming (faster responses for related than unrelated primes) was found in both experiments, only Experiment 2 confirmed our prediction of an ear by prime relatedness interaction. Results are interpreted in the context of models concerned with the role of each cerebral hemisphere in semantic processing as well as models of perceptual asymmetries.

*Keywords:* dichotic listening, perceptual asymmetries, auditory perception, semantic priming

## 1.0 Introduction

Research using dichotic listening as a means to localize of verbal functions in the brain has a long history, dating back to Kimura (1961a, 1961b). Her work with digits presented simultaneously to each ear suggested a right ear advantage (REA) in verbal processing that extended from lobectomy patients to a sample of participants with an intact brain (Kimura, 1961b). It is now widely accepted that the REA that Kimura observed in the 1960's can be explained as the result of neurological and physiological mechanisms in the central nervous system (Leshem, 2013; Westerhausen et al., 2009; see also Hugdhal, 2004).

### 1.1 Models of Perceptual Asymmetries

Perceptual asymmetries of the type observed by Kimura (1961a; 1961b) have been replicated under many conditions (see Voyer 2011 for a review). These asymmetries have commonly been explained through two dominant models, the attentional model and the structural model. The attentional model suggests that the processing of verbal material primes the left cerebral hemisphere, while simultaneously inhibiting the right cerebral hemisphere (Kinsbourne, 1970). This unilateral priming biases attention to the (contralateral) right side of space and produces the observed REA in performance. In fact, the strength and importance of this bias has been shown in recent work reporting a clear right ear bias even in the absence of auditory stimulation by either inducing auditory imagery (e.g., imagine hearing a voice: Prete, Marzoli, Brancucci, & Tommasi, 2016) or masking the auditory stimulus (Prete, D'Anselmo, Brancucci, & Tommasi, 2018). In contrast, the structural model links the REA to anatomy and physiology, relying on a process called "occlusion mechanism", stating that contralateral pathways inhibit ipsilateral pathways (Bryden, 1988). Neither the attentional model nor the structural model are independently able to explain perceptual asymmetries. According to Bryden (1988), the auditory system is not as clearly lateralized as hypothesized in the structural model. For example, sounds presented to the right ear travel to both the right and left auditory areas, although the contralateral cortex receives stronger, more complete, and more rapid signals. Sounds presented to the left ear must cross the corpus callosum after arriving at the right cortex, and stimulus information is lost during the inter-hemisphere transmission. Similarly, the attentional model does not account for the activation of both hemispheres simultaneously, but it does recognize that the differences in ear advantage for the same stimuli might be based on differential hemispheric priming (Bryden, 1988). Both models are relevant to dichotic laterality effects, but alone neither explain perceptual asymmetries fluently. Additionally, top-down manipulations (telling participants to direct attention to one ear only) and bottom-up manipulations (inducing relative interaural differences) have been shown to affect auditory asymmetries (Westerhausen et al., 2009). For example, Westerhausen et al. (2009), showed that intensity and attention manipulations are not independent from each other. By increasing the intensity of stimuli presented to either ear, they found that, in some cases, stimulus intensity determined the observed ear advantage. However, top-down manipulations were still effective considering that, when participants were instructed to attend to a specific ear, the attended ear had the advantage (see also Saetrevik & Hugdahl, 2007a). This type of attention manipulation have been replicated numerous times under a variety of settings (e.g., see Asbjornsen & Hugdhal, 1995; D'Anselmo, Marzoli, & Brancucci, 2016). The influence of both stimulus-based and attentional manipulations on auditory asymmetries suggest that the typical REA with verbal stimuli is not entirely a result of structural constraints nor is it entirely caused by an attentional bias, but a combination of the two (Hugdahl, 2000; Leshem, 2013).

### 1.2 Priming as a Top-Down Manipulation

Investigations of the influence of top-down (attentional) auditory asymmetries have also considered the potential effect of direct priming as a means to manipulate attentional biases. The present study aimed to examine how auditory asymmetries with verbal material might be affected by semantic priming. However, before addressing this purpose directly, we will define what semantic priming involves and present an overview of some priming work in the context of auditory asymmetries.

McNamara (2005) defined priming as “an improvement in performance in a perceptual or cognitive task, relative to an appropriate baseline, produced by context or prior experience” (p. 3). In this context, he also defined semantic priming as an “improvement in speed or accuracy to respond to a stimulus, such as a word or a picture, when it is preceded by a semantically related stimulus (e.g., cat-dog) relative to when it is preceded by a semantically unrelated stimulus (e.g., table-dog)” (p. 3). Essentially, in semantic priming, a person will typically have a quicker or more accurate response to a stimulus if it is preceded immediately by a semantically related word than if the stimulus is preceded by an unrelated prime (Coppens, 2010). In addition, considering that what is called “semantic” priming is often caused by a mixture of semantic and associative relations, we adopt the same approach as McNamara (2005) and use the term “semantic priming” to refer to both semantic and associative priming. Although the present paper uses mostly associative priming, as priming type is not the focus of our work, the distinction will not be discussed further.

In his book summarizing research on priming and the models derived from it, MacNamara (2005) suggested that lexical decision is the classical task used to study priming in research. In this task, a letter string forming a real word in a given language or a non-word is presented, and participants are required to make a word/non-word decision. Naming is also a common task used in semantic priming studies. In naming tasks, a word or picture is presented, and participants are required to pronounce the word or name the object. Regardless of the task, preceding the target with a stimulus that is either related or unrelated turns the procedure into a priming task.

Considering the common use of words and images in priming studies, it is not surprising that much of the work of relevance occurs in the visual modality. This conclusion also holds true for studies concerned with an examination of priming in the context of perceptual asymmetries (McNamara, 2005).

For our purpose, the idea that much of the semantic priming research relevant to perceptual asymmetries has been conducted with visual tasks is crucial if only because meta-analytic evidence suggests that dichotic listening produces asymmetries that are more reliable and valid than those found in divided visual field tasks (Voyer, 1998). Therefore, results obtained with dichotic listening are expected to provide a better representation of underlying constructs. However, the focus on visual tasks in semantic priming research also means that there is very little existing auditory work to use as a foundation for our purpose.

In fact, to date, no studies of semantic priming have been conducted in the context of dichotic listening with the purpose of establishing possible interactions with auditory asymmetries (see Aydelott, Jamaluddin, & Nixon Pearce, 2015; Dupoux, Kouider, & Mehler, 2003; Grainger & Holcomb, 2015; List & Justus, 2007 for examples of studies of dichotic listening and priming that do not address auditory asymmetries). The only relevant study was conducted with repetition priming and it produced a negative priming effect. Negative priming occurs when a prime stimulus inhibits the response to a target stimulus. Saetrevik and Hugdahl (2007b) conducted what is likely the only study to use a verbal dichotic task in a priming paradigm. These authors simply used one of the target syllables as prime before presenting the dichotic pair and they found that the prime decreased accuracy for the primed stimulus, thereby reflecting an instance of negative priming. They explained this finding as caused by interference from the trace of the prime stimulus leading attention to focus on perceiving novel stimuli, such as the unprimed stimulus in the dichotic pair. Similar results were observed by Saetrevik (2012), although that particular study did not use a pure priming task as repetition priming was inferred from stimuli presented on the previous trial.

Studies by Harding and Voyer (2016) and Voyer and Myles (2018) used dichotic listening but in the context of emotion priming. Harding and Voyer used facial expression primes presented in central vision with auditory targets presented dichotically. The target were words (bower, dower, power, or tower) pronounced in an emotional tone (anger, happiness, sadness) or a neutral tone of voice. These authors showed a reduced left ear advantage with right related primes in this cross modal priming design. In contrast, Voyer and Myles used unimodal priming (auditory prime and target) and found a reversal of the ear advantage as a function of prime relatedness (left ear advantage for left related; REA for right related). However, despite their relevance to both priming and dichotic listening, the studies by Saetrevik and Hugdhal (2007b), Harding and Voyer (2016), and Voyer and Myles (2018) do not contribute to our understanding of how semantic priming might affect auditory verbal asymmetries.

The current study is therefore poised to be the first example of a use of dichotic listening to investigate the potential effect of unimodal auditory semantic priming on the REA. We pursued this goal in two separate experiments. In Experiment 1, we used stimulus pairs from a classic task (the Fused Dichotic Word Task or FDWT: Wexler & Halwes, 1983) and obtained medium and high associates as binaural primes. In Experiment 2, we relied on stimuli obtained from an experiment by Holcomb and Neville (1990) where they demonstrated auditory priming effects in an event-related potential setting, although they presented their target stimuli binaurally rather than dichotically. In our dichotic paradigm, we considered three levels of prime-target relatedness (right ear related, left ear related, and unrelated). Additionally, we explored a narrow range of stimulus onset asynchrony (SOA; time difference between the onset of the prime and the onset of the target). Research with the divided visual field paradigm suggests that SOA often affects the magnitude of priming effects (Abernethy & Coney, 1993; de Groot, Thomassen, & Hudson, 1986; Koivisto, 1999), although researchers have reported variable results for this factor.

Models concerned with the role of the cerebral hemispheres in semantic priming with behavioral data have been derived exclusively from visual tasks relying mostly on lexical decision. The global notion that structures in both hemispheres contribute to semantic processing and are therefore subject to semantic priming is at the core of these models. However, where models differ is in defining the exact role for each hemisphere. For example, Kahlaoui, Scherer, and Joannette (2008) proposed from their review of brain lesions studies that the right hemisphere might be involved more when a conscious or attentional component is required. They concluded from behavioral data that the left hemisphere provides rapid meaning access and processing of close associations whereas the right hemisphere contributes to broader activation and deals with weaker associations. This view is somewhat consistent with the model proposed by Deacon et al. (2004; see also Grose-Fifer & Deacon, 2004) suggesting that, in the left hemisphere, semantic information is represented locally in a spreading activation network, whereas the representation is in terms of features encoding in a distributed network in the right hemisphere (see Deacon et al., 2004 for more details). This view fits with the notion suggested by Reilly, Machado, and Blumstein (2015) that the left hemisphere provides fine encoding, whereas the right hemisphere provides coarse encoding. Finally, on the basis of neuroimaging studies, Kahlaoui et al. (2008) suggested that the role of the right hemisphere in semantic processing increases with semantic complexity.

These selected models and views illustrate the fact that there is no consensus on the role of each hemisphere in semantic processing, especially as a function of the method used (behavioral, brain lesions, or neuroimaging). This lack of agreement suggests that our effort to pursue the study of priming with dichotic listening is timely in its purpose to provide an additional paradigm to investigate the role of the cerebral hemispheres in semantic processing. Specifically, considering that different priming processes likely operate for visual and auditory priming tasks (Holcomb & Neville, 1990; Koppehele-Gossel, Schnuerch & Gibbons, 2018), conclusions drawn from one modality may not apply to the other. Therefore, in view of the novelty of the present work, we have kept the number of manipulated variables to a minimum because, at this early stage, our intent was to determine whether semantic priming can actually affect the REA. We expect that semantic priming will potentially cancel out the type of generalized left hemisphere/right side bias hypothesized by Kinsbourne (1970). Specifically, on a given trial, a right related or unrelated prime should have minimal effect on the existing top-down priming resulting from the generalized verbal processing. Therefore, as a working hypothesis for both experiments, we predict a large REA for "right ear related" trials and "unrelated" trials. However, for left related primes, semantic activation favoring the related target should promote its recognition and report by the participants. Therefore, we also predict that the REA will be at least reduced for left ear related trials, compared to that for right ear related trials.

## 2.0 Experiment 1

## 2.1 Methods

### 2.1.1 Participants

Sixty-one Introductory Psychology students were recruited as participant in Experiment 1. They each received a bonus mark for their participation towards their final mark. All participants self-reported normal hearing. Two female participants were excluded for failing to complete the task as instructed. Therefore, the final sample comprised 59 participants composed of 41 females and 18 males. Ages of participants ranged from 18 to 35 years old ($M = 20.1$, $SD = 5.54$). Fifty-six participants were right-handed (Waterloo Handedness Questionnaire score > 0), the remaining three were left-handed (Waterloo Handedness Questionnaire score < 0). Scores ranged from -34 to 64 ($M = 35.48$, $SD = 20.66$). Data analysis with and without left-handed participants did not affect the results in that all significant findings remained unchanged. Therefore, the final analysis was based on the whole sample of 59 participants.

*A priori* power calculations with G*Power 3.1 (Faul, Erdfelder, Lang, & Buchner, 2007) suggested that a sample of 17 participants would be required to achieve 95% power at the .05 level of significance based on the effect size reported by Voyer and Myles (2018) for the main effect of relatedness on response time ($f = 0.47$) in their second experiment. As a way to maximize statistical power, we opted to use an overpowered sample size more in line with past research on priming with dichotic listening (e.g., Harding & Voyer, 2016; Voyer & Myles, 2018).

All participants were treated in accordance with proper ethical guidelines. In addition, the protocol was approved by the institutional ethics board.

### 2.1.2 Materials

***Waterloo Handedness Questionnaire.*** Waterloo Handedness Questionnaire (Steenhuis & Bryden, 1989) was used to measure hand preference. This questionnaire consists of a list of 32 uni-manual activities and participants are asked to circle which hand they use for each activity among five choices (left always, left usually, equally, right usually, and right always). The questionnaire is scored on a scale from -2 (left always) to +2 (right always). This results in a total score ranging from -64 to +64. A score above zero considers the participant to be right-handed and a score below zero to be left-handed.

***Dichotic Word Task.*** Experiment 1 relied on an established dichotic task in an attempt to provide continuity with past research on verbal auditory asymmetries. Accordingly, the Fused Dichotic Words task (FDWT: Wexler & Halwes, 1983) was used as a basis for the present experiment. We relied on a word association crowd-sourcing web page (http://www.wordassociation.org/search) to identify words associated with those used in the FDWT. In identifying potential primes, we aimed to select words with at least a medium association with the target words in hope that it would maximize the likelihood of observing priming effects. However, as a result of this restriction, only five out of the original 30 stimulus pairs presented by Wexler and Halwes (1983) could be used here. The final list of stimuli can be found in Table 1. As might be apparent from Table 1, although a prime existed for both targets, only one of the primes was presented on a given trial and it only applied to one of the targets. The location of the target (left or right ear) was counterbalanced across trials. During dichotic presentation, targets were aligned by their onset. On trials where the prime was unrelated, it was selected randomly from the primes related to other targets.

All stimuli (primes and targets) were adjusted to a mean peak intensity of 70 dB (as measured with a General Radio sound level meter). As these were the original FDWT stimuli, the target words were pronounced by a male native English speaker and their duration within each dichotic pair was equal. The primes were produced by a female native English speaker. **T**he discrepancy in the sex of the speaker was a matter of convenience. Specifically, the selected primes are not available in the original Wexler and Halwes stimuli used as target. Therefore, the programmer produced the primes. Essentially, we had no choice to use a different voice for the primes and targets but we felt safe with this decision considering findings that auditory priming effects show little influence of speaker variability (Lee & Zhang, 2015). Their duration was variable but it was always under 450 ms (range from 313 to 444 ms). Finally, all auditory stimuli were presented through Sony Dynamic headphones (model MDR-V 150).

### 2.1.3 Procedure

The experiment was conducted in a quiet room in groups of at most four, with participants seated at a computer and separated from neighbors by dividers. Each trial began with the binaural presentation of one prime word, followed by the dichotic presentation of the target words. The response alternatives, consisting of the words relevant to the pairings listed under response choice in Table 1, appeared in the middle of the screen immediately after the dichotic pair. For each trial, the task was to identify the word in the dichotic pair that was heard the clearest by clicking the mouse on the appropriate response for each trial with their dominant hand.

The task was completed on computers running Windows XP by means of a script written with E-Prime Version 1.1 (Schneider, Eschman, & Zuccolotto, 2002a, 2002b). The E-Prime script controlled the timing of presentation for both the prime and target stimuli, and recorded participant accuracy (coded as ear of report: left, right, or neither) and response time. Response time was measured as the number of ms from target offset until response.

Two SOA values were implemented: 1250 and 1500 ms. Considering the paucity of auditory priming research, these values were selected as a compromise between those used in the auditory study by Holcomb & Neville (1990: SOA = 1550 ms; mean prime duration of 400 ms) and those used in divided visual field studies (for example, de Groot et al., 1986, used SOAs ranging from 100 to 1240 ms for 40 ms primes). Finally, the SOA manipulation was implemented in a within-subjects blocked design with a counterbalanced block order.

Each block had 120 trials, for a total of 240 experimental trials in the task based on the following design: 3 relatedness (left, right, unrelated) x 2 ears x 5 pairs x 2 ISIs x 4 repetitions of each variable combination. Within each block, the presentation of the sound primes was randomized with one-third of trials (40) related for the left ear target, one-third related for the right ear target, and one-third unrelated for targets to both ears. The first block was preceded by five practice trials to familiarize participants with the task.

After the fused dichotic words test was complete, participants were asked to complete the Waterloo Handedness Questionnaire. They were then fully debriefed on the particulars of the experiment.

**2.2 Results**

All analyses were computed with the R statistical software (R core team, 2018). Data were analyzed by means of a mixed-design analysis of variance with the *ezANOVA* function from the *ez* package (Lawrence, 2016). The independent variables were SOA (1250, 1500 ms), ear of presentation (left or right) and relatedness of the prime (left, right or unrelated). The dependent variables were the proportion of reports for each ear (number of reports from each ear divided by the maximum score of 40; accuracy hereafter) and response time in milliseconds. Note that, although we do not have specific hypothesis about SOA, it was considered as an exploratory variable in our novel paradigm in view of its importance in previous work (Abernethy & Coney, 1993; de Groot, Thomassen, & Hudson, 1986; Koivisto, 1999). For the analysis of response time, only correct responses (i.e., reports for a specific ear) were included in the analysis. In addition, we generally followed the approach proposed by Ratcliff (1993). This author showed through simulation that an inverse transformation of response time (1/RT) and trimming provide robust control of outliers in the analysis of response time when compared to other popular approaches. However, following more modern guidelines (see Baayen & Millin, 2010), we used only minimal trimming, removing anticipation response times (<250 ms) and long response times (> 5000 ms) before proceeding with the inverse transformation. Although data analyses were computed on inverse transformed response times, the means presented in the text and figures reflect untransformed RTs for ease of interpretation. A Greenhouse-Geisser correction was applied when the sphericity assumption was violated, although the reported degrees of freedom do not reflect this correction. In addition, multiple comparisons among means used multiple t-tests with a Holm correction. The inclusion of sex in the design had no influence on the main results. Accordingly, this variable was excluded from further analyses.

### 2.2.1 Accuracy

The analysis of accuracy data produced a significant main effect of ear, $F(1, 58) = 53.45$, $p < .001$, $\eta_p^2 = .480$. Decomposing this finding into left ($M = .32$, $SD = .17$) and right ear accuracy ($M = .50$, $SD = .18$) indicated a large REA, reflecting a Cohen's $d$ of 1.05.

A main effect of SOA also emerged, $F(1, 58) = 8.12$, $p = .006$, $\eta_p^2 = .123$. This effect reflected more accurate reports for the 1500 ms SOA ($M = .42$, $SD = .22$) than for the 1250 ms SOA ($M = .40$, $SD = .21$). No other main effect or interactions achieved significance. Importantly, the main effect of relatedness and the ear by relatedness interaction were both non-significant (smallest $p$ = .24). Nevertheless, considering the relevance of the ear by relatedness interaction for our working hypothesis, Figure 1 (top) presents the number of reports as a function of ear and relatedness.

#### 2.2.2 Response time

The analysis of response time showed a significant main effect of relatedness, $F(1, 58)$ = 4.19, $p$ = .018, $\eta_p^2$ = .067. Multiple comparisons among means with a Holm correction at the .05 level of significance showed significantly slower response for unprimed targets ($M$ = 860 ms, $SD$ = 232) than for left related targets ($M$ = 827 ms, $SD$ = 230; $p$ = .018) and right related targets ($M$ = 829 ms, $SD$ = 215; $p$ = .018). The two types of related targets did not differ from each other ($p$ = .778). The priming effect (unrelated minus related) for the left related targets was 33 ms, whereas for the right related targets it was 31 ms.

No other main effects or interactions achieved significance. Importantly, the ear by relatedness interaction was non-significant ($p$ = .707). Nevertheless, Figure 1 (bottom) also presents response time as a function of ear and relatedness.

### 2.3 Discussion

The main purpose of Experiment 1 was to investigate how an auditory semantic prime might affect the REA. This was done using a modified Fused Dichotic Words Task, where participants heard primes related to a target presented to the left or right ear, or a prime that was unrelated to the target (neither ear). Although a REA was found for accuracy in the current study, the auditory semantic primes did not significantly affect the ear advantage on either accuracy or response time. A related auditory semantic prime did, however, significantly decrease response time regardless of the ear of presentation of the related target.

The REA found here can be added to the vast body of literature suggesting that the left cerebral hemisphere plays a significant role in speech processing. It also validates the ability of our procedure to replicate this classic finding. In addition, typical semantic priming findings were also replicated in that related primes significantly reduced response time compared to unrelated primes. For example, following one of the many models that have been proposed for semantic priming, the priming effect obtained here could be explained by bilateral spreading activation in the brain, similar to accounts of findings in visual word recognition (Chiarello, Burgess, Richards & Pollock, 1990; Kiefer, Weisbrod, Kern, Maier, & Spitzer, 1998).

These main effects are interesting but they fall short of our expectations that semantic priming should affect that magnitude of the REA. One possible reason why we did not observe the expected relatedness by ear interaction is that the auditory asymmetries for words might simply be too deeply ingrained in the left hemisphere. For this reason, it is possible that auditory semantic priming cannot provide enough top-down activation to affect the brain's structural wiring for language processing. From this perspective, it is plausible to believe that Harding and Voyer (2016) and Voyer and Myles (2018) were able to affect the magnitude of the ear advantage (and its direction in the latter study) with emotions as primes and targets because non-verbal asymmetries tend to be weaker than verbal ones (Voyer, 1996; 2011).

Before we conclude that verbal auditory asymmetries cannot be swayed by semantic priming, we need to consider the potential influence of 1) our choice of dichotic pairs and primes in Experiment 1 as well as 2) the strength of association between them. Concerning the first point, the use of only five word pairs may have affected the results as participants might have become overly familiar with them over the course of the experiment. For example, with such repetition of pairs, participants may have favored one word in the dichotic pair over the other, choosing that response regardless of the prime presented. In fact, the constant repetition of a small set of stimuli might have led to more automatic responses, with its correlate reduction of cognitive control. On the second point, the lack of a relatedness by ear interaction could stem from a weak association between the primes and the targets. Although the primes were selected on the basis of having at least a medium association with the target according to crowdsourcing on the wordassociation.org webpage, we used stimuli that were untested in the context of a semantic priming study. With this in mind, we will reserve further conclusions until these two basic problems have been addressed. Accordingly, in Experiment 2 we selected a larger set of stimuli with a demonstrated effectiveness to promote auditory semantic priming to clarify whether the lack of effect of priming on the ear advantage in Experiment 1 arose as a result of a strong structural processing bias that cannot be swayed or as a consequence of methodological limitations.

## 3.0 Experiment 2

### 3.1 Methods

#### 3.1.1 Participants

A new sample of ninety-six Introductory Psychology students was recruited. They each received a bonus mark towards their final grade for their participation. All participants self-reported normal hearing and none of them were involved in Experiment 1. Two female participants and one male participant were excluded for failing to complete the task as instructed. Therefore, the final sample comprised 93 participants consisting of 58 females and 35 males. Ages of participants ranged from 17 to 32 years old ($M$ = 19.5, $SD$ = 2.32). Eighty-five participants were right-handed (Waterloo Handedness Questionnaire score > 0) and the remaining eight were left-handed (Waterloo Handedness Questionnaire score < 0). Scores on the

Waterloo Handedness Questionnaire ranged from -47 to 64 ($M$ = 35.48, $SD$ = 20.66). Here as well, significance of the results remained unchanged when data analysis was computed with and without left-handed participants. Therefore, the final analysis used the whole sample of 93 participants.

As in Experiment 1, we used an overpowered design, although the even larger sample used here reflects the vagaries of volunteer participation within one academic term. All participants were again treated in accordance with proper ethical guidelines and the protocol was approved by the institutional ethics board.

**3.1.2 Materials and Procedure**

Although the procedure remained much the same as in Experiment 1, we developed a novel dichotic listening task on the basis of a new set of primes and targets drawn from those used by Holcomb and Neville (1990) in their auditory task. However, these authors used a single target on each trial rather than a pair as required in dichotic listening and a lexical decision task rather than the identification task required in dichotic listening. Therefore, in Experiment 2, the limiting factors in our choice of stimuli were our ability to produce a plausible distractor (non-target) on each trial that would fuse with the target as well as relevant distractor response alternatives, similar to the approach used in the Fused Dichotic Words task modified for Experiment 1. The final list of response alternatives, targets, and primes can be found in Table 2. All these sounds were produced by the same female native English speaker. Again, dichotic stimuli were aligned in accordance with their onset. Remaining parameters of the sounds were the same as in Experiment 1.

Table 2 reflects a larger set of stimuli in Experiment 2 (16 possible pairings) than in Experiment 1 (five possible pairings) in hopes that it might correct the problem with stimuli familiarity in the first experiment. Another change that arose from this new approach was that, although one binaural prime was presented on each trial as in Experiment 1**,** only one prime applied to a given pair and it related either to the left or right target (or to neither ear) in a counterbalanced fashion.

The change in the number of possible pairings in Experiment 2 also resulted in more trials in the task. Specifically, with 16 words pairs x 3 target placements (left related, right related, unrelated) x 2 SOAs (1250 ms, 1500 ms), this produces 96 combinations x 4 repetition, and the task had a total of 384 trials. Here as well, SOA was a blocked variable with the blocks presented in a random order and the presentation of the sound primes was randomized within each block with one-third of trials (64) related for the left ear target, one-third related for the right ear target, and one-third unrelated for targets to both ears. As before, participants completed the handedness questionnaire after the dichotic task and they were then fully debriefed.

### 3.2 Results

The same analytic software, design, and handling of outliers on response time as in Experiment 1 were used here. Therefore, the independent variables were ear of presentation (left or right), SOA (1250, 1500 ms)**,** and relatedness of the prime (left, right, or unrelated). The dependent variables were accuracy (proportion of reports for each ear, that is, the number of reports for each ear divided by the maximum of 64) and response time (in ms). Here as well, the inclusion of sex in the analysis had no influence on the results. Accordingly, this variable was excluded from further analyses.

#### 3.2.1 Accuracy

Accuracy data produced a significant main effect of ear, $F(1, 92) = 57.92$, $p < .001$, $\eta_p^2 = .386$. Mean performance for the left ($M = .54$, $SD = .25$) and right ear ($M = .30$, $SD = .25$)

reflected a large REA, with a Cohen's *d* of 0.95. As in Experiment 1, the main effect of relatedness and the ear by relatedness interaction were both non-significant (smallest $p = .19$), although means relevant to the interaction are plotted in Figure 2 (top). No other main effects or interactions achieved significance.

**3.2.2 Response time**

The analysis of response time showed a significant main effect of ear, $F(1, 92) = 17.36$, $p < .001$, $\eta_p^2 = .159$, reflecting significantly faster responses for the right ear ($M = 848$ ms, $SD = 228$) than for the left ear ($M = 927$ ms, $SD = 310$). This REA was associated with a Cohen's *d* of 0.30.

A significant main effect of relatedness also emerged on response time, $F(2, 184) = 18.58$, $p < .001$, $\eta_p^2 = .168$. As in Experiment 1, this finding reflected significantly slower responses for unrelated targets ($M = 923$ ms, $SD = 267$) than for left related targets ($M = 847$ ms, $SD = 192$; $p$ <001) and right related targets ($M = 892$ ms, $SD = 248$; $p = .002$). However, left related targets were also significantly faster than right related targets ($p = .010$). In Experiment 2, the priming effect (unrelated minus related) for the left related targets was 76 ms, whereas for the right related targets it was 31 ms.

These main effects were qualified by an ear by relatedness interaction, $F(2, 184) = 4.61$, $p = .011$, $\eta_p^2 = .048$. Means relevant to this finding are presented in the bottom panel of Figure 2. Simple main effects analyses for this interaction following the approach recommended by Winer (1962) showed a significant REA for right related and unrelated targets ($p < .001$ in both cases) but not for left related targets ($p = .199$; all values Holm corrected). Alternatively, the relatedness effect was significant for the left ear ($p < .001$) but not for the right ear ($p = .088$). No other main effects or interactions achieved significance (smallest $p = .166$).

**3.3 Discussion**

Experiment 2 still pursued our goal to investigate possible semantic priming effects in the auditory modality, with a focus on how they might affect the REA. In Experiment 2, we selected a set of targets and primes that had been used in a previous auditory priming study relying on binaural presentation. Our hopes were that an ear by relatedness interaction would emerge with this new stimulus set if this interaction reflected the true population state. Results showed a REA for both accuracy and response time. In addition, auditory semantic priming decreased response time regardless of the ear of presentation of the related target. More importantly, the ear by relatedness interaction emerged. It showed that a left-related prime produced a non significant ear effect whereas the typical REA emerged in other conditions. This finding was a consequence of the significant priming effect for the left but not for the right ear.

Again, the REA we found fits with the bulk of the literature. Its importance is in validating the ability of our newly designed task to replicate a finding that is viewed as a given for any verbal dichotic listening task. Although the main effect of priming is interesting, the ear by relatedness interaction is of critical importance as a matter of empirical import but also for its early theoretical implications.

The presence of a relatedness by ear interaction in Experiment 2 discounts the explanation that the auditory asymmetries for words is too deeply ingrained in the left hemisphere to be affected by semantic priming. Indeed, we showed that the ear advantage can be modified by the top-down activation elicited by semantic priming when the association is strong enough and when the potential role of stimulus familiarity is reduced.

From a theoretical standpoint, the observation that priming effect emerged for the right hemisphere (left ear) but not for the left hemisphere (right ear) seems somewhat unique, at least when considering the extensive literature reviewed by MacNamara (2005). However, McNamara considered only behavioral data obtained with visual tasks and, even then, results tend to vary in their particulars in terms of whether both hemispheres or only the left is involved when expectancy (proportion of related primes) and type of priming (e.g., purely semantic versus associative) are manipulated. For auditory priming, we have to draw conclusions from the few event-related potential (ERP) and neuroimaging studies in existence that used unimodal auditory tasks. For example, Holcomb and Neville (1990) reported a slightly ($p$ = .0515) larger priming effect for the left hemisphere on the N400 ERP component in the auditory version of their lexical decision task. Similarly, the only lateralized result of relevance in the functional magnetic resonance imaging (fMRI) study conducted by Kotz, Cappa, von Cramon, and Friederici (2002) was an association between the priming effect and increased activation in the left inferior frontal gyrus. In contrast, Anderson and Holcomb (1995) did not find consistent effects of hemisphere in a primed auditory lexical decision task in an ERP setting in which a range of SOAs was manipulated. Despite this last study's findings, the literature presented so far would lead us to expect a priming effect for the right but not the left ear.

In interpreting our results, it is important to remember that all past work of relevance (visual and auditory) was based on lexical decision, in which only one choice is presented and participants could base their judgment on their familiarity with the letter string (Besner & Johnston, 1989). In contrast, our task likely required deeper processing as we asked participants to identify the clearest word and to select it among a choice of four responses. Furthermore, imaging studies focus on structural activation and can only infer top-down components from the observed pattern. With this in mind, our interpretation is that our results cannot be mapped directly as reflecting that priming occurred only in the right hemisphere. Instead, our dichotic implementation of semantic priming produced bilateral activation as a starting point. This first step is compatible with the common finding that bilateral activity was predominant in the aforementioned ERP and fMRI studies as well as in recent studies using transcranial stimulation (D'Anselmo, Prete, Tommasi, & Brancucci, 2015; Prete, D'Anselmo, Tommasi, & Brancucci, 2018). This bilateral activation then acted to mitigate the effect of the attentional priming that was posited by Kinsbourne (1970). Therefore, the natural right ear bias was reduced for left related primes and this centered attention closer to a virtual midline as soon as the prime was presented. This then promoted perception and response toward the word that was associated with the prime, resulting in the observed reduction in the REA on response time, to the point that it did not achieve significance in such trials. According to this account, the prime mitigated the natural right sided bias expected for verbal material and therefore reflects an additional top-down influence on the asymmetry, as was hypothesized by Harding and Voyer (2016) and Voyer and Myles (2018) in the context of emotion priming.

Of course, the above explanation has to remain speculative, as the findings of Experiment 2 require replication. The manipulation of a number of variables such as the implementation of lateralized primes, variation in the proportion of related primes, and a broader range of SOAs might provide a more refined account of the results. In the meantime, the results of Experiment 2 hold much promise for future investigations of the role of bottom-up and top-down factors involved in priming and perceptual asymmetries.

## 4.0 General Discussion and Conclusions

The present study built on two incremental experiments to investigate how semantic priming might affect the classic REA found in dichotic listening tasks with verbal material. The first experiment did not produce the expected reduction of the REA for left related primes.

However, after identifying potential limitations of Experiment 1, we did find the predicted interaction when we corrected them in Experiment 2.

It is noteworthy that neither experiment produced the complete reversal of the ear advantage as a function of the primed ear relatedness that was observed by Voyer and Myles (2018). In explaining this discrepancy, it is important to remember that Voyer and Myles used emotions as stimuli and that such non-verbal asymmetries tend to be weaker than verbal ones (Voyer, 1996; 2011). Therefore, the stronger verbal asymmetries that we found here might be less subject to priming manipulations. In addition, Voyer and Myles required participants to report two responses on each trial, reflecting the stimulus they heard for each ear. This clearly introduced a larger memory load and could explain the more striking priming effects that they obtained. In fact, working memory load has been found to affect semantic priming in a lexical decision task (Heyman, Van Rensbergen, Storms, Hutchison, & De Deyne, 2015). However, the importance of the type of material and the potential role of memory load remain an empirical question requiring replication and extension of the present results. Their extension to a within-subject design where the same participants would complete a non-verbal and a verbal dichotic task under priming conditions either with one or two responses would allow a clear examination of the potential role of these factors in the present paradigm.

Another finding that requires some discussion is that only response time data were affected by priming in both experiments, not accuracy. In fact, Voyer and Myles (2018) found priming effects for both accuracy and response time in their two experiments. Our findings of priming effect only on response time are not unique considering that such effects are often measured as the response time difference between related and unrelated items (Lucas, 2000). Therefore, the lack of a priming effect on accuracy in our experiments does not invalidate the response time results. In addition, Voyer and Myles' findings of priming effects on both accuracy and response time might be accounted for by the greater malleability of the weaker non-verbal effects that these authors were investigating. Alternatively, it is also possible that semantic priming is bound to produce effects that manifest themselves only on response time in a dichotic listening paradigm. In contrast, many of the binaural auditory priming studies we found report a semantic priming effect on accuracy (e.g., Anderson & Holcomb, 1995; Holcombe & Neville, 1990; Kotz, Cappa, von Cramon, & Friederici, 2002). Therefore, the present study might be at variance with previous auditory priming work in finding no effect on accuracy. Three potential factors could be at play to account for this discrepancy. Our results on accuracy could be sample specific, they could be accounted for by the use of dichotic listening, or they could be caused by the use of binaural primes. In any case, the relative contribution of these factors remains to be elucidated in future work. For example, the use of lateralized primes might be advisable in the context of semantic priming with dichotic listening to maximize the priming effect.

From our results, we would argue that the paradigm implemented in Experiment 2 holds much promise for future research. In particular, they suggest further behavioral work in which various factors that have been manipulated in visual research could be examined in the context of auditory priming (e.g., expectancy and SOA) as well as the examination of manipulations specific to perceptual asymmetries (e.g., use of lateralized primes). In addition, the present task could be implemented in the context of ERP or fMRI settings to produce a more detailed model of how the prime affects the top-down processes involved in the perceptual and response stages of the overall priming effect.

In the meantime, we will leave readers with what is, to our knowledge, the first demonstration of semantic priming linked with auditory asymmetries. Considering the established high reliability and validity of dichotic listening in this context, this initial finding holds much promise.

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Table 1

*Presented Pairs, Primes, and Response Choices Used in Experiment 1*

| Response choice | Presented pairs | Primes |
|---|---|---|
| den, ken, pen, ten | Ten, pen | Nine, paper |
| boat, coat, goat, tote | Coat, goat | Fur, sheep |
| big, dig, pig, rig | Dig, pig | Hole, cow |
| cage, gage, page, rage | Cage, page | Bird, book |
| boy, coy, roy, toy | Toy, boy | Ball, girl |

*Note:* Response choices are in the alphabetical order in which they appeared during the task. The left-right ear placement of each word in the presented pair was randomized to reflect the primed ear.

Table 2

*Presented Pairs, Primes, and Response Choices Used in Experiment 2*

| Response choice | Presented pair (target) | Prime |
|---|---|---|
| Cop, bop pop, top, | Cop, (top) | Bottom |
| Bail, pail, tail, rail, | Pail, (tail) | Wag |
| Bank, dank, rank, tank | (Bank), tank | Money |
| Bat, cat, rat, tat | (Cat), tat | kitten |
| Bug, pug, rug, tug | (Bug), tug | Insect |
| Den, ken, pen, ten | Den, (pen) | Ink |
| Cart, dart, part, tart | (Cart), tart | Wagon |
| Boat, coat, goat, tote | (Boat), coat | Ship |
| Die, pie, rye, tie | (Die), pie | Live |
| Care, dare, pear, tear | (Tear), pear | Rip |
| Bad, dad, pad, tad | (Bad), pad | Good |
| Bee, key, pea, tea | (Tea), bee | Coffee |
| Big, dig, pig, rig | Dig, (pig) | Hog |
| Bar, car, par, tar | (car), bar | Auto |
| Book, cook, rook, took | (cook), took | Stove |
| Cry, dry, pry, try | (cry), dry | Sad |

*Note:* Response choices are in the alphabetical order in which they appeared during the task. The left-right ear placement of each word in the presented pair was randomized to reflect the ear to which the prime related. For clarity, the prime “live” was pronounced as in “to live or die”.

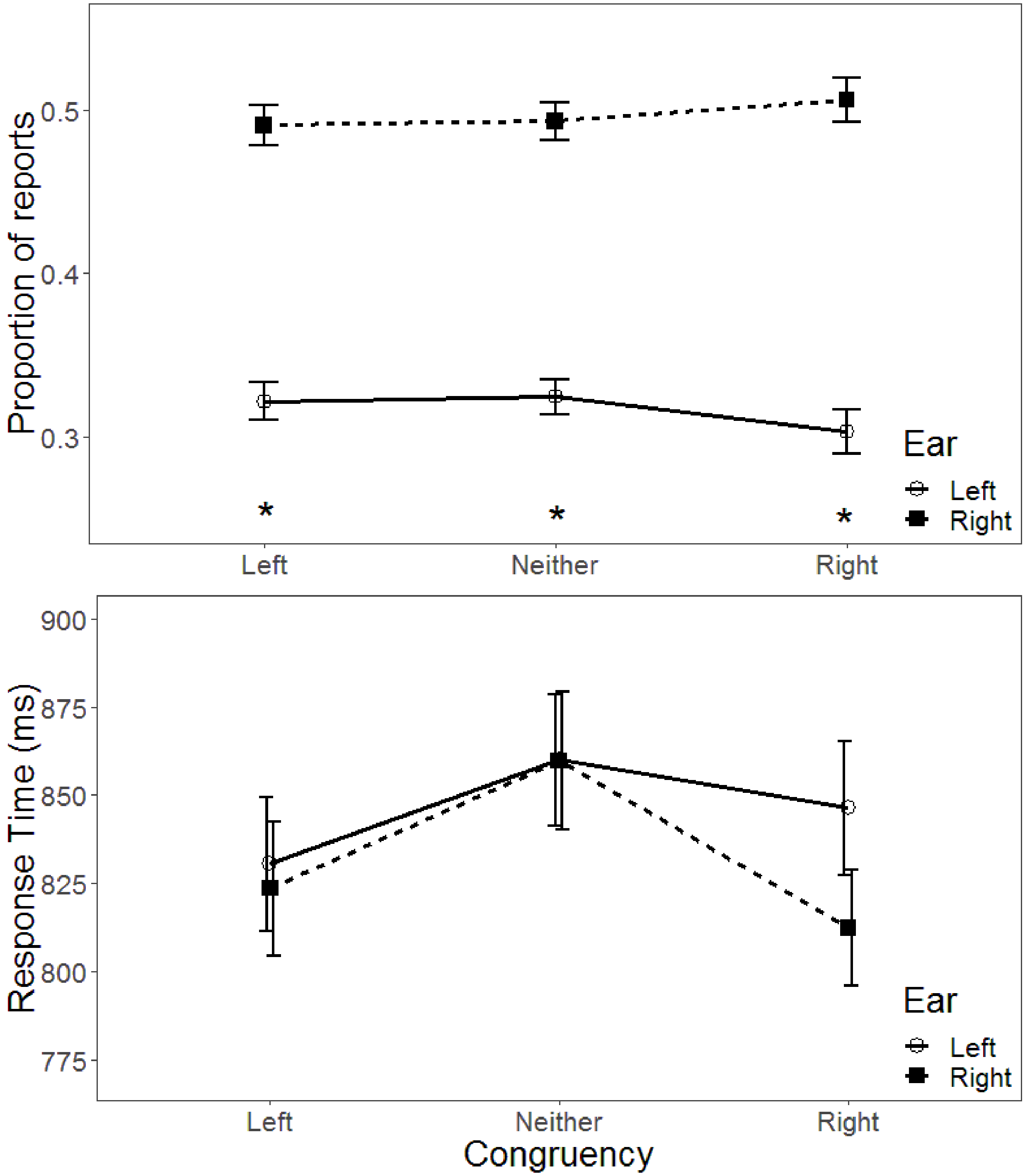


*Figure 1.* Mean number of reports (top) and response time (in ms; bottom) as a function of ear of report and prime relatedness in Experiment 1. Error bars represent the standard error of the mean adjusted for within-subject measurement (see Morey, 2008). An asterisk (*) appears above the congruency condition labels where the ear effect is significant with $p < .05$.

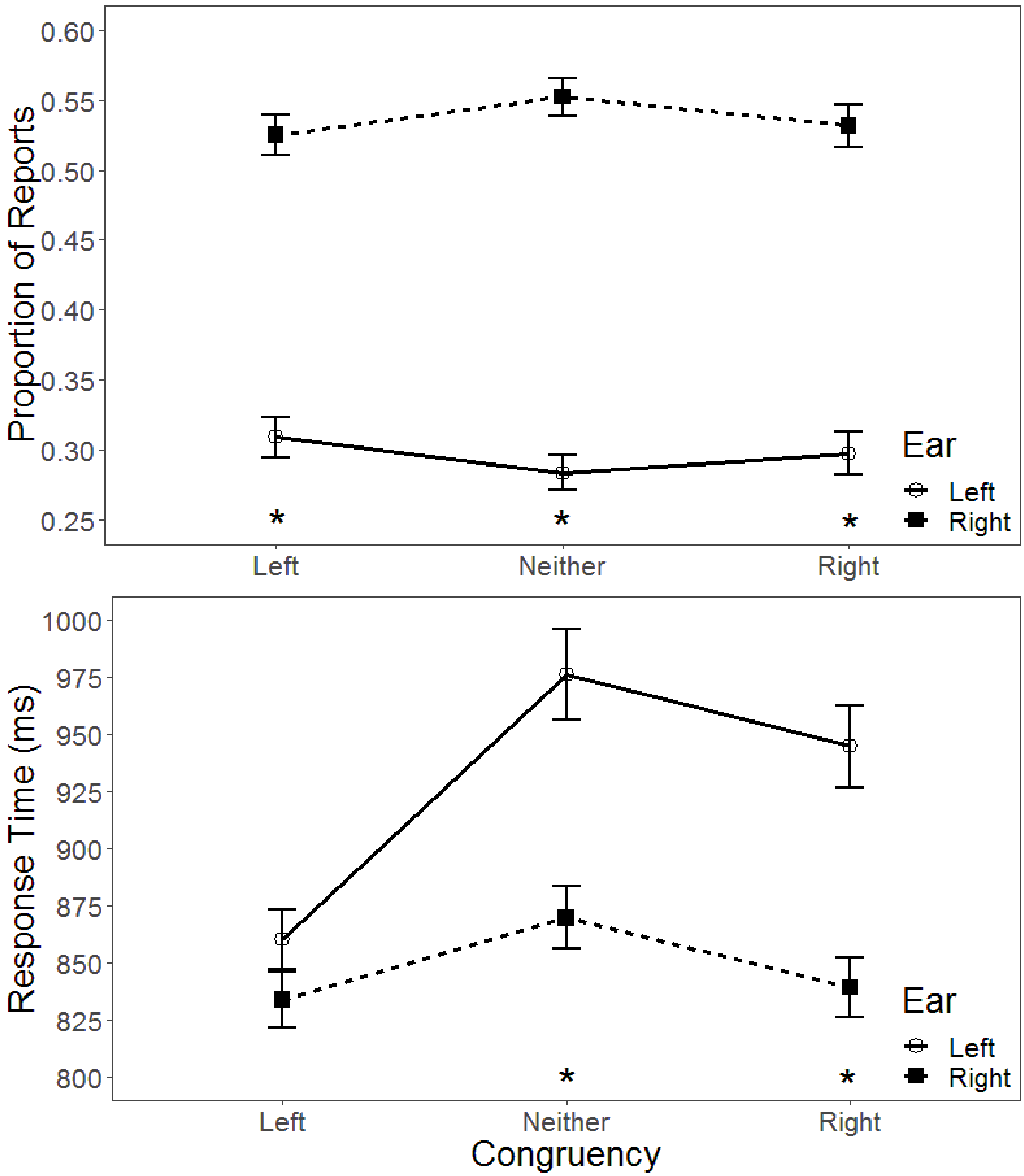


*Figure 2.* Mean number of reports (top) and response time (in ms; bottom) as a function of ear of report and prime relatedness in Experiment 2. Error bars represent the standard error of the mean adjusted for within-subject measurement (see Morey, 2008). An asterisk (*) appears above the congruency condition labels where the ear effect is significant with $p < .05$.

# Auditory semantic priming and the dichotic right ear advantage

**Voyer, Daniel; Hearn, Natalie**

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