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Priming inhibits the right ear advantage in dichotic listening: Implications for auditory laterality

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Abstract

The typical finding in dichotic listening with verbal stimuli is the right ear advantage (REA), indicating a left hemisphere processing superiority, thus making this an effective tool in studying hemispheric asymmetry. It has been shown that the amplitude of the REA can be modulated by instructions to direct attention to left or right side. The current study attempted to modulate the REA by changing the dichotic listening stimulus situation. In Experiment 1, a consonant vowel (CV) syllable prime was presented binaurally briefly before the dichotic stimuli (consisting of two CVs). The prime could be the same as either the left or right ear dichotic stimulus, or it could be a different stimulus. Participants were instructed to report the CV they heard best from the dichotic syllable pair. The traditional REA was found when the prime was different from both dichotic stimuli. When the prime matched the CV in the left half of the subsequent dichotic pair, the REA was increased, while if the prime matched the right half, the REA was reduced. In order to see at which perceptual stage the modulation takes place, in Experiment 2 the prime was visual, presented on a PC screen. The same effect was seen, although the modulation of the REA was weaker. We propose that the memory trace of the prime is a source of interference, and causes cognitive control of attention to inhibit recognition of stimuli similar to recent distractors. Based on previous studies we propose that this inhibition of attention is performed by prefrontal cortical areas. Similarities to the mechanisms involved in negative priming and implications for auditory laterality studies are pointed out.

Keywords: Perception; Attention; Inhibition; Hemispheric asymmetry; Language; Negative priming

Dichotic listening (DL) to consonant vowel (CV) syllables is one of the most frequently used techniques to study hemispheric asymmetry for speech sound processing (Bryden, 1988; Hugdahl, 1995; Springer & Deutsch, 1993). When using verbal stimuli, the typical finding is the so-called right ear advantage (REA), which means more correctly recalled items from the right ear than from left ear in a free recall situation (Hiscock, Cole, Benthall, Carlson, & Ricketts, 2000; Hugdahl, Helland, Faerevaag, Lyssand, & Asbjornsen, 1995). The REA is often explained by the sensory projections being more preponderant to the contralateral hemisphere, while language perception is lateralized to the left hemisphere, and it is thus a bottom-up influence on perception (Kimura, 1967; Sidtis, 1988; Sparks & Geschwind, 1968). However, as has been reported by several authors (e.g. Asbjornsen & Bryden, 1996; Bryden, Munhall, & Allard, 1983; Gadea, Gomez, & Espert, 2000; Hiscock & Stewart, 1984; Hugdahl & Andersson, 1986), the REA can be either increased or decreased by instructing the participant to explicitly focus attention only on the right or the left ear stimulus. This was termed the "forced-attention DL paradigm" by Hugdahl and Andersson (1986), and implies a top-down modulation of a bottom-up laterality effect.

A limitation of the forced-attention procedure is, however, that it does not allow for the study of how changing the attentional properties of the stimuli situation itself will affect the ear advantage. One potential way to manipulate the attentional properties of the dichotic stimuli is to let it be preceded by another stimulus. Such a manipulation could be understood as priming, that an additional stimulus (the prime) is presented before the stimulus to be processed (the probe), and is expected to facilitate (Jancke, 1994; Kinsbourne, 1970) or impede (Buchner & Mayr, 2004; Tipper, 1985) the processing of the probe stimulus. In the current study, a single CV syllable was presented immediately before the dichotic CV syllables in order to manipulate the

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attentional properties of the dichotic stimuli through priming. In half of the trials, the prime syllable matched one of the two dichotic syllables (either the right or left ear syllable). In the other half of the trials, the prime syllable was unrelated to the dichotic syllables. The prime stimulus was presented in both the auditory (Experiment 1) and visual (Experiment 2) modalities.

If the effect is excitatory, one would expect the representation of the syllable in the dichotic probe that has been primed to become more strongly activated than the representation of the syllable that has not been primed and thus be more frequently reported. On the other hand, if the effect is inhibitory, one would expect the primed syllable representation to be less activated compared to the syllable representation that was not primed. An inhibitory effect can be understood from an attention perspective, in the sense that the prime would constitute a distraction stimulus, and cognitive control attempts to divert attention away from the distracting stimulus (Tipper, 2001). Thus, an excitatory model would predict a stronger REA in the situation when the prime syllable matches the right ear probe syllable, and a weaker REA or left ear advantage (LEA) in the situation when the prime syllable matches the left ear probe syllable. In contrast, an inhibitory model would predict a weaker REA in the situation where the prime syllable matches the right ear probe syllable, and a stronger REA in the situation where the prime syllable matches the left ear probe syllable. Selective attention in the dichotic listening paradigm has previously been associated with prefrontal cortical areas (Thomsen, Rimol, Ersland, & Hugdahl, 2004), and the attention modulation in the current experiment is expected to be mediated by the same cortical region.

1. Experiment 1

1.1. Methods

1.1.1. Participants

There were 15 participants (six male, nine female), aged 22–30 years, who had Norwegian as first language, normal hearing, and had not suffered brain trauma. Twelve participants were right-handed and three were left-handed, as measured with the Edinburg Handedness Inventory (Oldfield, 1971). Both experiments were conducted in accordance with the ethical standards of the 1964 Declaration of Helsinki.

1.1.2. Stimuli

The prime and probe stimuli were the CV syllables /ba/, /da/, /ga/, /pa/, /ta/ and /ka/ pronounced by a Norwegian male voice, with a duration of 500 ms. A dichotic (probe) stimulus consisted of two different CV syllables presented simultaneously, one in each ear. All thirty CV combinations were used in randomized order. The prime stimulus was one syllable presented monaurally, and was either the same syllable as one of the two syllables in the following dichotic pair, or one of the remaining four syllables. Each syllable was digitized, and a standard PC running the E-prime programming platform (www.pstnet.com; Psychology Software Tools) was used for stimulus presentation and response collection. All stimuli were presented through a pair of Sony MDR-V5000J headphones.

1.1.3. Procedure

Each trial consisted of the monoaural prime stimulus, a 500 ms interval, the dichotic probe stimuli, and the response-screen. The response-screen was a clock-like display of all six possible CV syllables (syllable position counterbalanced between participants). The participant indicated which syllable he or she had heard by clicking with the mouse on the corresponding syllable on the PC-screen using the preferred hand. Although the hand used for clicking could have an activation effect in general, it cannot explain the specific effects on the different experimental conditions. There was an 800–1200 ms interval before the next trial began. See Fig. 1a for an overview of the trial procedure.

The prime and dichotic probe stimulus were combined in such a way that in 33% of the trials the prime syllable was the same as the left ear probe syllable ("prime-left" condition), in 33% of the trials the prime syllable was the same as the right ear probe ("prime-right" condition), and in 33% of the trials the prime was one of the remaining four CV syllables ("prime-neither" condition). There were a total of 168 trials in the experiment (56 trials in each of the three conditions), interspersed with four participant-timed intervals. As a control for allocation of attention, there were an additional 168 trials (randomized among the other trials) in which the participants were instructed to report the prime stimulus.[1] The instruction of which stimulus to report was given by showing the number "1" or "2" on the response-screen, so that at the time of presentation the participant had to allocate attention to both prime and probe. There were 11 training trials before the experiment proper, after which the participants were given the option to repeat the instructions or the training trials. In order to reduce working memory load, the participants were instructed to report only one stimulus on each dichotic probe trial, "the one they heard best or first". They were not instructed about the dichotic presentation mode, i.e. that there were two different syllables presented on each trial, or that the prime in some cases match the prime.

1.2. Results

No sex-differences were found in Experiment 1, so this factor has been collapsed. Participants were close to 100% correct when asked to report the prime stimulus. This indicates that the prime was perceived and paid attention to. The data from this control condition were not analyzed further.

Responses from the main task were categorized according to if they matched the left ear CV syllable (left ear responses, LER) or the right ear CV syllable (right ear responses, RER) of the dichotic probe. There were overall few errors (where the response matched neither left nor right probe stimulus), and there were no significant differences in the number of errors between conditions. A repeated measures 3×2 analysis of variance (ANOVA), with priming condition ("prime-left", "prime-right", "prime-neither") × ear (LER, RER) was performed on the data. All repeated measures were corrected for violations of the assumption of data sphericity using the Greenhouse and Geisser correction (Greenhouse & Geisser, 1959; Vasey & Thayer, 1987). There were no significant main-effects, but a significant interaction between priming and ear response ($F(2, 36) = 28.50$, $p = 0.000003$, $\varepsilon = 0.68$). See Fig. 2. The interaction was followed-up with Fisher's LSD test (because of directed hypotheses), which showed a significant REA in the "prime-neither" and "prime-left" conditions, and a significant LEA in the "prime-right" condition (all $p < 0.05$). No effect was seen on reaction times. However, reaction times were long (average of 1847 ms across conditions), and any effect here may have been hidden by the visual search for the response alternative.

[1] For the attention control task trials, the distribution of stimulus combinations was 66% "prime-neither", 17.5% "prime-left" stimulus and 17.5% "prime-right". This was done in order to have half of the trials in the experiment overall primed, while half were unprimed. This should control for participants learning the predictive value of the prime.

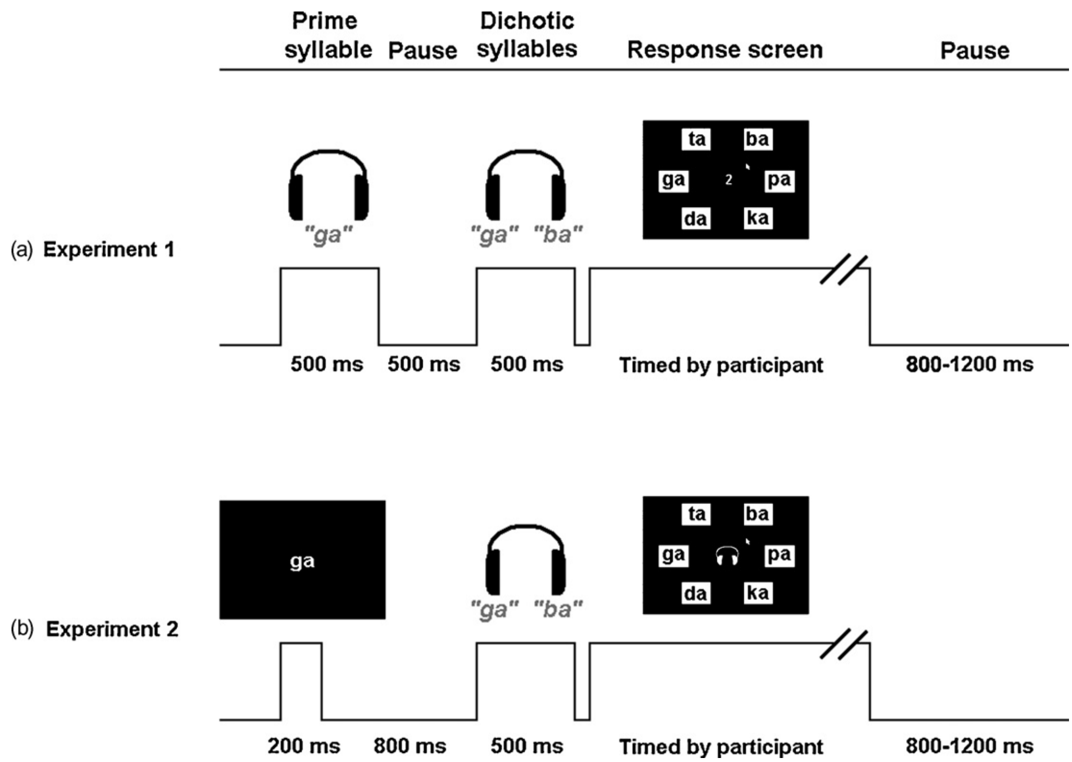

Fig. 1. For each trial, a 500 ms single syllable was presented equally to both ears (Experiment 1) or as text on screen for 200 ms (Experiment 2). After a 1000 ms stimulus onset asynchrony (SOA) the dichotic stimuli were presented, which consisted of one 500 ms syllable to each ear. Six response boxes were displayed on-screen until a response was selected by a mouse click. There was an 800–1200 ms intertrial interval (ITI).

1.3. Discussion

Experiment 1 showed a REA in the "prime-neither" condition. This indicates that hearing a monaural syllable before the dichotic syllables did not affect the traditional REA effect when the prime syllable was not related to the probe. When the prime syllable was the same as the left ear probe stimulus, the REA was increased. The effect consisted of both decreased number of responses to the right ear stimulus and increased number of responses to the left ear stimulus relative to the "prime-neither" condition. Similarly, the "prime-right" produced a LEA, also by decreasing responses to the left ear stimulus and increasing responses to the right ear stimulus. Thus, both inhibiting responses to the repeated syllable and facilitating responses to the other syllable in the dichotic pair were seen.

Experiment 1 showed that an auditory prime affects dichotic listening. In order to investigate whether this effect occurs early or late in the perceptual process, Experiment 2 was performed, which had the same task as Experiment 1, but used a visual prime.

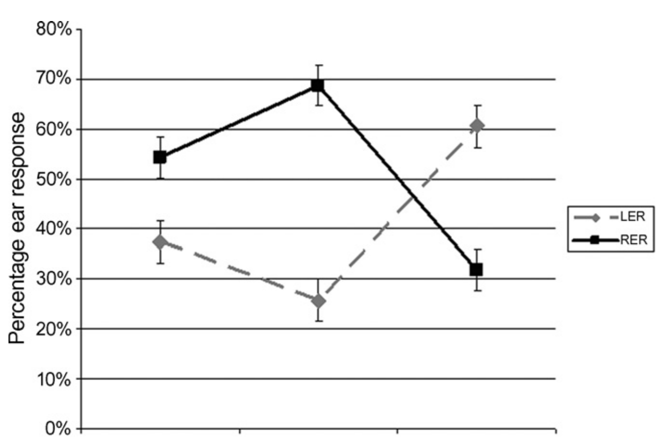

Fig. 2. Mean correct responses split for right and left ear dichotic stimulus, and the three priming conditions for Experiment 1 (dichotic listening with auditory prime). RER, right ear response; LER, left ear response. The figure shows standard error of the mean. See Section 1.1 for further details.

2. Experiment 2

2.1. Methods

2.1.1. Participants

There were 23 participants in Experiment 2, 8 male and 15 female. They fulfilled the same inclusion criteria as in Experiment 1. The sample in Experiment 2 was different from the sample in Experiment 1.

2.1.2. Stimuli and procedure

The dichotic CV syllables were the same as in Experiment 1, however, the prime stimulus was changed to text presented for 200 ms in the middle of the PC-screen. In order to have equal onset-to-onset stimulus duration and equal trial length as in Experiment 1, the interval between the prime and probe stimuli was extended to 800 ms. In all other respects the procedure was identical to the procedure in Experiment 1. As in Experiment 1, an attention control task where participants were to report the prime instead of the probe was included, and which task to perform was indicated by a stylized picture of a computer screen or of a pair of headphones on the response-screen. See Fig. 1b for an overview of the trial procedure.

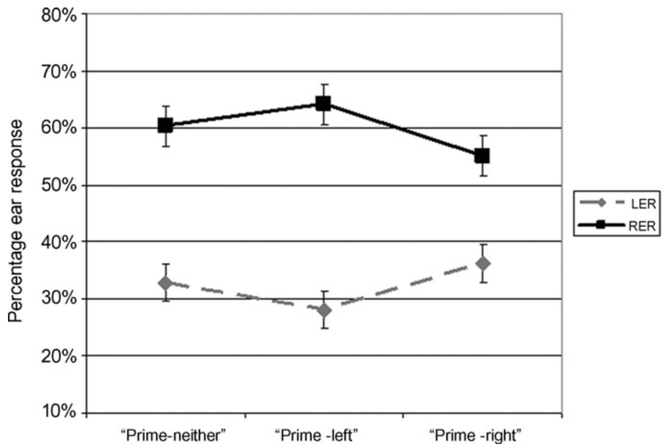

Fig. 3. Mean correct responses split for right and left ear dichotic stimulus, and the three priming conditions for Experiment 2 (dichotic listening with visual prime). RER, right ear response; LER, left ear response. The figure shows standard error of the mean. See Section 2.1 for further details.

2.2. Results

No sex-differences were found in Experiment 2, so this factor has been collapsed. The results from the attention control task showed performance close to 100%. This indicated that the visual stimuli were indeed perceived, and no control for gaze or attention seemed necessary. As in Experiment 1, there were few errors, and the number of errors did not vary between conditions.

A repeated measures 3 × 2 ANOVA was performed with the same conditions as in Experiment 1. This showed a significant main-effect of ear ($F(1, 21) = 25.66$, $p = 0.00005$). Follow-up tests with Fischer's LSD revealed a significant REA in all three prime conditions. There was moreover a significant interaction effect between ear and prime condition ($F(2, 42) = 3.79$, $p = 0.047$, $\varepsilon = 0.72$) with the same direction of difference as in Experiment 1, i.e. REA in the "prime-neither" condition, a stronger REA in the "prime-left" condition, and a weaker REA in the "prime-right" condition when tested with Fischer's LSD test (all $p < 0.05$). See Fig. 3. As in Experiment 1, no effect was seen on RT data.

2.3. Discussion

The results in Experiment 2 were in the same direction as in Experiment 1, i.e. a REA in the "prime-neither" condition, an increase in REA in the "prime-left" condition, and a reduction of the REA (although not switching to a LEA) in the "prime-right" condition. This indicates that the priming effect in Experiment 1 was not caused by a perceptual bottom-up effect alone, since a prime stimulus presented in the visual modality produced similar results as the auditory prime (Driver & Tipper, 1988; Greenwald, 1972). Presumably, the visual prime activated a modality-independent representation, which had an effect on the processing of subsequent auditory stimuli, and favored the recognition of the syllable that was not included in the prime stimulus. The fact that there is a REA across conditions in Experiment 2, but not in Experiment 1, indicates that the visual prime is less effective than the auditory prime in modulating the bottom-up REA.

3. General discussion

The results can be accounted for by reference to a top-down model of how cognitive control of attention interacts with perception (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Egner & Hirsch, 2005; Hommel, Ridderinkhof, & Theeuwes, 2002). When the decision is made about which syllable was presented in the dichotic syllable pair, the trace of the prime syllable is present in working memory, which presents a potential for interference. This is a state of conflicting information, and in order to resolve the conflict, attention is focused to facilitate perception of novel stimuli and inhibit the relevance of previously perceived stimuli. When the previously perceived stimulus matches part of the dichotic stimuli (in the "prime-left" and "prime-right" conditions), the cognitive control of attention inhibits the representation of the prime and thus also the primed half of the dichotic stimulus, having the effect that the unprimed syllable is reported rather than the primed one. This could be thought of as suppressing the stimulus on a perceptual level or by preventing access at an executive function level. In Experiment 1 the stimulus that was inhibited mapped directly onto half of the dichotic stimulus, while in Experiment 2 the stimulus being inhibited was only relevant when the information was transferred from a phonetic to an orthographic level of processing. This may explain why the effect of the prime to bias information processing appeared stronger in Experiment 1 than in Experiment 2.

The explanation offered here is roughly similar to the distractor inhibition account of the negative priming effect. Negative priming studies have shown that responses to recently ignored stimuli are slower or more error-prone than responses to control stimuli (Neill, 1977; Tipper, 1985). This has been explained by an inhibitory attentional selection mechanism that suppresses competing distractor input and thus prevents access of ignored objects (Houghton & Tipper, 1996; May, Kane, & Hasher, 1995; Tipper, 2001; see however Neill, Valdes, Terry, & Gorfein, 1992, for an alternative account).

The fact that the priming effect was present in both the auditory and the visual modality, although stronger in the auditory modality, could indicate that the effect is present both at early and late perceptual stages, but to different extents. This resonates with the view of the perceptual and attentional processes in dichotic listening presented by Hugdahl (Hugdahl, 2003; Hugdahl et al., 2003), in which cognitive manipulations have effects on both "stimulus-driven", or automatic information processing, and "instruction-driven", or controlled information processing. Also relevant is the two-stage model of dichotic listening (Hiscock, Inch, & Ewing, 2005), where the first stage is a rapid automatic processing of input, in which manipulations have an effect on the accuracy of detecting a stimulus. The second stage is a controlled processing stage, which is slow, effortful, capacity limited and participant regulated, in which manipulations have an effect on the localization of stimuli.

Regardless of the causal mechanisms at work, one can ask why speech perception should be subject to such a priming effect in the first place. If language perception is a sequential recognition task, then the object is to identify and parse discreet language components of varying complexity, and subsequently move on to the next component, in order to finally structure the components into an intelligible message. In a degraded environment, it would make sense for the perceptual system to automatically focus on novel language components, recognize them, and once recognized disregard them and start processing the next component. A mechanism to inhibit attention to already recognized speech elements could develop through evolutionary pressures or within individual language acquisition. Such an attentional process would involve a mechanism for conflict recognition, which is often associated with anterior cingulated cortex, and a mechanism for inhibiting attention to certain stimuli, often associated with medial prefrontal areas (Botvinick et al., 2001; Egner & Hirsch, 2005; Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004).

The current two experiments show that priming with a monaural auditory and visual stimulus modulates the response to the dichotic stimuli that follow. This effect may be analogous to the modulation seen in forced-attention dichotic listening (Asbjornsen, Hugdahl, & Bryden, 1992; Hugdahl & Andersson, 1986; Mondor & Bryden, 1991), where the participant is instructed to attend the right or left ear for several consecutive trials, working through separate cognitive mechanisms. However, while the attention instruction has its effect through an explicit and intentional focusing of attention, presenting a syllable before the dichotic syllables appears to bias attention implicitly in order to resolve cognitive conflict. Further research on this effect may provide knowledge about the mechanisms involved in speech lateralization and attention modulation. In addition, the prime manipulation may be a methodological alternative to the forced-attention dichotic listening paradigm, since it allows for the study of endogenous attention-shifts in contrast to the instruction-driven exogenous attention-shifts (Posner & Petersen, 1990).

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