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Endogenous and Exogenous Control of Attention in Dichotic Listening

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Dichotic listening to verbal stimuli results in a right ear advantage (REA), indicating a left hemisphere processing superiority. The magnitude of the REA can be modulated by instructions to direct attention to the left or right ear stimulus. A previous study from our laboratory showed that presenting a prime syllable before the presentation of the dichotic syllables increases reports of the nonprimed syllable, apparently a negative priming effect that inhibits attention to the distracting prime representation. The present study combined attention instruction and priming, making up a 3 × 3 factorial design. The prime stimulus was a single consonant–vowel syllable presented binaurally just before onset of the dichotic consonant–vowel syllables. Results showed that both instructions and priming manipulations had an effect on which dichotic stimulus was selected. There was also a significant interaction between attention instruction and priming manipulation, indicating that the mechanism for instructed attention and the mechanism for negative priming work on the same level of processing.

Keywords: attention, inhibition, dichotic listening, negative priming

In dichotic listening experiments with consonant–vowel (CV) syllables, a right ear advantage (REA) is a typical finding that is interpreted as indicating a left hemisphere processing superiority for speech syllables (Bryden, 1988). Though a stable and robust empirical effect, the REA can be modulated by instructed attention (Asbjornsen & Bryden, 1996; Bryden, Munhall, & Allard, 1983; Gadea, Gomez, & Espert, 2000; Hiscock & Stewart, 1984; Hugdahl & Andersson, 1986; Hugdahl, Bodner, Weiss, & Benke, 2003). By focusing attention on the right or left ear, the REA can be modulated to either increase or decrease, respectively. This could be theoretically construed as a top-down modulation effect through selective deployment of attention to the right or left side in auditory space. The instructed attention effect has been seen to be instantiated by prefrontal cortical areas (Thomsen, Rimol, Ersland, & Hugdahl, 2004). A previous study in our laboratory (Sætrevik & Hugdahl, 2007) showed that priming with a binaurally presented CV syllable before the presentation of the dichotic stimuli, where the prime was the same as either the right or the left ear dichotic stimulus, decreased the number of reports of the same syllable in the following dichotic pair. The behavioral tendency to suppress responses to primed dichotic stimuli can be accounted for by both top-down and bottom-up models, such as pop-out effects. A possible explanation for the effect may be that the distracting prime representation is inhibited, and thus at the time of the dichotic presentation the syllable representation that is not inhibited is more likely to be attended. The experiment also showed that the effect was present when using a visual prime (although a weaker effect than when using an auditory prime), with the prime syllable presented on a PC screen just before the dichotic auditory syllables. The fact that the negative priming effect was carried across sensory modalities appears to support a top-down modulating mechanism, rather than a bottom-up stimulus-driven mechanism, although the latter cannot be ruled out.

The effect observed by Sætrevik and Hugdahl (2007) was interpreted as comparable to negative priming (Houghton & Tipper, 1996; May, Kane, & Hasher, 1995; Tipper, 2001). In a typical auditory negative priming experiment, participants are asked to attend to the left or right ear stimulus on consecutive trials. This often results in prolonged response latency or more errors when the currently attended stimulus was the unattended stimulus on the previous trial. One account for this is that the allocation of attention to inhibit the distracting stimulus on the current trial carries over when the same stimulus becomes an attended stimulus on the next trial (Buchner & Mayr, 2004). Negative priming is believed to be controlled from the same prefrontal cortical areas (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Egner & Hirsch, 2005; Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004) as observed in the instructed attention dichotic listening paradigm previously studied by Hugdahl and colleagues (Hugdahl et al., 2000; Thomsen et al., 2004).

Thus, previous results with the CV-syllable dichotic listening paradigm indicate that there are two possible manipulations of the REA in dichotic listening: an instruction-effect, as seen in numerous other studies (see, e.g., Hugdahl et al., 2003; Jancke, 1994; O'Leary et al., 1997), and a stimulus-driven negative priming effect. Both effects appear to work through a top-down mechanism, as reported by Sætrevik and Hugdahl (2007). We postulate that instructed attention works by selecting in hemispace, whereas priming works by selecting stimulus representation. This could be seen as analogous to Posner's (1980) visual cuing studies, in which visual attention shifts are directed by central or peripheral cues. Whereas a centrally placed cue directs attention through a symbol that causes a conscious decision to shift attention (endogenous

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attention shift), a peripherally placed cue automatically shifts attention in hemispace (exogenous attention shift). Translated to the dichotic listening situation, instructed attention may be said to represent an endogenous shift of attention in auditory hemispace, whereas the priming condition represents an exogenous orienting toward the nonrepeated stimuli.

The current study combined both manipulations in the same experiment, where the instructed attention manipulation had three conditions (no instructed attention, focus on the right ear stimulus, and focus on the left ear stimulus), each of which were tested with either no relevant prime, a prime that matches left ear syllable, or a prime that matches right ear syllable, combined to create a 3 × 3 factorial design. It was expected that both instructed attention and priming should have an effect on the REA in dichotic listening. If the negative priming effect previously observed by Sætrevik and Hugdahl (2007) was caused by a bottom-up perceptual mechanism whereas the instruction effect was a top-down attentional mechanism, then the instructed attention and priming manipulations would be predicted to have additive and independent effects. This would be so because the mechanisms have effects on different areas in the progression from perception to response selection. On the other hand, if the mechanisms share cognitive resources, an interaction between priming and attention instruction would be expected. Because an instruction effect necessarily works top-down, this would support the former assumption that the negative priming effect in dichotic listening is due to attention inhibition.

Method

Participants

Twenty undergraduate psychology students (12 women, 8 men) aged 22 to 27 years participated in the experiment. They all had Norwegian as their first language and were right-handed, as measured with the Edinburgh Handedness Inventory (Oldfield, 1971). The experiment was conducted in accordance with the ethical standards of the Declaration of Helsinki (World Medical Association, 1964).

Stimuli

The prime and dichotic stimuli were the CV syllables /ba/, /da/, /ga/, /pa/, /ta/, and /ka/ pronounced by a Norwegian male voice, each with a duration of 450–500 ms. Each syllable was digitized and presented in Sony MDR–V5000J headphones via a standard PC running the E-prime programming platform (Psychology Software Tools, 2006). The PC also recorded the participants' responses. The prime stimulus was a single syllable presented binaurally to the participants just before the presentation of the dichotic syllables. The dichotic stimuli consisted of two different syllables that were presented simultaneously, one in each ear. Left and right sound channels were synchronized using the Soundswell software (Ternström, 2000) and set to the initial energy release in the consonant segment of the syllables. All 30 unique combinations of the six CV syllables were used in randomized order.

Procedure

Each trial consisted of the binaural prime syllable, a 500-ms interval, the dichotic syllable pair, and a response screen. The response screen was a clocklike display of all six CV syllables (syllable position on a screen counterbalanced between participants). The participants moved the computer mouse with the right hand to one of the displayed syllables and clicked the mouse button to make a response. There was no maximal response time, and after a response was made, there was an 800–1,150-ms silent pause before the next trial started. There were two independent variables, priming and attention instructions, each with three levels. For the instructed attention variable, the different instructions were written on the computer screen at the onset of each of the three blocks of trials. In the nonforced (NF) instructed condition the participant was asked to report the probe syllable heard best. In the forced-right (FR) instruction condition the participant was asked to ignore the left ear dichotic syllable and report only the right ear syllable, and vice versa for the forced-left (FL) instruction condition. The priming conditions were defined by how the prime syllable matched the dichotic syllables; in the prime-left condition the prime was the same as the left ear syllable in the succeeding dichotic presentation. In the prime-right condition, the prime was the same as the succeeding right ear syllable. In the prime-neither condition there was no match between prime and probe syllable (i.e., one of the four other CV syllables was used as the prime). The participants were instructed to ignore the prime syllable and to report the dichotic syllable that they heard best on each trial. The priming conditions were randomized across the trials, with a 50% prime-neither, 25% prime-left, and 25% prime-right distribution of trials. This distribution was used to prevent the prime information from being used to predict the dichotic stimuli.

The experiment consisted of a short training phase and three blocks of trials, corresponding to the three different instruction conditions. The first trial block was always the NF condition, whereas the second and third trial block conditions were either first an FR block and then an FL block or first an FL block and then an FR block (counterbalanced between participants). The priming conditions were randomized within the three blocks. There were a total of 240 trials, and the experiment took approximately 20 min.

Data Analysis

To control whether there was an overall REA effect and an overall effect of priming on responses, *t* tests were done. Responses were classified according to whether they matched the right-ear (right ear responded, or RER) or the left-ear (left ear responded, or LER) stimulus or none (error). A laterality index was calculated according to the formula [(RER – LER)/(RER + LER) × 100]. The result is a number between –100 and 100, indicating the strength of the REA, where a positive laterality index indicates an REA in responding, whereas a negative laterality index indicates a left ear advantage (Hugdahl, 2003). The laterality index for each condition in the design matrix was submitted to a 3 × 3 repeated measures analysis of variance (ANOVA; Attention Condition × Priming Condition), with Tukey's honestly significant difference (HSD) test used for follow-up testing.

The laterality index is not well suited for analyzing priming effects, because a leftward or rightward bias could indicate either positive or negative priming effects, depending on which of the dichotic syllables the prime matches on the current trial. To avoid this, we recalculated scores according to whether the response matched the prime or not. A *priming index* was calculated on the basis of this formula: [(responded with the primed syllable – responded with the not primed syllable)/(responded with the primed syllable + responded with the not primed syllable) × 100]. A positive priming index indicated a positive priming effect, that is, the dichotic syllable that was primed had an increased probability of being selected. A negative priming index indicated a negative priming effect, that is, the primed dichotic syllable had a decreased probability of being selected. The priming index for each condition was submitted to a 3 × 2 repeated measures ANOVA (Attention Condition × Priming Direction, omitting the prime-neither condition), with Tukey's HSD test used for follow-up testing. All repeated measures with more than 1 degree of freedom in the numerator were corrected for violations of the assumption of data sphericity using the Greenhouse and Geisser correction procedure (Greenhouse & Geisser, 1959; Vasey & Thayer, 1987).

Results

To test for the existence of an overall REA in the data matrix, we computed a two-sample t test for number of RER versus LER results, collapsed over experimental conditions. This showed a significant REA, $t(19) = 2.61$, $p < .05$, Cohen's $d = 1.14$. To test for the existence of a general negative priming effect, a two-sample t test was computed for the number of trials that show a positive priming effect versus the number of trials that show a negative priming effect, collapsed over experimental conditions and omitting the prime-neither condition. This showed an overall negative priming effect, $t(19) = -2.22$, $p < .05$, Cohen's $d = -0.95$. There were no significant effects for error responses or for any differences between males and females. The mean percentage of LER and RER answers and standard errors (*SE*s) are shown in Figure 1.

The 3 × 3 repeated measures laterality index ANOVA showed significant main effects of attention instruction, $F(2, 38) = 90.86$, $p < .001$, $\varepsilon = 0.78$, $f^2 = 3$, and of priming, $F(2, 38) = 4.44$, $p < .05$, $\varepsilon = 0.76$, $f^2 = .12$, with no significant interaction between the two variables. As can be seen in Figure 2, the REA was increased in the FR and decreased in the FL instruction condition compared with the NF condition. Moreover, the REA was increased in the prime-left condition and decreased in the prime-right condition, compared with the prime-neither condition. A Tukey's HSD-test showed that the instruction effect was significant at $p < .05$ for all comparisons among the means, whereas the priming effect was significant only in the prime-left and prime-right comparisons.

Figure 3 shows priming index scores, with positive priming effects as positive values and negative priming effects as negative values. The 3 × 2 repeated measures priming index ANOVA showed no significant main effects. This indicates that the effect observed in the priming t test was independent of both the direction of instructed attention and whether the prime stimulus matched the left or right ear stimulus. There was, however, a significant interaction between instruction and priming, $F(2, 38) = 78.58$, $p < .001$, $\varepsilon = 0.79$, $f^2 = 1.29$. An inspection of Figure 3 reveals that positive priming effects are seen when the prime matches the stimulus on the side that has attention directed to it. Negative priming effects are seen when attention is not directed and when the prime matches the opposite side from where the attention is directed. Tukey's HSD test showed that these

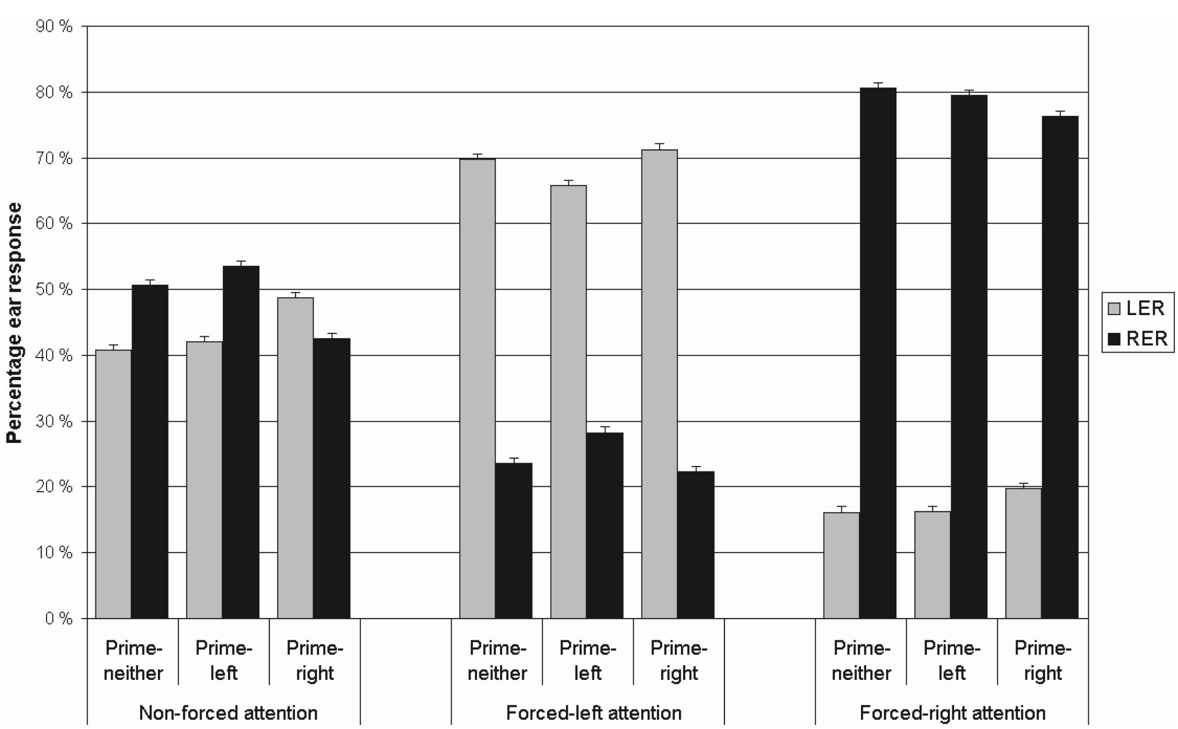

Figure 1. Percentage of correct left and right ear responses, with standard errors, for the instruction and priming conditions. LER = left ear responded; RER = right ear responded.

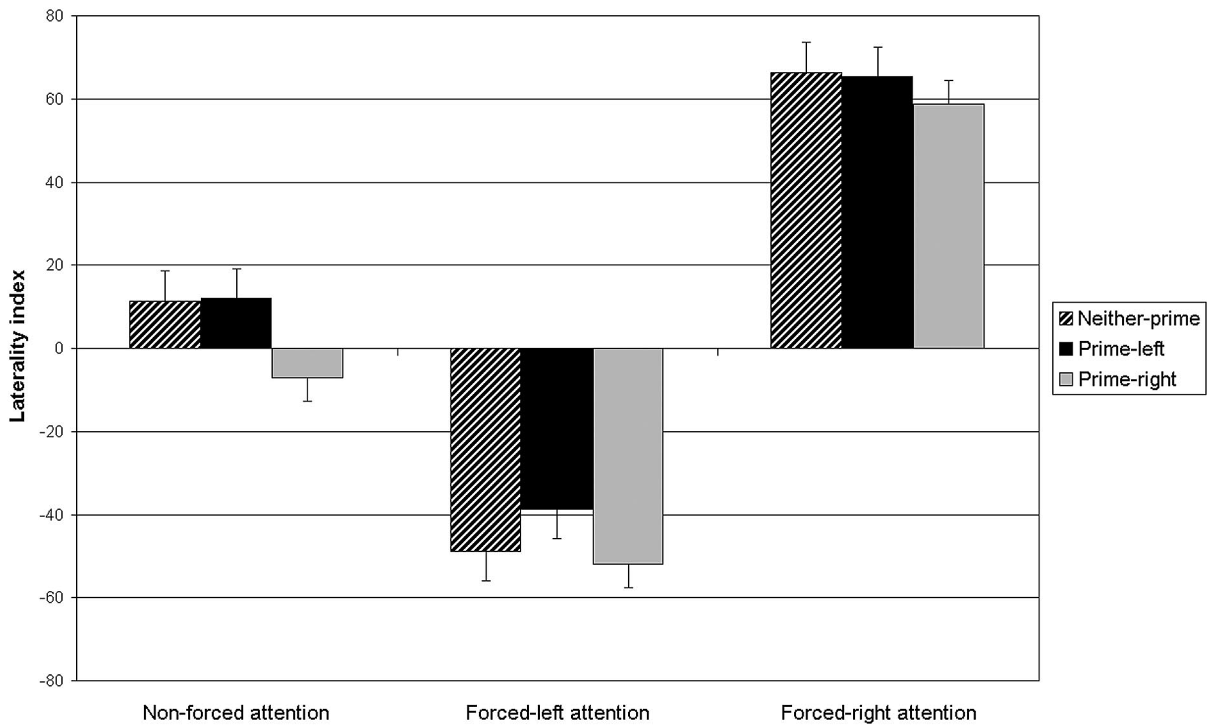

Figure 2. Laterality index scores, with standard errors, for the instruction and priming conditions.

comparisons (between FL prime-right vs. prime-left and between FR prime-left vs. prime-right) were significant at $p < .05$.

Discussion

The current experiment attempted to modulate the dichotic listening REA by using two types of experimental manipulation: one that initiates a conscious decision to shift attention in auditory hemispace and one that uses an external cue to direct responses to the stimuli regardless of position in right or left auditory hemispace. The results showed an overall REA, validating the expected bottom-up effect of a left hemisphere processing superiority for dichotic presentations of CV syllables. The results also showed an overall negative priming effect, which resulted in decreased reporting of the primed syllable, replicating the results seen in a previous study (Sætrevik & Hugdahl, 2007). Analyzing the data with regard to laterality shows that whether the left or right syllable of the dichotic pair was reported is influenced by both attention instructions and priming but shows no interaction between the two. Thus, instruction to attend to the right ear stimulus increased the REA, and instruction to attend to the left ear stimulus decreased the REA, as seen in numerous previous studies (Asbjornsen & Bryden, 1996; Bryden et al., 1983; Gadea et al., 2000; Hiscock & Stewart, 1984; Hugdahl & Andersson, 1986; Hugdahl et al., 2003). Similarly, priming the left ear stimulus increased the REA, whereas priming the right ear stimulus decreased the REA.

Analyzing the data with regard to whether responses showed priming revealed no significant main effects. This indicates that the overall decrease in reports of primed information was equally strong regardless of the direction of the instructions (attend left or attend right) and regardless of the direction of the priming (prime matches left or right dichotic syllable). An analysis of the priming index scores showed that the overall effect of negative priming was present only on trials where attention was not directed at the primed dichotic syllable. Furthermore, the fact that there was an interaction between the two experimental manipulations indicates that the underlying mechanisms may share a common stage of processing. Because the instruction effect can be regarded as a top-down modulation effect, shared resources are likely to be at higher cognitive levels of processing, that is, exerting a top-down effect on perception and/or response selection. If the priming had been caused by a bottom-up mechanism independent of attention, the two types of manipulation would have additive effects and would not have shown an interaction-effect when examining the priming index. Thus, both the experimental effects seen in the current experiment should correspond to neuronal activation in prefrontal cortical areas, rather than in temporal perceptual areas, following previous positron emission tomography and functional magnetic resonance imaging studies of the instructed attention effect in dichotic listening (Hugdahl et al., 2000; Thomsen et al., 2004).

In the study by Sætrevik and Hugdahl (2007), the negative priming effect in dichotic listening was explained as inhibition of the primed syllable. The explanation for this was that the memory trace of the prime syllable is still active at the time of arrival of the dichotic stimuli and would therefore create a source of distraction. Attention to the potentially distracting prime syllable representation is inhibited, and if one of the dichotic syllables presented immediately after the prime stimulus matches, it is less likely to be attended and reported. This explanation is similar to a distracter inhibition account of negative priming, in which an inhibitory

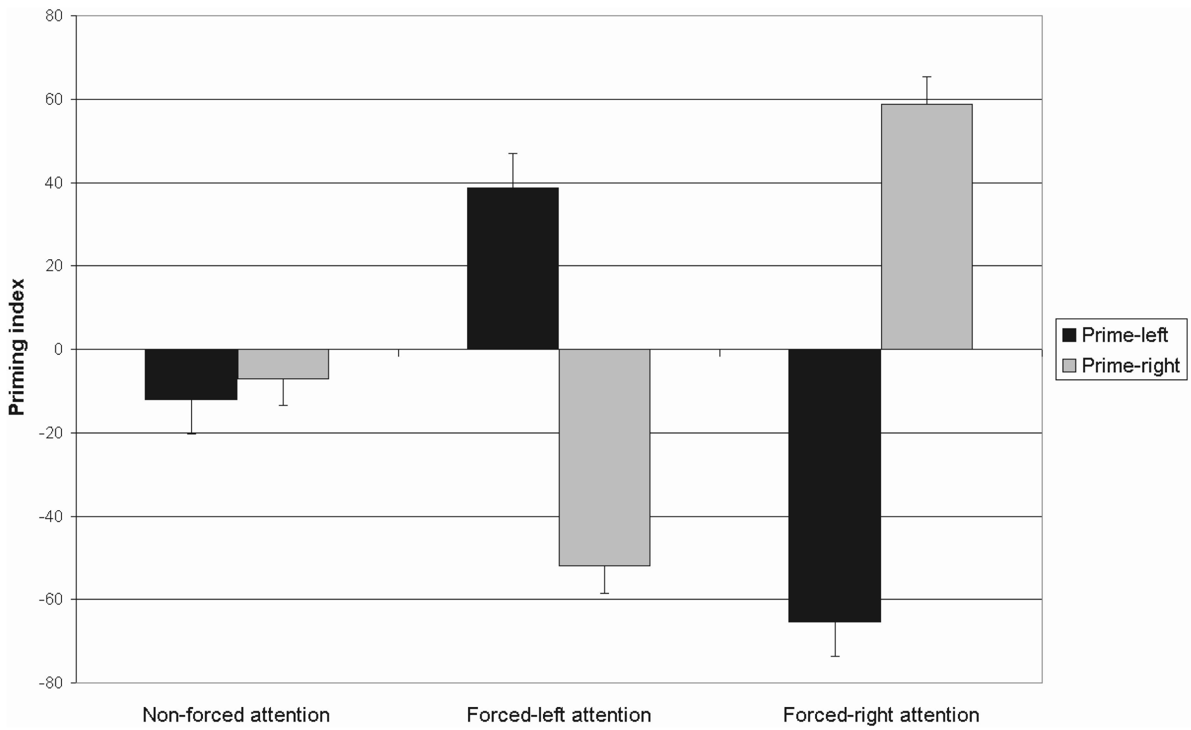

Figure 3. Priming index scores, with standard errors, for the instruction condition and for the prime-left versus prime-right condition.

attentional selection mechanism suppresses competing distracter stimulus input and thus prevents access of ignored objects (Houghton & Tipper, 1996; May et al., 1995; Tipper, 2001; see however Neill, Valdes, Terry, & Gorfein, 1992, for an alternative account). 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). Negative priming is regarded as a top-down mechanism, as opposed to positive priming, which is typically regarded as a bottom-up mechanism that works by facilitating perception of repeated stimuli (Schacter & Buckner, 1998). In the current study, there was no direct control of whether the participants attended the prime stimulus; in fact, the participants were instructed to ignore the prime. However, in the previous study by Sætrevik and Hugdahl (2007), attention was controlled for, and the results showed the same effect of priming as in the present study. The fact that the participants did not explicitly attend the prime does not contradict the possibility that the prime was actively inhibited.

In the present study, responses to the dichotic listening test were modulated by two different experimental manipulations: attention instructions and stimulus priming. The former reflects explicit volitional control of attention, whereas the latter reflects implicit automatic control of attention. This is analogous to the concepts of endogenous and exogenous attention for the study of visual attention (Klein, 2004; Posner, 2004), introduced in the cuing paradigm for shifts of visual attention (Posner, 1980; Posner & Petersen, 1990). By this we mean that attention can be endogenously shifted in hemispace by an internalized semantic instruction without the presentation of a lateralized cue, or attention can be exogenously shifted by the presentation of an external cue that has a different relationship to the left than to the right target stimuli. Another similarity is that whereas an instructed attention effect is subject to motivational and vigilance factors, a priming effect appears to happen automatically and outside of consciousness. The significant interaction between direction of attention and direction of priming on whether a positive or negative priming effect is seen could indicate that the mechanisms behind the attention effect and the negative priming effect have at least one common stage of processing. Thus, the current study supports the hypothesis based on a previous study (Sætrevik & Hugdahl, 2007) claiming that negative priming in dichotic listening could be caused by a top-down mechanism. Combining these two approaches to attention control may be a way to study attention deficits in clinical populations. For example, patients who fail to comply with directed attention instructions may still show an attention modulation effect as a result of priming. This could be the case for ADHD children or schizophrenia patients, both of whom show impaired prefrontal executive deficits (Hiscock, Kinsbourne, Caplan, & Swanson, 1979; Pearson, Lane, & Swanson, 1991).

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