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Research paper

The influence of memory and attention on the ear advantage in dichotic listening

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ABSTRACT

The role of memory retention and attentional control on hemispheric asymmetry was investigated using a verbal dichotic listening paradigm, with the consonant–vowel syllables (/ba/,/da/,/ga/,/ka/,/pa/and/ta/), while manipulating the focus of attention and the time interval between stimulus and response. Attention was manipulated using three conditions: non-forced (NF), forced left (FL) and forced right (FR) attention. Memory involvement was varied using four delays (0, 1, 3 and 4 s) between stimulus presentation and response. Results showed a significant right ear advantage (REA) in the NF condition and an increased REA in the FR condition. A left ear advantage (LEA) was found in FL condition. The REA increased significantly in the NF attention condition at the 3-s compared to the 0-s delay and in the FR condition at the 1-s compared to the 0-s delay. No modulation of the left ear advantage was observed in the FL condition. These results are discussed in terms of an interaction between attentional processes and memory retention.

1. Introduction

One of the most common techniques for investigation of hemispheric asymmetries is the dichotic listening (DL) paradigm; it involves presenting two different auditory stimuli simultaneously, one at the left and the other at the right ear (Bryden, 1988). This technique, initially proposed by Broadbent (1954) as a way to study attention, has been employed in the investigation of hemispheric asymmetries (Brancucci and San Martini, 1999; D'Anselmo et al., 2013; Tervaniemi and Hugdahl, 2003).

A typical finding in this field is that subjects are faster and more accurate in reporting verbal stimuli (such as consonant-vowel [CV] syllables) presented to the right ear, than to the left ear (REA, right ear advantage) (Kimura, 1961). A left ear advantage (LEA) is usually found in tasks involving nonverbal material, such as melodies or tones (Boucher and Bryden, 1997; Brancucci and San Martini, 2003; Brancucci et al., 2008a). The ear advantage can be explained using the structural, or neuroanatomical, model suggested by (Kimura, 1967; Sidtis, 1988). According to this model, the REA is a consequence of the activity of the auditory pathways where the contralateral pathway suppresses the ipsilateral one, along with the left-hemisphere advantage for language. This allows each of the dichotic stimuli to excite the contralateral auditory cortex more strongly (Brancucci et al., 2004; Della Penna et al., 2007; Kimura, 1967). Since the left hemisphere is specialized for language processing in most right-handed individuals, a REA is usually observed in DL tasks with verbal material. However, the input to either ear can reach the ipsilateral areas via the contralateral auditory cortex and the corpus callosum (Pollmann et al., 2002). Of note, this view refers only to bottom-up stimulus processing, in the absence of specific instructions to focus attention on either the left or the right ear (Hugdahl, 2000).

The size and direction of any ear advantage can be altered by varying the focus of attention. In forced-attention paradigms, top-down manipulation is usually implemented by instructing subjects to attend to and report the stimulus from only one ear (Bryden et al., 1983; Foundas et al., 2006; Hugdahl and Andersson, 1986). When attention is directed to the right ear (forced-right attention, FR) the REA for verbal material is enhanced in comparison to a condition without attention instructions (non-forced attention, NF). In contrast, a LEA is usually observed when subjects are instructed to attend to the left ear (forced-left attention, FL; for a review see Hugdahl, 2003). The laterality effects found in DL thus reflect an interaction between bottom-up and top-down processes. The REA for the NF and FR conditions and the LEA for the FL condition (Hugdahl, 2003) have been studied in relation to the timing

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of the cortical response to stimuli presentations. Attention actually affects the speed required for transferring and integrating information between the two hemispheres. An EEG study (Eichele et al., 2005) showed that with NF and FR attention the left hemisphere is activated earlier than the right one. This difference in latency was not observed with FL attention, which led to the same latency for the two hemispheres. These effects suggest that response reaction time may be a useful indicator of underlying hemispheric asymmetries, as it is strictly linked to the specific route that the stimulus information has to cover before eliciting a response.

In addition to being a useful technique for studying hemispheric asymmetry, DL can also be used to study executive and cognitive control functions (Westerhausen and Hugdahl, 2010; Andersson et al., 2008; Salthouse, 2000). Recent functional neuroimaging studies have shown that DL is a complex process that involves a distributed neural network, including the prefrontal cortex (Brancucci et al., 2008b; Jäncke et al., 2003; Thomsen et al., 2004). This area is also the most important substrate for working memory processes, including rehearsal, and contributes to cognitive control by maintaining representations of information during auditory cognitive processing (Cabeza and Nyberg, 2000; Curtis and D'Esposito, 2003).

Although the role of attention in determining ear asymmetries in DL has been well established, this study tries to assess whether it interacts with memory processes. Previous research investigating the role of memory in DL showed that delaying subject responses by 5–10 s decreases the REA (Yeni-Komshian and Gordon, 1974; Belmore, 1981; Voyer et al., 2014). In a DL CV task, memory was manipulated here by using shorter retention intervals of 0, 1, 3 and 4 s. These permitted testing DL both when information is held in a phonological store (before about 2 s; Vallar and Baddeley, 1984) and in the successive retention period, that is when the verbal rehearsal system comes into play (Baddeley, 2003; Henry, 2011). In addition, conditions with non-forced and forced attention towards each ear were used, to assess the role of bottom-up and top-down processes (Hugdahl, 1995).

On the basis of the mentioned literature, it was expected that lateralized attention would influence hemispheric asymmetry and that such an influence would depend on memory retention, as measured by recall accuracy and reaction time. Longer delays should moderate asymmetry effects due to different attention conditions, as encoded information has more time to spread and to be shared between the hemispheres and among different brain areas.

2. Materials and methods

2.1. Subjects

Thirty-nine healthy subjects, 9 males and 30 females, aged from 19 to 23 years (average = 21 years) took part. None of them had auditory impairments or different hearing thresholds (±5 dB) between left and right ears, as measured by audiometry (Brancucci et al., 2005). Only right-handed subjects were recruited, according to the outcome of the Edinburgh Handedness Inventory (Oldfield, 1971) for which score can range from −100 (totally left handed) to +100 (totally right handed). Scores were distributed as follows: 22 subjects scored ≥75, 15 scored ≥50 and < 75), and 2 scored ≥5 and < 50 (group mean ± standard error = 74 ± 3).

2.2. Stimuli

The stimuli were 6 CV-syllables (/ba/,/da/,/ga/,/ka/,/pa/and/ta/) recorded from a natural female voice. The sample rate was 44.1 kHz and the amplitude resolution was 16 bit. The peak level of the stimuli was 70 dB as measured with a sound level meter using A weighting with fast time constant. The approximate duration of the CV syllables was 350 ms (range: 280 ms–470 ms). The dichotic stimuli were obtained presenting one CV-syllable to the left ear and at the same time a different CV-syllable to the right ear. The different syllables were temporally aligned for simultaneous onset, using the GoldWave software (V.5.08, GoldWaveInc.), yielding a total of 30 dichotic pairs.

2.3. Procedure

Subjects performed the dichotic test under three different task instructions: NF, FL and FR. In the NF condition, subjects were informed that they would hear a sequence of CV syllables and that they should report always the syllable they heard most clearly immediately after appearance of the response screen. In conditions FL and FR, subjects were instructed to focus their attention only on the left or right ear and to report what they heard, ignoring the syllable presented to the other ear.

An acoustic and a visual cue were used to instruct subjects about the direction of their attention. In the NF condition a beep was presented binaurally, and at the same time a red square appeared at the centre of the screen. This indicated to the subjects that they should not direct attention to a specific ear. In the FL and FR conditions the beep was presented monaurally to the left or right ear, and simultaneously a red square appeared on the screen at the same side as the beep. This indicated to the subjects that they should direct attention to the left or right ear. For each condition, the 30 stimuli pairs were presented 4 times (for a total of 120 trials). Trials were grouped into 24 blocks of 5 trials each on a random basis. Instruction not to direct attention and to direct attention to the left or right ear changed with every block. The blocks were separated by a 4-s interval.

Each trial consisted of a dichotic target stimulus, composed of 2 CV syllables, followed by a response phase during which the screen displayed all 6 CV syllables in a clock-like display (syllable position on the screen was counterbalanced across participants). The task was to respond by clicking with the mouse on the appropriate syllable, using the right hand. For every trial the mouse cursor appeared in a central position, equidistant from each syllable.

Trials were grouped in 4 delay conditions. In the no-delay condition the response screen was displayed immediately after the presentation of the dichotic target (delay = 0 s). In the delay conditions, the interval between the presentation of the dichotic target and the response alternatives on the screen was 1, 3 or 4 s. The order of presentation of delay conditions was random between subjects. The total duration of the experiment was approximately 40 min including breaks of around 5 min between the 4 delay conditions.

The experiment was run using software written in E-prime on a computer with a 15.4-inch monitor. The type and latency of response were automatically stored for subsequent analyses. Participants were tested in a quiet room; they sat comfortably in front of the computer monitor (approximately 70 cm from subject's head) and wore a pair of headphones (Sony MDR-XD100). To control for possible asymmetries in the audio equipment, the headphone orientation was counterbalanced across participants.

2.4. Data analysis

Statistical analysis was based on repeated measures analysis of variance (ANOVA), and was aimed at testing whether participants' lateral bias (in terms of both number of responses and RT) was affected by the different attention and/or delay conditions. Responses were classified according to whether the correctly reported syllables matched the left ear (L) or the right ear (R), excluding as errors responses not matching the stimulus presented to either the left or right ear. Responses with RT values deviating by more than 2 standard deviations from the subject's mean for any condition (according to delay and attention) were excluded. After excluding outliers, the mean RT in each condition was calculated for each subject. Finally, a laterality index (LI) was calculated using the formula $LI = (R - L)/(R + L) \times 100$ for the number of correct responses and the formula $LI = (L - R)/(L + R) \times 100$ for RT. In both cases, a positive value indicates a REA, whereas a negative value indicates a LEA. The results for seven subjects scoring more than 2 standard deviations from the mean in any condition were excluded from further analyses. Two ANOVAs were performed, one with the number of responses and the other with RT as dependent variable, using the factors Attention (3 levels: FL, NF, FR) and Delay (4 levels: 0, 1, 3, 4 s). To assess how the degree of asymmetry changed independently from the attention condition, a second analysis was performed using the absolute values of LI. This allowed us to observe the "pure" asymmetry, independently from its direction. Absolute LI values were computed by transforming all laterality scores in positive scores, i.e. all negative LI were multiplied by -1. Absolute LI values were then averaged within each attention condition and two repeated measures ANOVAs (one on the number of responses and the other on RT) with Delay as a factor were performed.

Preliminary statistical analyses showed that the sex and handedness of two subjects did not influence the results. Also the headphone position (normal or reversed) showed no significant effects or interactions with LI scores. These variables were therefore not included in the subsequent analyses.

3. Results

3.1. Main analysis

The mean correct responses and reaction times for LI are shown in Figs. 1 and 2 and those for absolute LI are shown in Figs. 3 and 4. The mean percentage of correct responses for the FL condition for each temporal delay for the left and right ears, were respectively: 50 and 31 (0-s delay), 53 and 27 (1-s), 52 and 27 (3-s) and 49 and 27 (4-s). For the NF condition, values for the left and right ears were:

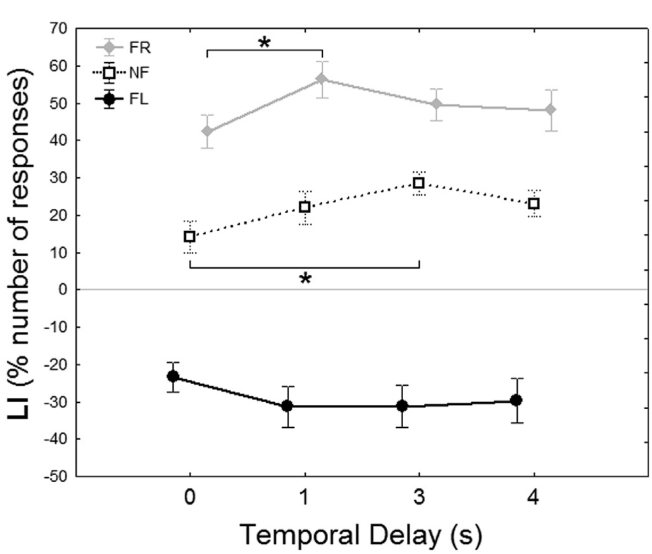

Fig. 1. Laterality index based on the percentage of correct responses for each attentional condition (FL, NF, FR) and for each temporal delay.

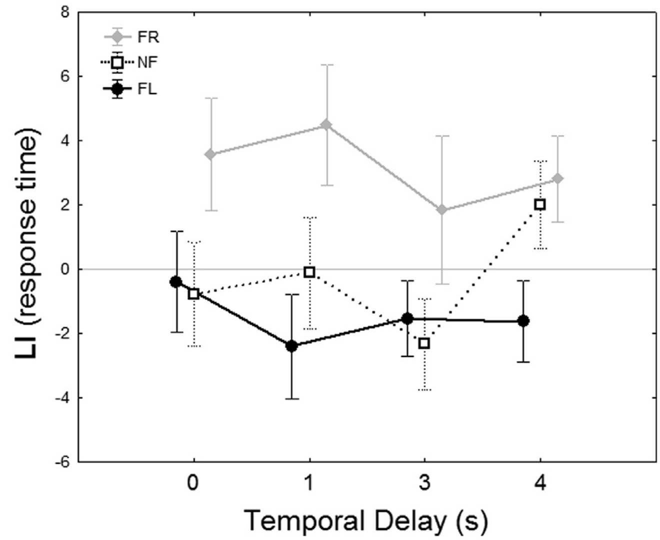

Fig. 2. Laterality index based on reaction time for each attentional condition (FL, NF, FR) and for each temporal delay.

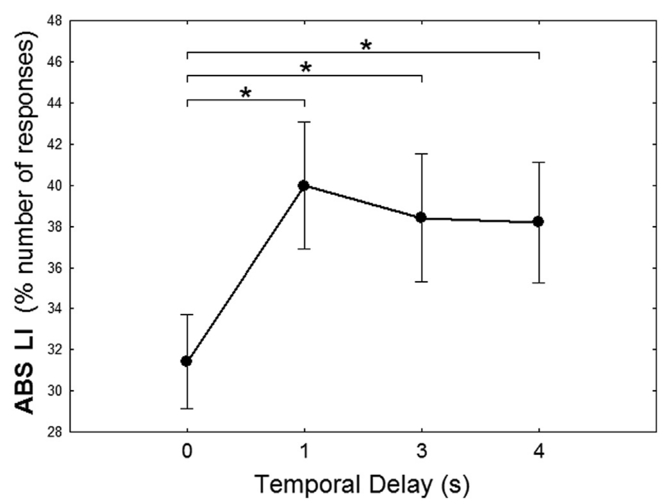

Fig. 3. Absolute laterality index based on the percentage of responses for each temporal delay.

34 and 46 (0-s delay), 32 and 50 (1-s), 29 and 52 (3-s) and 30 and 49 (4-s). For the FR condition, values for the left and right ears were: 23 and 58 (0-s delay), 17 and 62 (1-s), 20 and 61 (3-s) and 20 and 60 (4-s). An ANOVA of the LI scores for correct responses showed a significant main effect of Attention condition ($F_{2,62} = 115.26$; $p < 0.001$, $\eta_p^2 = 0.79$. Duncan's post-hoc tests showed that the comparison between FL and NF conditions was significant ($p < 0.001$). The LI was negative in the FL and positive in the NF condition. The comparison between NF and FR conditions was also significant ($p < 0.001$), due to a greater LI in the FR than in the NF condition. The interaction Attention × Delay was significant ($F_{6,186} = 2.97$; $p = 0.009$, $\eta_p^2 = 0.09$). Duncan's post-hoc tests indicated that in the FR condition, the LI was smaller for the 0-s than for the 1-s delay ($p = 0.006$). In the NF condition, the LI was smaller for the 0-s than for the 3-s delay ($p = 0.005$) (see Fig. 1). Single sample t-tests with reference value of 0 (absence of asymmetry between ears) showed that the LI differed significantly from 0 in each condition (FL: $t = -7.66$, $p < 0.001$; NF: $t = 7.16$, $p < 0.001$; FR: $t = 11.98$, $p < 0.001$).

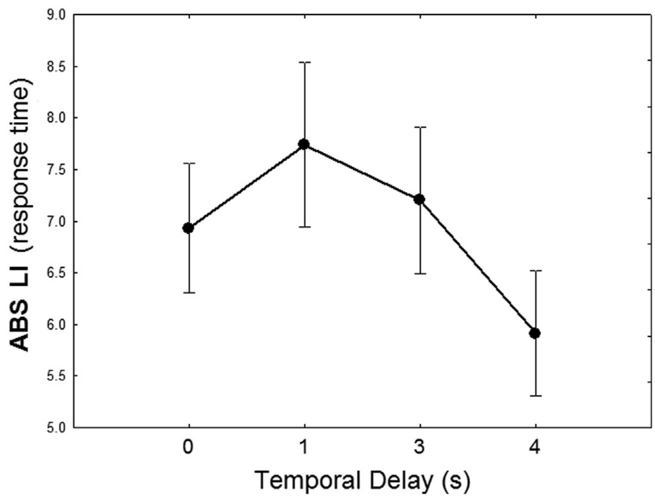

Fig. 4. Absolute laterality index based on the reaction time for each temporal delay.

Mean RTs for the FL condition for each temporal delay for the left and right ears were, respectively: 1103 and 1104 ms (0-s delay), 868 and 916 ms (1-s), 882 and 912 ms (3-s) and 988 and 1021 ms (4-s). For the NF condition, values for the left and right ears were: 1074 and 1078 ms (0-s delay), 926 and 921 ms (1-s), 898 and 950 ms (3-s) and 1058 and 1017 ms (4-s). For the FR condition, values for the left and right ears were: 1147 and 1047 ms (0-s delay), 933 and 1047 ms (1-s), 931 and 877 ms (3-s) and 1047 and 982 ms (4-s). For the LI for RT, there was a significant main effect of Attention ($F_{2,58} = 9.81$; $p < 0.001$, $\eta_p^2 = 0.25$). Duncan's post-hoc tests showed that the comparison between FL and FR conditions was significant ($p < 0.001$). The LI was negative in the FL and positive in the FR condition. The comparison between NF and FR conditions was also significant ($p = 0.003$) due to a greater LI in the FR than in the NF condition. The interaction Attention × Delay was not significant (see Fig. 2). Single sample t-tests with a reference value of 0 showed that the LI differed significantly from 0 only in condition FR ($t = -3.68$, $p < 0.001$).

For the number of correct responses, the ANOVA using absolute LI showed a significant effect of Delay ($F_{3,93} = 4.39$; $p = 0.006$), with Duncan's post-hoc tests indicating smaller absolute LI values in the 0-s delay condition than in the 1-s ($p = 0.002$), 3-s ($p = 0.010$) and 4-s ($p = 0.010$) conditions. No significant effect was found in the ANOVA for absolute LI based on RT (see Figs. 3 and 4).

4. Discussion

The present study aimed to investigate the potential influence of memory and attention on hemispheric asymmetries measured with DL. To achieve this goal, subjects were asked to perform a dichotic CV syllable task while the delay between stimulus presentation and response and the focus of attention were manipulated. An increase in the magnitude of the REA with increasing retention interval was found, from 0 to 1 s in the FR attention condition and from 0 to 3 s in the NF condition. No asymmetry differences were observed with the 4-s delay, and no change in the magnitude of the LEA was observed in the FL condition with changing retention interval.

Memory involvement in DL has been studied previously using retention intervals of varying lengths. Yeni-Komshian and Gordon (1974) studied DL with verbal material and with retention intervals from 0 to 15 s. They found that the REA decreased after 5 or 10 s and increased at 15 s. The increase in the REA was primarily due to a growth in the accuracy of the right ear score but this could be confounded with a possible practice effect, because the order of the retention intervals was 0, 5, 10 and 15 s for all subjects. Belmore (1981) used retention intervals of 0, 5, 10, 30, and 60 s and found an initial REA with delays of 0 and 5 s, and a decrease in the magnitude of the REA with longer delays.

A reduction of the laterality effect with an increase of the temporal delay was also found by Voyer et al. (2014), who investigated the role of memory and rehearsal in a dichotic emotion recognition task. In this paradigm, two dichotic stimuli were pairs of words pronounced with different emotional tones. Subjects were asked to identify the emotion of each pair. A LEA was found for emotion recognition and it was larger for the condition with no delay than with a 5 s delay. This reduction of the LEA with increasing delay was due to a reduction of responses to stimuli at the left ear and an increase of responses to stimuli at the right ear. These results confirm the influence of memory on perceptual asymmetries in DL.

Due to the lack of research examining the influence of memory processes on DL for retention delays below 5 s, the present study focused on shorter delay intervals, since, as mentioned in the introduction, a temporary storage system holds memory traces of verbal information for about 2 s. During this interval, information decays unless it is refreshed by the second component (the articulatory rehearsal mechanism). In the NF condition, in which mainly bottom-up processes are involved, increasing the delay from 0 to 3 s led to an increase of the REA. These results are in line with those of Penner et al. (2009), who investigated the role of memory load on DL by varying the number of letter pairs presented dichotically. The REA increased with increasing memory load. In the present study the information was probably encoded in the left hemisphere via the phonological loop and maintained in working memory when the response was delayed. When the involvement of short-term memory increases, there may be a greater demand on cognitive resources, resulting in an increase of the REA, possibly due to a faster deterioration of the cortical representation of the left than of the right ear input.

Concerning attention, the results of the NF condition confirmed the classical REA for speech perception (D'Anselmo et al., 2015; Della Penna et al., 2007; Hugdahl, 2003). The forced attention conditions also confirmed data from the literature (attention directed to the right ear increases the REA whereas attention directed to the left ear increases the LEA) (Asbjornsen and Hugdahl, 1995; Hugdahl and Andersson, 1986; Hugdahl et al., 2000). Reaction times corroborated these results regarding the ear advantage in DL with different attention conditions. Faster responses for the right ear in the NF and FR attention conditions and for the left ear in the FL attention condition were reported previously (Brancucci et al., 2005; D'Anselmo et al., 2013). Note that the use of the right hand for giving the response with the mouse should have not introduced any bias, because it has been shown that response hand manipulation does not interact with ear advantage in a dichotic listening task in which the processing of words with different emotions was required (Grimshaw et al., 2003). For the FR condition, the laterality index increased when the delay was increased from 0 to 1 s. In this condition, a delay between stimulus and response improved performance for the attended ear. The difference from the NF condition was that FR attention involves top-down processes, and thus the ear advantage is not stimulus driven but is related to attentional processes that direct data processing to the left hemisphere. The increase of the REA in the NF and FR conditions when the delay increased could have been due to more time available for response. When the answer is required after a temporal delay rather than immediately after the stimulus, the dichotic information has more time to be transferred via the corpus callosum from the left to the right hemisphere and vice versa. The effect of this transfer depends both on the nature of the stimulus and on the attentional process involved. Thus in the NF and FR conditions it is possible that after a temporal delay the information from the right ear becomes better represented in the left hemisphere. For the FL condition, in which no effect of delay on lateralization was found, it is possible that with more time between stimulus and response, the transfer of information would lead to a more bilateral representation of the stimulus across the two hemispheres. The results found for the FL condition, in which the delay did not affect lateralization, might have also been due to a rehearsal system that allows maintenance of the information in the phonological loop (Baddeley, 2003) and that, with verbal material, could preferentially involve the left hemisphere (thus favouring the right ear input). This could also account for the significantly increased REA with increased delay in the NF and FR conditions.

The present pattern of results could be related to the differential demand on cognitive resources in the different conditions. In the NF condition lateralization increased when the information was held in the phonological store (until 2 s) and decreased after 2 s (during the retention period). The early increase of the REA in the FR condition at 1 s could be due to higher cognitive demands required by forced attention (Hugdahl et al., 2009). The FL condition requires an attentional shift to the left ear, inducing a processing engagement due to the speech content of the right ear stimulus (which has a favored connection with speech cortical areas) and thus a need for more cognitive resources (Kompus et al., 2012). In conditions requiring more resources, lateralization would be modifiable only for shorter delays, in accordance with the observation of a lack of LEA increase with longer delays.

The analysis of absolute LI investigating whether the asymmetry changes independently from its direction, is a way to test the effect of the memory load independently from the direction of attention. Absolute LI values, averaged across attention conditions, showed that lateralization increased at 1-s delay and remained stable over subsequent delays (3 and 4 s). These results suggest that perceptual asymmetries increase with increased memory demand when there is a retention delay. Moreover, the persistence of ear asymmetry in the delayed conditions may indicate that retention processes do not abolish it at least for temporal delays up to 4 s. This possibility cannot be ruled out for larger delays, as previous studies showed that the REA decreased when the response was delayed for 5–10 s (Yeni-Komshian and Gordon, 1974; Belmore, 1981).

Interestingly, the influence of attentional control on hemispheric asymmetries in DL has also been investigated in the context of cognitive capacity decline, as observed in ageing or in patients with Alzheimer's dementia (Andersson et al., 2008; Duchek and Balota, 2005). Members of an old group showed a REA in NF and FR conditions which did not reverse in the FL condition (Andersson et al., 2008). These results have been explained in the context of cognitive decline associated with ageing, given that healthy older adults have a reduced ability to use cognitive resources and selective attention to guide stimulus selection in the FL condition, which requires more cognitive resources (Westerhausen et al., 2015). In addition to decline in attentive functions, old age is associated with a decline of other cognitive functions (Singer et al., 2003), such as memory (Rönnlund et al., 2005). In this regard, a paradigm involving not only selective attention but also working memory functions could be a complete tool for a more accurate investigation of cognitive ability in ageing. Given that DL with top-down attention modulation (in particular the FL condition) is sensitive to change in cognitive control, and given that hemispheric asymmetry could be modulated by memory involvement, it would be interesting to use this paradigm to evaluate jointly these cognitive functions in older people.

In conclusion, this study demonstrated that perceptual asymmetry can be modulated when factors of higher cognitive level such as attention and memory retention processes are manipulated simultaneously. This results in an increase or in a decrease of the magnitude and direction of the right or left ear advantage. In particular, in the FR condition, with higher memory demand the increase of lateralization occurred earlier than when attention was driven from the bottom (NF condition). Moreover, in the FL condition the LEA was not significantly modulated by memory processes, which was probably due to the additional cognitive effort required in this condition. Thus, the present research supports the hypothesis that FR and FL conditions differ in the involvement of cognitive control processes (Hugdahl et al., 2009; Westerhausen and Hugdahl, 2010). Moreover, in agreement with the structural model (Kimura, 1967), this study, using different delays between stimulus and response, suggests that attention condition could affect the time needed to transfer the information between the hemispheres across the corpus callosum. Further research should investigate the several processes that may be involved in auditory hemispheric asymmetries, possibly using behavioural techniques in combination with *in vivo* brain imaging methods.

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