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Research report

N270 sensitivity to conflict strength and working memory: A combined ERP and sLORETA study

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HIGHLIGHTS

- We create an audiovisual conflict task with simultaneous target and distractor.
- We assess the N270 sensitivity to the conflict strength and the working memory.
- The conflict cost is higher for the auditory target than for the visual target.
- The N270 is sensitive to the conflict strength and the load in working memory.
- Conflict processing and working memory share common neural subtract.

ABSTRACT

The event-related potential N270 component is known to be an electrophysiological marker of the supramodal conflict processing. However little is know about the factors that may modulate its amplitude. In particular, among all studies that have investigated the N270, little or no control of the conflict strength and of the load in working memory have been done leaving a lack in the understanding of this component. We designed a spatial audiovisual conflict task with simultaneous target and cross-modal distractor to evaluate the N270 sensitivity to the conflict strength (i.e., visual target with auditory distractor or auditory target with visual distractor) and the load in working memory (goal task maintenance with frequent change in the target modality). In a first session, participants had to focus on one modality for the target position to be considered (left-hand or right-hand) while the distractor could be at the same side (compatible) or at opposite side (incompatible). In a second session, we used the same set of stimuli as in the first session with an additional distinct auditory signal that clued the participants to frequently switch between the auditory and the visual targets. We found that (1) reaction times and N270 amplitudes for conflicting situations were larger within the auditory target condition compared to the visual one, (2) the increase in target maintenance effort led to equivalent increase of both reaction times and N270 amplitudes within all conditions and (3) the right dorsolateral prefrontal cortex current density was higher for both conflicting and active maintenance of the target situations. These results provide new evidence that the N270 component is an electrophysiological marker of the supramodal conflict processing that is sensitive to the conflict strength and that conflict processing and active maintenance of the task goal are two functions of a common executive attention system.

Keywords:
N270
Supramodal conflict processing
Working memory
Executive attention
Dorsolateral prefrontal cortex
sLORETA

1. Introduction

In the spatial domain, the human attentional system often has to integrate concurrent stimulation from different modalities (e.g., visual and auditory) at one single location, which helps spatial orienting [22] and allows a plausible interpretation of the world. Although this integration is efficient most of the time, the spatial discrepancy between two modalities may lead to perceptual illusions like those observed in the ventriloquism [3] where the vision (puppet's mouth movements) "captures" the sound [35]. Since the princeps work of Colavita [7], the visual dominance over other modalities and particularly over hearing in most of spatial tasks has

been largely demonstrated (for a review see [14]). Consequently, inhibiting a visual distractor when focusing on an auditory target in spatial tasks often implies a higher behavioral cost than the reciprocal – at least when visual and auditory stimuli are equisalient and well localized [1,4]. Over the last decades several researchers have tackled the neural and electrophysiological correlates of the conflict processing. It has been proposed that the N200 and N270 components of the event related potentials (ERPs) correspond to the electrophysiological markers of the conflict monitoring [11,13,30] and conflict processing [33,34,39] respectively. The studies focusing on the N200 revealed that this component is generated by the dorsal anterior cingulate cortec (dACC) (for a review see [13]). In parallel, Zhang et al. [39] showed that a N200 associated with a subsequent N270 could be elicited by the incongruent situation in a visual matching task. Using the same task in a fMRI study [38], they showed that conflicting information increased activation in the ACC (BA 24/32) together with the right dorsolateral prefrontal cortex (DLPFC, BA 9/46). Along with the strong effective connectivity existing between the ACC and the DLPFC [31], these results suggest that the N270 could correspond to a downstream process – based upon afferent ACC signal – that takes place within the DLPFC to select the appropriate motor response.

Unlike the studies of the N200 component, the study of the N270 has essentially been done using sequential *Same Different Judgment* (SDJ) tasks. In these tasks, a first stimulus (S1) is presented and followed by a second stimulus (S2) some hundred milliseconds later that is either the same (match) or different (mismatch) in a given dimension. The matching comparison has been assessed over different modalities and dimensions like the crossmodal gender match [34,25], visual color or shape match [32], number magnitude [16], arithmetic conflicts [33], and spatial matching [18,36]. All these studies have shown that the mismatch condition elicited a large negative amplitude in the fronto-central region of the scalp (although some authors [18,23] have found a more parietal topography) around 270 ms after the onset of S2. This component has been since called supramodal (i.e., independent of the stimulus modality) conflict processing component. As reported by Zhang et al. [37], one problem with the sequential SDJ tasks is that comparing the S2 stimulus to the previous S1 is necessarily a sequential process. Hence, the effects over the N270 observed in the aforementioned spatial mismatch studies could result from a comparison process between a cued attribute of a stimulus and a subsequent target stimulus – referred to as the "template mismatch" by Folstein and Van Petten [13] – than about a stimulus or response conflict processing between two competitive sensory-motor plans.

Based on this work, some authors have tackled the question to what extent the conflict-related N270 amplitude is modulated by the experimental context. To our knowledge only selective attention and cumulative mismatch effects have been evaluated. First, it has been shown that the N270 amplitude could be modulated by selective attention [32,18,37]. In these studies, the mismatch between S1 and S2 was assessed for both a relevant attribute of the visual stimulus (e.g., the shape) and an irrelevant one (e.g., the color) and led to N270 effects in both cases (i.e., larger N270 amplitude within the mismatching condition) albeit weaker within the irrelevant condition. This result indicates that mismatches in task-relevant and task-irrelevant dimensions are processed automatically and independently. In another study, Bennett et al. [2] found that the presentation of a visual distractor enhanced the N270 amplitude both in a perceptual match and mismatch conditions compared to situations with no distractor. They concluded that the distractors may differentially affect the N270 through the generation of task-irrelevant mismatch responses. Finally, Wang et al. [32] showed no effect of cumulative relevant mismatches over the N270 amplitude when it concerned two attributes of a same visual stimulus (i.e., shape + color) compared to the situations with

only one attribute that mismatched. Instead, they found that the conjunction condition elicited an additional negative peak following the N270, leading to the conclusion that the two mismatches have been processed successively.

These findings provide crucial information about the N270 characteristics and conflict processing, however, there are still several questions that need answers regarding this component. One of a great importance is to know whether the N270 is sensitive to the conflict strength. Indeed, research has often provided evidence that the N270 is an electrophysiological marker of the supramodal conflict processing but no indication about its sensitivity to the strength of the conflict for task-relevant stimuli has been provided yet. In addition, in all conflict tasks, the active maintenance of the pertinent attributes is mandatory to achieve the goal. Thus, if the N270 is generated by the DLPFC – as already suggested [38] – it is legitimate to consider that manipulating the working memory in terms of active maintenance levels of the relevant attributes in a conflict task could interfere with the conflict processing at the electrophysiological level namely via N270 modulations.

In the present study, we considered Zhang et al. [37] argument – regarding the sequential presentation used in most of the SDJ tasks – and proposed to investigate the electrophysiological mechanisms underlying the spatial audiovisual conflict with simultaneous cross-modal target and distractor presentation. More precisely, we first evaluated the responsiveness of the N270 to the strength of the conflict by manipulating the target and distractor modalities. According to the literature [1,4,7,14] the visual dominance should lead to a larger behavioral conflict cost for the auditory target with a visual distractor than for the visual target with an auditory distractor. Thus we hypothesized that a larger N270 amplitude for the stronger conflict would reflect a conflict processing cost at the electrophysiological level. Additionally, we evaluated the impact of increasing the target maintenance effort over the N270 using a target-modality switching task to dissociate working memory from conflict processing effects. It was expected that keeping the current target-modality in working memory within a two target-modality conflict task could interfere with the conflict processing observed in a single target-modality task. This would be observed as an increase in the conflict cost at the behavioral level, associated to larger N270 conflict effects. Finally, a source localization analysis was used to pinpoint the N270 cortical generators.

2. Method

2.1. participants

Sixteen healthy volunteers (8 women, mean age: 50.1, SD: 5.8) received a financial compensation for participating in this study. All were right-handed, as measured by the Edinburgh Handedness Inventory [24] and native French speakers, with normal or corrected-to-normal vision and normal hearing. No participant had a history of neurological disease, psychiatric disturbance or substance abuse, or taking psychoactive medications. This research was approved by the French "Southwest and Overseas Person Protection Committee number 1" and was conducted in accordance with the Declaration of Helsinki.

2.2. Spatial audiovisual conflict tasks

Stimuli were delivered with Presentation software (Neurobehavioral system®). Auditory stimuli were 1000 Hz normalized pure tones (78 dB SPL) presented *via* binaural earplugs (Nordic-NeuroLab) and visual stimuli were filled white circles (2-degree diameter), presented at a constant angle of 15 degrees from a white central fixation cross on an ACER 17″ monitor placed one meter
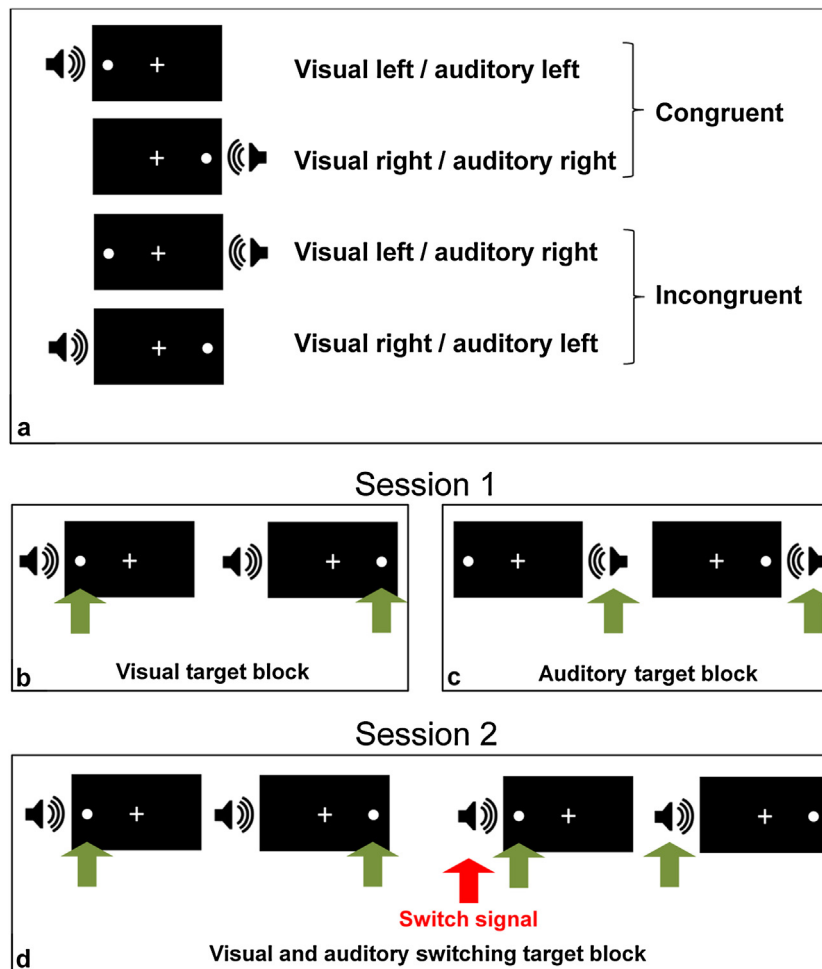
Fig. 1. Illustration of the audiovisual stimuli. The same stimuli have been used to create spatial audiovisual congruent and incongruent trials (a) for the first session ('no-switch') where participants had to respond according to the visual target (b), or the auditory target (c), and for the second session ('switch', d) where they had to alternate between the visual and the auditory targets the trial after the switch signal. Green arrows indicate the target.

from the participant. Auditory and visual stimuli were presented simultaneously during 200 ms and were either on the same side in congruent trials or on opposite sides in incongruent trials, (Fig. 1). Inter-trial interval was set to 2300 ms during which the white cross was always present. Behavioral responses were recorded with a 2-button mouse (left button for left target; right button for right target) across two sessions.

In the first session – referenced as the 'no-switch' session – the task consisted in detecting the presentation side of the visual stimuli in one block (visual targets with auditory distractors) and the auditory stimuli in another block (auditory targets with visual distractors). The presentation order of the two blocks was counterbalanced across participants. For each blocks, 60 congruent and 60 incongruent trials were presented resulting in two 5-min duration blocks. In the second session (the 'switch' session) an additional distinct auditory signal (pure tone at 750 Hz, 78 dB SPL) was pseudorandomly presented every 4–10 trials (mean 6.5), 32 times instead of 32 regular auditory stimuli (16 times in visual target trials and 16 times in auditory target trials). This sound – referred as the "auditory switch signal" – informed the participants that they had to alternate between visual and auditory targets. The volunteers were asked to keep responding to the current modality target for the trial containing the auditory switch signal and to prepare to switch from the current target modality to the other one for the next trial. A total of 208 trials were presented. 172 trials were distributed into 44 congruent and 44 incongruent trials within each

target modality. 32 trials containing the auditory switch signal were equally distributed into congruent and incongruent trials for each target modality. The switch session duration was 8.5 min.

2.3. Experimental procedure

Before the experiment, a 64-electrode cap was placed on the participants' head. Participants then seated in a comfortable reclining armchair, placed in a dimly lit, sound-damped room. They were instructed to keep their forearms lying on the chair's arms, with the right forefinger and middle finger resting on the two-button mouse. The overall experiment was completed for each participant in less than one hour, including installation and a training session of 5 min to ensure that they all had reached the maximum level of performance.

2.4. EEG recordings and pre-processing

EEG data were recorded continuously with a BioSemi EEG system (BioSemi, Amsterdam) from 64 active (preamplified) Ag-AgCl scalp electrodes located according to the International 10/20 system, at a 512-Hz sampling rate and with a 0–104 Hz band-pass filter. Data were processed with a matlab SPM8-based script (The Wellcome Trust Centre for Neuroimaging, UCL). They were re-referenced offline to the algebraic average of the left and right mastoids, filtered with a band-pass of 0.1–30 Hz and downsampled

at 500 Hz. An independent component analysis using the EEGlab *runica* function (www.sccn.ucsd.edu/eeglab) was performed to isolate eye blinks and movements that have been subsequently subtracted to the signal. A visual inspection of the data was done to reject residual artifacts region (1.4% of the trials). Data were later segmented in 1200 ms epochs starting 200 ms before the onset of each stimulus (baseline) to compute individual avaraged ERPs. Finally, the epoched data containing artifacts (>100 μV) were automatically excluded (i.e. on average 4%) before proceeding to grand averages.

2.5. Data analyses

All behavioral and EEG data were analyzed with Statistica 10 (StatSoft). Due to a lack of variance for the response rate (almost 100% correct in each condition), we did not proceed to accuracy analyses. In addition, the trials containing the auditory switch signal in the modality-switch session were to few for an ERP analysis and involved switching processes that were of no interest regarding our hypotheses, hence were excluded from analyses. Finally, all analyses have been made on averaged left and right target trials as the laterality was not studied.

A three-way repeated-measures analysis of variance (ANOVA) was carried out on mean reaction times with within-subject 'Modality-switch' (no-switch *vs.* switch), 'Target modality' (auditory target *vs.* visual target) and 'Spatial congruency' (congruent *vs.* incongruent) factors. The stimulus-locked ERPs elicited within each condition were computed as the averaged responses to repeated presentations of that condition. ERPs' amplitudes for the N270 analysis were averaged in a time window from 230 to 320 ms after the stimulus onset, determined both from visual inspection and from results of consecutive analyses of 25-ms latency windows. Eight regions of interest (ROIs) were defined to identify the N270 topographic distribution. This was done by first separating the 64 electrodes into two groups: midlines (10) and laterals (54), and then defining subsets of electrodes for analysis. The midlines were divided into two ROIs: fronto-central (FPz, AFz, Fz, FCz and Cz) and centro-occipital (CPz, Pz, POz, Oz and Iz). The lateral electrodes were separated into six ROIs: left (FP1, AF7, AF3, F7, F5, F3, F1, FT7 and FC5) and right (FP2, AF8, AF4, F8, F6, F4, F2, FT8 and FC6) fronto-central; left (FC1, FC3, C1, C3, C5, T7, CP1, CP3 and CP5) and right (FC2, FC4, C2, C4, C6, T8, CP2, CP4 and CP6) centro-parietal, and left (TP7, P1, P3, P5, P7, P9, PO3, PO7 and O1) and right (TP8, P2, P4, P6, P8, P10, PO4, PO8 and O2) parieto-occipital (See Fig. 2 for a graphical representation).

For the midline electrodes, a within-subjects ANOVA with factors 'Modality-switch' (no-switch *vs.* switch), 'Target modality' (auditory target *vs.* visual target), 'Spatial congruency' (congruent *vs.* incongruent), ROI (fronto-central vs. parieto-occipital) and 'Electrodes' (5), was computed on the mean amplitudes of the ERPs. A similar ANOVA was computed for the lateral electrodes, with factors 'Modality-switch' (no-switch *vs.* 'switch'), 'Target modality' (auditory target *vs.* visual target), 'Spatial congruency' (congruent *vs.* incongruent), Hemisphere (left *vs.* right), ROI (fronto-central *vs.* centro-parietal *vs.* parieto-occipital) and 'Electrodes' (9). All *p*-values for ERP results were adjusted with the Greenhouse-Geisser correction for non-sphericity. Tukey's HSD (Honestly Significant Difference) were used for all post-hoc comparisons.

2.6. Source localization

On the basis of individual mean ERPs, sLORETA software (standardized Low Resolution Electromagnetic Tomography [27,26]; free academic software available at http://www.uzh.ch/keyinst/loreta.htm), was used to compute the three dimensional cerebral distribution of the current density at the time point of the
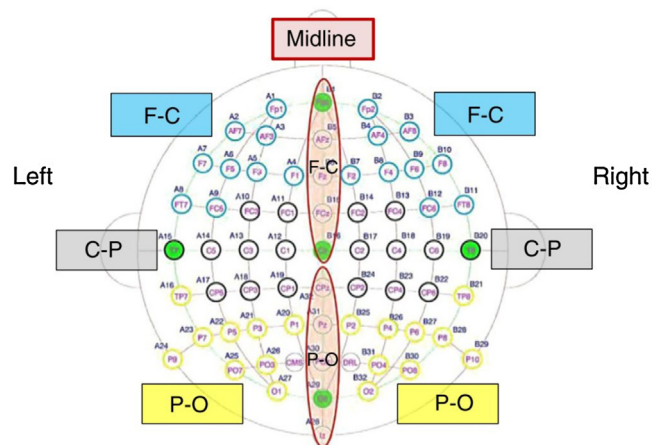

Fig. 2. Electrode groups for statistical analyses. The 64 electrodes are first divided in two groups: midlines and laterals. The midlines are then subdivided in two ROI groups (red circles; FC: Fronto-Central; PO: Parieto-Occipital). The laterals are divided in two hemisphere groups (left and right) and then in three ROI groups (colored rectangles; FC: Fronto-Central; CP: Centro-Parietal; PO: Parieto-Occipital).

individual N270 peak. sLORETA is based on a three-shell spherical head model with electrode coordinates derived from cross-registrations between spherical and realistic head geometry registered to standardized stereotaxic space (MNI, Montreal Neurological Institute). sLORETA solves the inverse problem by assuming synchronous and simultaneous activation of neighboring neurons. Solution space consists of 6239 cortical voxels (spatial resolution 5 mm). The difference in source localization for the congruency effect (incongruent *vs.* congruent) and the modality-switch effect (no-switch *vs.* switch) were investigated using nonparametric statistical analyses of functional sLORETA images (Statistical non-Parametric Mapping; SnPM) over the N270 latency, based on the subject-wise normalized power of the estimated electric current density. The results correspond to maps of log-F-ratio statistic for each voxel, for corrected $p < 0.05$. This procedure gives the exact significance thresholds regardless of non-normality. Finally, sLORETA log-F-ratio maps were exported in nifti format and plotted as overlays in mricron software (https://www.nitrc.org/projects/mricron) to locate brain areas commonly activated by conflict processing and working memory during the N270 occurrence.

3. Results

3.1. Behavior

Reaction times over all conditions are presented in Fig. 3. The ANOVA revealed a significant main effect of the target modality ($F_{(1,15)} = 22.82$, $p < 0.001$; $\eta_p^2 = 0.60$) that corresponded to faster RTs for the visual target than for the auditory one. A main effect of the congruency ($F_{(1,15)} = 59.50$, $p < 0.001$, $\eta_p^2 = 0.80$) was also found and corresponded to longer RTs for the incongruent trials. In addition, we found a significant target modality × congruency interaction ($F_{(1,15)} = 10.76$, $p < 0.01$, $\eta_p^2 = 0.42$). As revealed by the Tukey's HSD post-hoc tests, a significant target modality effect was present for both congruent and incongruent ($p < 0.001$) conditions, as well as the significant congruency effect was present for both target modalities (auditory target: $p < 0.001$, visual target: $p < 0.01$); the interaction effect was thus due to a larger congruency effect within the auditory target condition compared to the visual one. Finally, a main modality-switch effect ($F_{(1,15)} = 10.75$, $p < 0.01$, $\eta_p^2 = 0.42$) showed that RTs were longer in the switching modality session than for the non switching ones. No significant interaction of modality-switch with spatial congruency ($F_{(1,15)} = 2.98$, p=0.11)
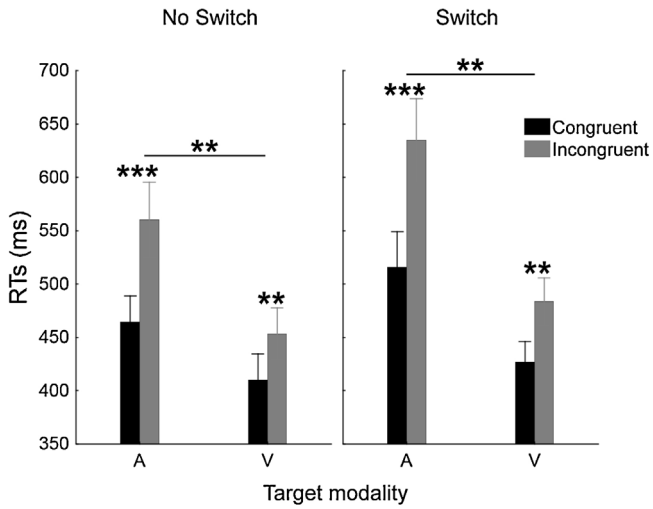
Fig. 3. Reaction times for the 'No modality-switch' sessions (left) and the 'modality-switch' session (right). Error bars represent standard errors. ** $p < 0.01$. *** $p < 0.001$.

or target modality ($F_{(1,15)} = 2.88$, p=0.58) was found meaning that the observed target modality, spatial congruency and modality × congruency effects were not affected by the modality-switch.

3.2. N270

Main N270 component statistical results over the midline and lateral electrodes are summarized in Table 1.

3.2.1. Topographic effects

The ANOVA over the midline electrodes showed a significant ROI × electrode interaction effect ($F_{(4,60)} = 7.88$, $p < 0.001$, $\eta_p^2 = 0.34$). The ANOVA over the lateral electrodes showed a significant hemisphere × ROI × electrodes interaction effect ($F_{(16,240)} = 2.69$, $p < 0.001$, $\eta_p^2 = 0.15$). Looking at post-hoc tests for both interactions, we found that the N270 amplitude was maximum over frontal regions, more precisely the left fronto-central area (mean N270 amplitude = $-1.64\,\mu$V for AF3).

3.2.2. Modality and congruency main effects

A main effect of the target modality was found for both midline ($F_{(1,15)} = 6.17$, $\eta_p{}^2 = 0.29$) and lateral electrodes ($F_{(1,15)} = 5.92$, $p < 0.05$, $\eta_p^2 = 0.28$) and corresponded to a larger mean N270 amplitude for the auditory target than for the visual target. In addition, the congruency also led to a significant main effect

largely distributed over the scalp (midline: $F_{(1,15)} = 11.36$, $p < 0.01$, $\eta_p^2 = 0.43$; lateral: $F_{(1,15)} = 11.80$, $p < 0.01$, $\eta_p^2 = 0.44$) with a larger mean N270 amplitude for the incongruent condition.

3.2.3. Modality and congruency interaction effects

Interestingly, a largely scalp distributed target modality × congruency effect has been found (midline: $F_{(1,15)} = 7.93$, $p < 0.05$, $\eta_p^2 = 0.35$; lateral: $F_{(1,15)} = 7.22$, $p < 0.05$, $\eta_p^2 = 0.32$). Post-hoc tests indicated a significant congruency effect for the auditory target ($p < 0.001$ for both midline and lateral electrodes) but not for the visual target ($p = 0.44$ in the best case). Taking into account the ROI and electrode factors we found significant interactions with the target modality and the spatial congruency for midline electrodes only. In fact, the target modality × congruency × ROI × electrodes interaction effect was significant over the midline electrodes ($F_{(4,60)} = 3.50$, $p < 0.05$, $\eta_p^2 = 0.19$). More precisely, post-hoc tests revealed that a congruency effect was present for the auditory target condition for all midline electrodes ($p < 0.001$ in all cases) except for FP1 (p=0.07); as well as for the visual target condition but over a reduced central region of the scalp from FCz to POz ($p < 0.01$ for these electrodes; $p = 0.25$ at best for frontal and occipital remaining electrodes); (see Fig. 4). Finally, the same post-hoc test revealed that the congruency effect was always larger for the auditory target than for the visual one due to significant differences between auditory incongruent and visual incongruent conditions ($p < 0.01$ from FCz to POz), and no differences between auditory congruent and visual congruent ones (p values ranging from 0.10 to 0.80).

3.2.4. Modality-switch effects

First, a main effect of the modality-switch was found over the midline electrodes ($F_{(1,15)} = 6.95$, $p < 0.05$, $\eta_p^2 = 0.32$) but not over the lateral electrodes ($F_{(1,15)} = 3.09$, $p = 0.10$). This effect corresponded to a larger N270 amplitude within the switching session compared to the non-switching one. A significant interaction between the modality-switch and the topographic factors was found solely for the midline electrodes (modality-switch × ROI × electrodes: $F_{(4,60)} = 16.634$, $p < 0.001$, $\eta_p^2 = 0.53$). Post-hoc tests specified that the modality-switch effect was significant over a large fronto-occipital midline going from Fz to Oz (i.e., excluding FPz, AFz and Iz). Finally, no interaction with the target modality (midlines: $p = 0.74$; laterals: $p = 0.61$), spatial congruency (midlines: $p = 0.77$; laterals $p = 0.99$) or both (midlines: $p = 0.66$; laterals: $p = 0.78$) has been found (Fig. 5)

3.2.5. N270 cortical source localization

At the time point of the individual N270 peak, the statistical analyses for the main effect of the congruency showed a greater

Table 1
Main ANOVA results on the mean N270 amplitudes.

Electrodes	Effects	F(df)	Adjusted p (G-G)	Epsilon (G-G)	η_p^2
Midline	Mod	(1,15) = 6.17	*	1.00	0.29
	Congr	(1,15) = 11.36	***	1.00	0.43
	M-S	(1,15) = 6.95	*	1.00	0.32
	Mod × Congr	(1,15) = 7.93	*	1.00	0.35
	ROI × Elec	(4,60) = 7.88	**	0.29	0.34
	Mod × Congr × ROI × Elec	(4,60) = 3.50	*	0.30	0.19
Lateral	Mod	(1,15) = 5.92	*	1.00	0.28
	Congr	(1,15) = 11.80	**	1.00	0.44
	M-S	(1,15) = 3.09	0.10	1.00	–
	Mod × Congr	(1,15) = 7.22	*	1.00	0.32
	Hem × ROI × Elec	(16,240) = 2.70	***	0.26	0.15

Mod: Target modality; Congr: Spatial congruency; M-S: Modality-switch; Hem: Hemisphere; ROI: Region of interest (Fronto-central and centro-occipital for midline electrodes, fronto-central, centro-parietal and parieto-occipital for lateral electrodes); Elec: Electrodes.

* $p < 0.05$.
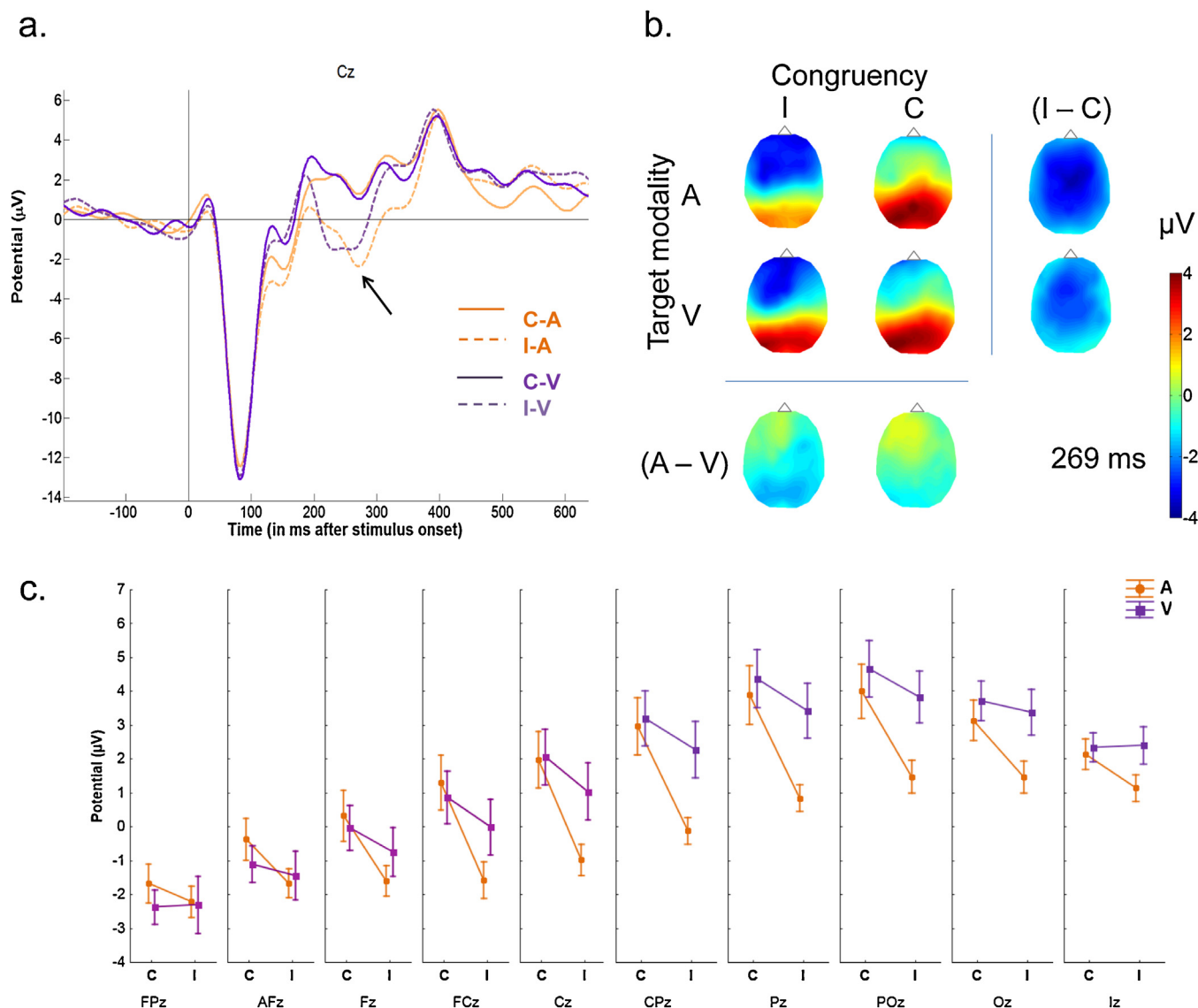** $p < 0.01$.
*** $p < 0.001$.

Fig. 4. EEG group results (*n* = 16) according to the target modality and the congruency. (a) ERPs for the auditory target (C-A: congruent auditory target; I-A: incongruent auditory target) and the visual target (C-V: congruent visual target; I-V: incongruent visual target). The black arrow designates the N270 peak. (b) Scalp maps and difference maps of the N270 peaks (*t* = 269 ms post-stimulus onset) for the 2 modality targets and congruency conditions. (c) Mean N270 amplitudes (time window [230–320] ms) for the central electrodes (10–20 system) from anterior (left) to posterior (right) sites. A: auditory target, V: visual target; C: congruent condition, I: incongruent condition.

activation in a large region of the right prefrontal cortex (PFC) for the incongruent condition. This region extended from the inferior to the superior frontal gyrus (IFG, SFG), including the DLPFC. (see Table 2). Similarly, we found a greater activation of a large part of the right PFC for the modality-switch session compared to the no-switch session. Although this area was more superior then the conflict-related one, the right DLPFC was also included. Finally, the conjunction map between conflict and modality-switch effects showed that only the rDLPFC was activated during both processes (Fig. 6).

4. Discussion

The goal of this study was to evaluate the responsiveness of the N270 amplitude to (a) the conflict strength in a spatial audiovisual conflict and (b) an additional working memory effort induced in a switching target-modality task. To do so, we designed a simultaneous audiovisual target and distractor task and created two types of conflict (visual target with auditory distractor and auditory target

with visual distractor) that needed an easy target-modality maintenance in a first place. In a second part of the experiment – using the same set of stimuli – we added distinct auditory stimuli that indicated the participants to switch from one target modality to the other. Hence, an increase in the task difficulty was provoked by the frequent switch which led to an additional effort to maintain the target modality in working memory among two alternating ones. The findings of this study provide a first evidence that the N270 amplitude may by modulated by the strength of the conflict (modality-dependent in this case) and that the supramodal conflict processing and the active maintenance in working memory can be both evaluated through the N270 amplitude modulations within the right DLPFC, but do not interact with each other.

4.1. Spatial conflict

Behavioral conflict costs have been observed for both visual and auditory target conditions. Moreover, the visual dominance in a spatial context led to a larger behavioral conflict cost when
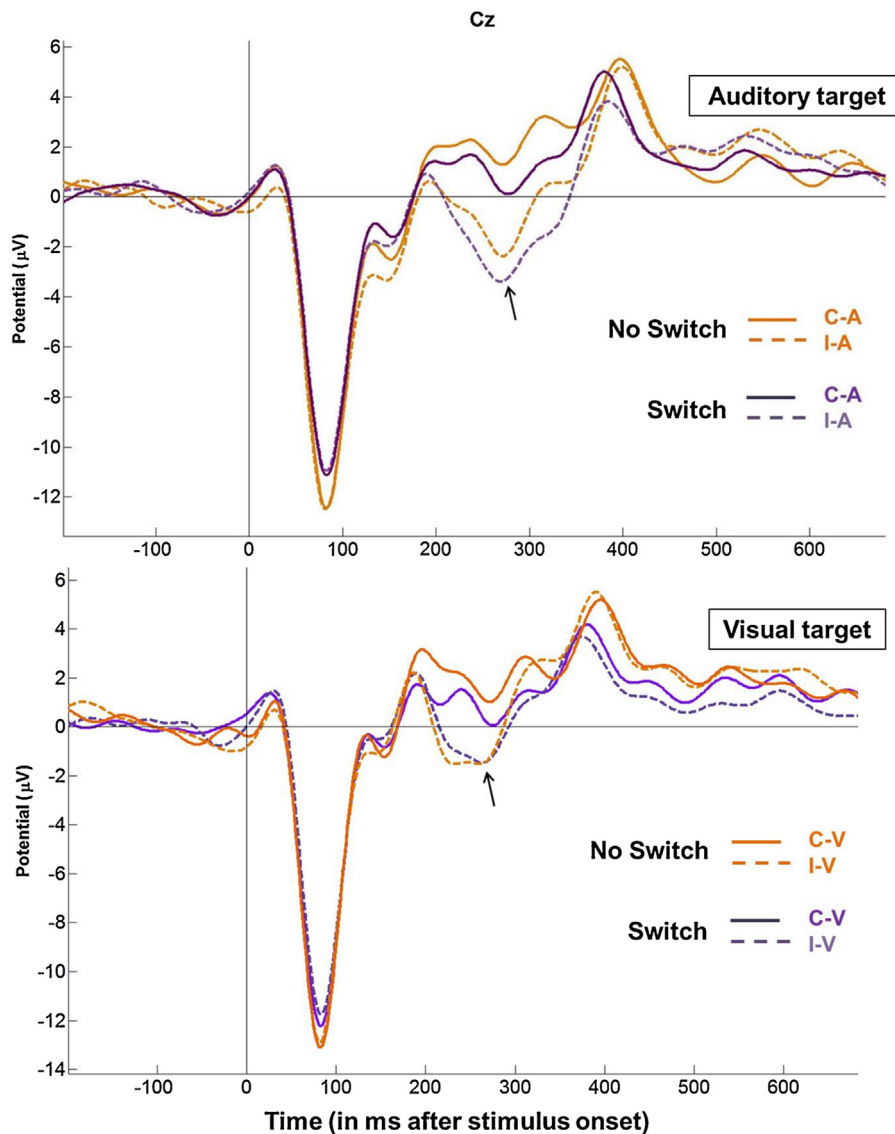
Fig. 5. ERP group average (*n* = 16) results according to the modality-switch and the congruency for the auditory and the visual targets. C-A: congruent auditory target; I-A: incongruent auditory target; C-V: congruent visual target; I-V: incongruent visual target. No switch: no modality-switch blocs of the first session. Switch: modality-switch of the second session. The black arrow designates the conflict-related N270 peak.

Table 2
Brain regions that showed significant differential activation between conditions as a function of congruency and modality-switch at the individual N270 peak latency.

Anatomical region	BA	MNI Coordinates	Log-F-ratio
Congruency : I > C			
R Middlle Frontal Gyrus	10	(45, 50, 15)	0.97
	10	(45, 45, 15)	0.96
	10	(40, 45, 15)	0.95
	46	(45, 45, 20)	0.92
R Superior Frontal Gyrus	8	(30, 40, 45)	0.92
R Middlle Frontal Gyrus	9/46	(45, 40, 25)	0.91
R Inferior Frontal Gyrus	45/46	(35, 35, 15)	0.91
Modality − switch : Sw > NoSw			
R Superior Frontal Gyrus	9	(45, 35, 35)	0.98
R Anterior cingulate	32	(10, 45, 10)	0.97
R Medial Frontal Gyrus	10	(10, 50, 10)	0.96
	10	(10, 50, 15)	0.93
L Inferior Frontal Gyrus	45	(−55, 30, 5)	0.91
L Superior Frontal Gyrus	9	(−20, 40, 40)	0.91

R: right hemisphere; L: left hemisphere; I: Incongruent; C: Congruent; Sw:Switch; NoSw: No-Switch. BA: Brodmann Area; MNI: Montreal Neurological Institute coordinates. Corrected *p*<0.05.

participants had to inhibit an incongruent visual distractor while detecting the auditory target position. Similarly, we found that both auditory and visual target tasks induced significant modulations of the N270 amplitude over a large fronto-central area of the scalp. Whatever was the target modality, the spatial incongruity created by the crossmodal distractor led to significant larger N270 amplitude compared to the congruent conditions. These results are in accordance with all SDJ task results that have shown an increase of the N270 amplitude within the mismatch condition compared to the match condition. They add, furthermore, interesting complementary information to the N270 literature. Yang and Wang [36] found that the spatial discrepancy of two stimuli presented in a sequential order elicited a larger N270 than the spatial match. They hence concluded that the N270 should correspond to the brain activity for processing spatial discrepancy. Zhang et al. [37], however, pointed out the fact that sequential stimuli presentation in SDJ tasks involves comparison processes between a cued stimulus attribute and a subsequent one. Thus, N270 modulations in SDJ tasks could result from a "template mismatch" [13] between the second stimulus and the mental template created from the first
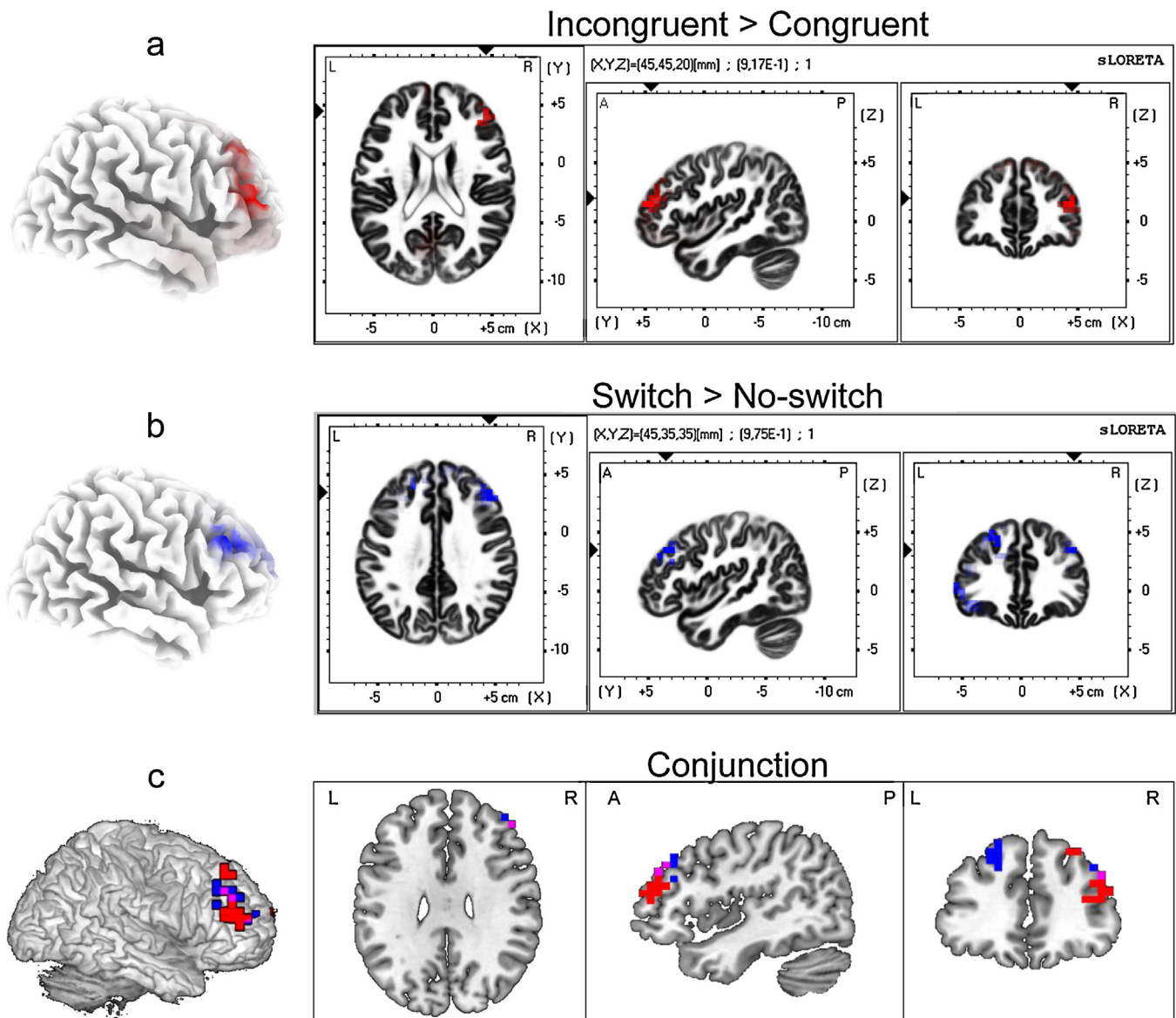
Fig. 6. Graphical representation of the N270 current density for the congruency effect (a) and the modality-switch effect (b) from sLORETA. Coordinates in MNI space in mm. Corrected $p < 0.05$. (c) Conjunction map of the congruency effect (red) and the modality-switch effect (blue) plotted with mricron; intersection MNI coordinates: 45, 40, 30 (purple); overlay threshold > 0.907; corrected $p < 0.05$.

stimulus. In our task the conflict arose from audiovisual spatial incongruity – left hand side *versus* right hand side – of simultaneous target and distractor presentations. Thereby, both stimuli were processed and compared at the same time inducing a competition between the target and the distractor. We hence confirm Yang and Wang [36] and Zhang et al. [37] results by giving additional evidence that the N270 could be the cortical electrophysiological signal of the supramodal conflict processing in absence of template representation.

4.2. Target modality and conflict strength

More interestingly, the reaction times confirmed that it was more difficult to inhibit a visual distractor when focusing on spatial attributes of an auditory target than the converse in our paradigm. This difference in behavioral effects supports previous findings of a visual dominance in spatial target detection [7,14]. This mandatory result allowed us to dispose of two conflicting tasks that solely differed in terms of conflict strength. At the electrophysiological level, we found that the crossmodal spatial incongruity not simply evoked a N270 but led to a greater – and more largely distributed over the scalp – N270 effect for the auditory target than for the visual one. This was due to a larger N270 amplitude for the auditory incongruent condition compared to the visual incongruent one and no difference when comparing the congruent ones. According to the present results, we now argue that the behavioral cost is quantifiable at the electrophysiological level through the conflict-related N270 modulations: the higher the conflict, the larger the conflict-related N270 amplitude. We thus bring clues that the N270 could be a qualitative (conflict occurrence) and quantitative (sensitive to the conflict strength) marker of the conflict processing.

4.3. Target-modality maintenance and working memory

The second motivation of this study was to evaluate the impact over the conflict-related N270 amplitude of the active maintenance in working memory. In all the aforementioned N270 studies participants had to give their answer according to a relevant stimulus

dimension that remained the same within a session. In the second session of the present study, we added a distinct auditory switch signal indicating the participants that they had to change the target modality for their response (randomly every 4–10 trials). While waiting for this signal they had to retain in working memory the current target modality among two possible for correct responses – compared to solely one modality in the first session – and to update it from the switch signal. We found that increasing the working memory effort in the task led to a general increase of reaction times in the detection of the visual and the auditory targets, confirming the need of an additional cognitive effort for correct responses. This working memory effort also led to a significant global effect over the N270 component corresponding to a general increase of its amplitude. Based on theses observations, we hence argue that the active maintenance of the target modality in the modality-switch session compared to the no-switch session has led to a supplementary cognitive effort observable at both the behavioral (i.e., global increase of reaction times) and the electrophysiological levels – in terms of an increase of the N270 amplitude in all conditions. This suggests that conflict processing and working memory share common resources. An important nuance however, is that, contrary to our initial hypotheses, the increase of difficulty in active maintenance of the target modality affected equivalently interference (incongruent trials) and facilitation (congruent trials) processes at both behavioral and electrophysiological levels. Thereby, conflict processing and active working memory in our task did not interact with each other although they may share common neural subtract. This result may be interpreted in terms of a cumulative effect over the N270 amplitude, comparable to those observed for different ERP components in the literature [5,15,37].

4.4. N270 and DLPFC

As suggested by several studies [6,20,29] the right DLPFC is a key area for the inhibition of non-pertinent motor plans. A significant part of the literature however, showed that other parts of the prefrontal cortex (PFC) are also involved in motor output inhibition [9,12]. This apparent divergence may find a uniformity in the paper of Munakata et al. [21] where authors have shown that both the ACC/Pre-SMA, the rIFG and the rDLPFC may be involved in the inhibition of non-pertinent motor plans. They suggest that two distinct PFC neural mechanisms act for response "inhibition". On the one hand, the rDLPFC would be in charge of an active maintenance of the target attributes in corresponding areas via excitatory neurones, hence indirectly inhibiting other attributes by subsequent lateral inhibition within these specific areas. On the other hand, the ACC/Pre-SMA and rIFG would be involved in a more direct inhibition mechanism via excitation of subthalamic nucleus (STN) which then provides global inhibition over the output of the basal ganglia. In accordance with Zhang et al. [38] hypotheses and the work of Munakata et al. [21], our source localization results showed that while the conflict-related N270 was generated by both the right IFG (BA 45/46) and the right DLPFC (middle frontal gyrus, BA9/46), the conjunction source localization for the conflict processing and working memory engagement showed only the rDLPFC as a common area for these processes. One plausible explanation is that selecting the relevant modality among audiovisual information by an active maintenance in working memory and selecting the relevant target modality by inhibiting the distractor in crossmodal presentation are both processes that belong to the executive attention function of the PFC [10,19].

4.5. Limits

In the present study we were not able to isolate a N200 component, which is however known to be a marker of the conflict

monitoring. This point perfectly illustrates the difficulty in some cases to identify overlapping components, particularly for temporally close ones and when one of them has a larger amplitude. Thus it is likely that a N200 has been evoked but it could have been overlapped by the large amplitude of the N270. Further technical investigation to isolate the N200 component is needed and should help in understanding the link between the N200 and the N270. In addition, one could argue that the N270 component, when it has a fronto-central scalp distribution, actually corresponds to an anterior N200. For example, in their extensive N200 review, Folstein and Van Petten [13] cited a work achieved by Zhang et al. [39] to illustrate the impact of the perceptual matching and response conflict over the N200. Looking at the cited paper however, revealed that the conflicting situation induced a N270 whereas a N2b was present solely in the congruent processing condition. In addition, other studies [16,33] have made distinctions between the N200 and N270 showing that both components can be elicited successively within the same task. The temporal proximity of the N200 and the N270, along with previous fMRI studies showing ACC and DLPFC activations in mismatching tasks [8,28,38], is a supplementary argument in favor of a plausible cingulo-prefrontal network that would be involved in mismatching information processing [38]. Finally, the participants' mean age was 50 years old (i.e., middle age) for the purpose of future comparisons with brain damaged patients. Therefore, it is legitimate to put our results into the perspective of the group's age. Some studies have shown differences in conflict effects between young and middle-aged persons. For example Mager et al. [17] have found age effects over the level of performance that corresponded to a larger conflict effect for middle-aged than for young participants albeit present in both groups. At the electrophysiological level however, they did not find any difference between these two groups which is in favor of the results presented in this paper.

5. Conclusion

In the present study we analyzed ERPs and cortical current density to investigate the sensitivity of the N270 component to the conflict strength in an audiovisual conflict task and to the load in working memory involved in active maintenance of the target modality. Our findings suggest for the first time that the N270 amplitude is sensitive to the conflict strength of relevant attributes (i.e., the stronger the conflict, the larger the conflict-related N270 amplitude). In addition, increasing the load in active maintenance did not impact the conflict cost but led to systematic larger N270 amplitudes suggesting common neural substrate for motor inhibition and working memory as revealed by an increase in the right DLPFC current density at the time point of individual N270 peaks for both processes.

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