An fMRI study of the perception of contrastive prosodic focus in French

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Abstract

This fMRI study deals with the perception of prosodic contrastive focus in French. Twenty-two right-handed French participants listened to two kinds of utterances: with contrastive prosodic focus (Focus) and without (Neutral). The task was to judge whether the utterances contained focus. The Focus vs. Neutral contrast revealed bilateral activation of the inferior frontal, superior and middle temporal, premotor cortex and supramarginal gyri, as well as of the superior parietal lobule and anterior insula. Among these regions, the inferior frontal and supramarginal gyri, as well as the anterior insula, were significantly more activated to the left. These results suggest that the auditory perception of contrastive prosodic focus involves a large cerebral network which is partially predominant to the left.

1. Introduction

Contrastive focus is used to emphasize a constituent in an utterance as opposed to another. In French, it can be conveyed by prosody using a specific intonational contour on the constituent pointed at (THOMAS$_F$ a mangé la pomme. 'THOMAS$_F$ ate the apple.').

The studies of the neural correlates of the perception of prosody have led to different conclusions (see [1] for a review). Early works claimed that prosody is processed in the right hemisphere (e.g. [2-7]), a view reflecting the traditional conception of prosody as a well adapted subordinate to the left-hemisphere processed syntax and semantics. Other studies have shown that prosodic processing cannot be restricted to the right hemisphere (e.g. [8-10]).

A few neuroimaging studies have specifically analysed the processing of prosodic focus. Wildgruber *et al.* [11] aimed at studying affective vs linguistic prosody. The linguistic prosodic task consisted of indirect informational focus detection (*find the most suitable answer to a specific question*). The affective prosodic task consisted in the evaluation of emotional expressiveness. The linguistic prosodic task (vs. baseline) yielded bilateral activations of the primary and secondary auditory cortices, of the anterior insular cortex and of the frontal operculum (BA 6/44/47), as well as right hemisphere dominant activations of dorsolateral-frontal regions and left hemisphere activation of the primary sensorimotor cortex. Linguistic vs. Affective prosody yielded activation in left inferior frontal cortex (Broca's area). [12] examined the processing of prosodic focus and aimed at differentiating the processing of 'intonation' (question/affirmation discrimination) and that of contrastive stress. It additionally compared English and Chinese. For the processing of contrastive stress, the authors obtained bilateral activation of the intra-parietal sulcus (BA 40/7), right hemisphere predominant activation of the medial frontal gyrus (BA 9/46) and, for the Chinese group, left hemisphere predominant activation of the supramarginal gyrus and of the posterior medio-temporal (BA 21/20/37) cortex.

This functional magnetic brain imaging (fMRI) study deals with the perception of prosodic contrastive focus in French.

2. Methods

2.1. Participants

Twenty two adults, 11 males and 11 females, age range 22-34 (mean = 27.45, SD = 3.48) participated in the experiment. All participants were right-handed according to the Edinburgh Handedness Inventory [13], were native speakers of French and had no history of language, neurological and/or psychiatric disorders. They gave their informed written consent for the experiment and the study was approved by the local ethic committee (CPP n°09-CHUG-14, 04/06/2009).

2.2. Stimuli

The experiment compared two conditions: "sentences with narrow contrastive focus" (Focus condition, Task) and "sentences with broad focus" (Neutral condition, Control). The stimuli were 24 short French sentences. All sentences had the same syntactic and syllabic structure: Subject (S: 2-syllable first name) – Verb (V: 2 syllables, past tense) – Object (O: 1-syllable determiner, 2-syllable noun), as in the following example: "Thomas cassait le vélo" ("Thomas broke the bike"). The syllabic structure of all the constituents of the sentences was controlled (CVCV) using a French lexical database (http://www.lexique.org/). For the "Focus condition", the sentences were uttered once with focus on the subject (FS: THOMAS broke the bike) and once with focus on the object (F0: Thomas broke the BIKE). Overall, 72 utterances (24 sentences, three focus cases: broad, FS and FO) were uttered by a trained French female speaker in a soundproof room.

2.3. Tasks

The subjects were asked to judge whether the audio stimuli contained contrastive focus. The "Yes" and "No" responses were provided with the index and the middle fingers of the right hand, by means of two response keys. They were recorded and the performance of task execution was evaluated.

2.4. fMRI paradigm

The stimuli were presented via E-Prime (E-prime Psychology Software Tools Inc., Pittsburgh, USA) running on a PC computer. They were delivered by means of headphones, one stimulus every two seconds. Between stimuli, the subjects maintained their gaze on a white fixation cross centrally displayed on a black screen. A total of 96 stimuli were presented in a random order (focus condition: 24 FS, 24 F0: neutral condition: 24 stimuli presented twice).

After receiving instructions, the participants were trained outside the scanner with audio stimuli different from those presented during the actual fMRI experiment.

A pseudo-randomized event-related fMRI paradigm, including one functional run, was designed based on the optimisation of the onset for each type of stimuli for each condition [14]. Two pseudo-randomized lists of stimuli were created, their order was counterbalanced across participants.

The functional run was composed of 48 events per prosodic condition (96 total). In addition, 30 null-events (five at the end of the session) were also included in order to provide an appropriate baseline measure [14]. The null-event was a white fixation cross at the centre of the black screen. The average inter-stimulus interval was 4s and the functional run duration was 8′39. The functional run started with 5 dummies. Overall, 168 functional volumes were acquired.

2.5. MR acquisition

The fMRI data were acquired using a whole-body 3T scanner (Bruker MedSpec S300). For functional runs, a gradient-echo/T2* weighted EPI method was used (39 adjacent axial slices parallel to the bi-commissural plane, interleaved mode, slice thickness 3.5 mm, voxel size 3×3 mm, TR = 3 s, TE = 40 ms, flip angle = 77°). Images were corrected for geometric distortions using a B0 fieldmap. Finally, a T1-weighted high-resolution three-dimensional anatomical volume was acquired (field of view = 256 × 224 × 176 mm; resolution: 1.333×1.750×1.375 mm; acquisition matrix: 192×128×128 pixels; reconstruction matrix: 256× 128×128 pixels).

2.6. fMRI data processing

Data analysis was performed using the general linear model [15] in SPM5 (Welcome Department of Imaging Neuroscience, www.fil.ion.ucl.ac.uk/spm). First, the functional volumes were time-corrected (slice timing). Then, all volumes were realigned to correct for head motion. Unwrapping was performed using the individually acquired fieldmaps, to correct for interaction between head movements and EPI distortions [16]. T1-weighted anatomical volume was co-registered to mean images created by the realignment procedure and was normalized to the MNI space using a trilinear interpolation. The anatomical normalization parameters were then used for the normalization of functional volumes. Finally, each functional volume was smoothed. Time series for each voxel were high-pass filtered (1/128 Hz cutoff) to remove low frequency noise and signal drift.

Following spatial pre-processing steps, the statistical analysis was performed on functional images. The spatial resolution of the statistical parametric maps was the same as the spatial resolution of functional MR acquisition (3×3×3.5 mm). The two conditions of interest ("Focus", F vs. "Neutral", N) were modelled as two regressors convolved with a canonical hemodynamic response function (HRF). The movement parameters derived from realignment corrections (3 translations and 3 rotations) were included in the design matrix as additional factors. The general linear model was then used to generate the parameter estimates of activity for each voxel, each condition and each participant. Statistical parametric maps were generated from linear contrasts between the HRF parameter estimates for the two experimental conditions.

At the individual level, we contrasted the main conditions, F vs. N and N vs. F, in order to assess the network of regions specifically involved during F and during N conditions.

Secondly, we performed a random-effect group analysis on the contrast images from individual analyses [17] by using one-sample t-tests. Based on the intensity of individual response ($p < 0.001$, uncorrected, height threshold: $T = 3.53$), we identified clusters of activated voxels composed of at least 15 adjacent voxels. The activated regions for each condition were identified according to Talairach coordinates [18].

Thirdly, we defined Regions of Interest (ROI) based on the whole-brain activation obtained by contrasting F vs. N and by taking into account the results obtained by previous studies in the literature [12, 19]. Specifically, we retained all activated voxels included inside a 5 x 5 x 5 size sphere around each peak of activation, in the left and right hemispheres. The peaks of activation are shown in Table 1. To build the ROI we used the MarsBar software (http://marsbar.sourceforge.net/). The MR signal intensity variation (%MR, parameter estimates) from each ROI was then extracted. The parameter estimates values for each ROI and for each subject, were included in an analysis of variance (ANOVA) to detect significant differences according to experimental conditions and hemispheres.

Table 1. *Peak coordinates of Regions of Interest*

Region of Interest	x	y	z	BA
Premotor	± 3	33	37	6
Inferior frontal	± 50	12	18	44
Inferior frontal	± 53	29	-4	47
Insula	± 33	18	2	13
Superior temporal	± 59	-31	4	22
Middle temporal	± 62	-52	5	21
Supramarginal	± 50	-53	41	40

3. Results

3.1. Behavioural results

The behavioural responses obtained during the fMRI experiments (manual responses recorded) were correct on most trials: Focus ($M = 92.99\%$, $SD = 6.73\%$) and Neutral ($N = 97.72\ \%$, $SD = 3.85\%$). Responses obtained were above chance level, during Focus ($t\ (21) = 29.26$, $p<.001$) and Neutral ($t\ (21) = 58.10$, $p<.001$) conditions.

3.2. fMRI results

3.2.1 Main contrasts between conditions

The activated regions provided by the F *vs.* N contrast are mentioned in Table 2 and Figure 1. The frontal activation was bilateral: left premotor (BA 6) and left inferior frontal gyrus (BA 47); right inferior frontal gyrus (BA 44, 47). The temporal activation included left superior (BA 22) and right middle (BA 21) temporal gyri. We also obtained bilateral activation of the supramarginal gyrus (BA 40) and left activation of the superior parietal lobule (BA 7).

3.2.2 Parameter estimates (% MR signal variation) in ROIs

The seven ROIs (Table 1) were delineated in the left and right hemispheres symmetrically. For each ROI, the parameter estimates values were analyzed by means of a repeated ANOVA with hemisphere as a within-subject factor. ANOVA was performed in order to detect significant hemisphere predominance of the activation. Our results (Table 3 and Fig. 2) show significant left hemisphere predominance of the inferior frontal (BA 47) and supramarginal (BA 40) gyri, as well as for left anterior insula (BA 13) during the F condition.

Table 3. *ROI analysis: Statistical p value of the left-right hemisphere difference for each ROI*

ROI	BA	F	*p*
Premotor	6	0.49	0.49
Inferior frontal	44	1.33	0.26
Inferior frontal	47	6.04	**0.02**
Insula	13	5.32	**0.03**
Superior temporal	22	2.9	0.1
Middle temporal	21	0.21	0.64
Supramarginal	40	6.97	**0.01**

4. Discussion and Conclusion

Our results show that the processing of contrastive focus involves left hemisphere specialization of regions of interest which suggests that the processing of prosody is not strictly right-hemisphere lateralized, as claimed by some studies. Among the left hemisphere predominant regions of interests, we obtained the activation of the inferior frontal (BA47, LIFG) and supramarginal (BA 40) gyri and the anterior insula.

The LIFG is classically related to semantic processing [20] but also to syntactic judgment tasks. According to [21], thematic role assignment which involves lexical-semantic and morpho-syntactic processes recruits both the anterior (BA 45/47) and the posterior (BA 44/45) portions of the LIFG. The LIFG was also reported by [19] as involved in thematic role monitoring in speech production. This last interpretation is reinforced by the present findings, on the perception side.

The left anterior insula may be related to the articulatory loop [22] probably involved in focus detection as subjects may need to covertly repeat the utterance in the perception process.

The left superior parietal lobule was reported during production of multimodal pointing, including vocal pointing (contrastive focus), manual- and ocular- pointing [23]. Given the key role of the left superior parietal lobule in body part localization processing, it was suggested that speakers may use multisensory body representations in order to produce prosodic focus, just like they do to produce manual or ocular pointing gestures. Interestingly, the present results suggest that perception of prosodic focus also makes use of brain regions ordinarily used for spatial localization of body parts. In line with embodied approaches to language [24], this might indicate that neural systems for perception and action are also engaged during language comprehension and, more specifically, the detection of contrastive prosodic focus.

The strong right middle temporal activation suggests that the melodic processing of the intonational contour rather takes place in the right whereas the linguistic decision rather involves the left hemisphere.

Contrary to many brain imaging studies, these results suggest that both hemispheres participate in the auditory perception of prosody, with a left-dominant contribution for morpho-syntactic processes and thematic role monitoring.

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Table 2. *Activated regions for F(ocus) > N(eutral) provided by random-effect group analysis, p > 0.001 (uncorrected). H=hemisphere, R=right; L=left, k=number of voxels for each cluster; BA=Brodmann area.*

Cortical region	H	BA	k	x	y	z	T
Premotor	L	6	108	-3	34	37	8.14
Inferior frontal	L	47	80	-50	21	2	6.55
	R	47	67	53	29	-4	5.32
Inferior frontal	R	44	47	50	13	19	5.66
Middle temporal	R	21	352	62	-52	6	6.11
Superior temporal	L	22	78	-59	-32	5	4.91
Supramarginal (parietal)	L	40	90	-50	-53	41	5.70
	R	40	27	50	-32	50	4.29
Superior parietal	L	7	55	-42	-67	52	5.16
Insula (anterior)	L	13	18	-33	18	2	4.85

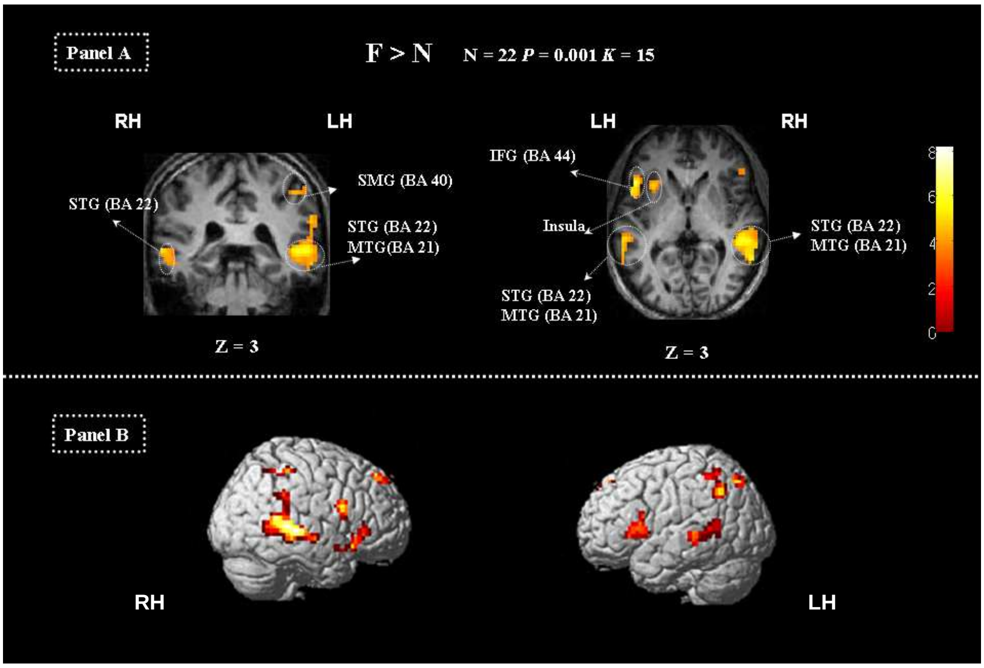

Figure 1: *Activated regions for the contrast F(ocus) > N(eutral). Panel A: projections onto 2D anatomical slices in coronal and axial orientation. Panel B: projections onto 3D anatomical templates (lateral view of the left (L) and right (R) hemisphere (H)). STG=superior temporal gyrus, SMG=supramarginal gyrus, MTG=middle temporal gyrus, LIFG=inferior frontal gyrus.*

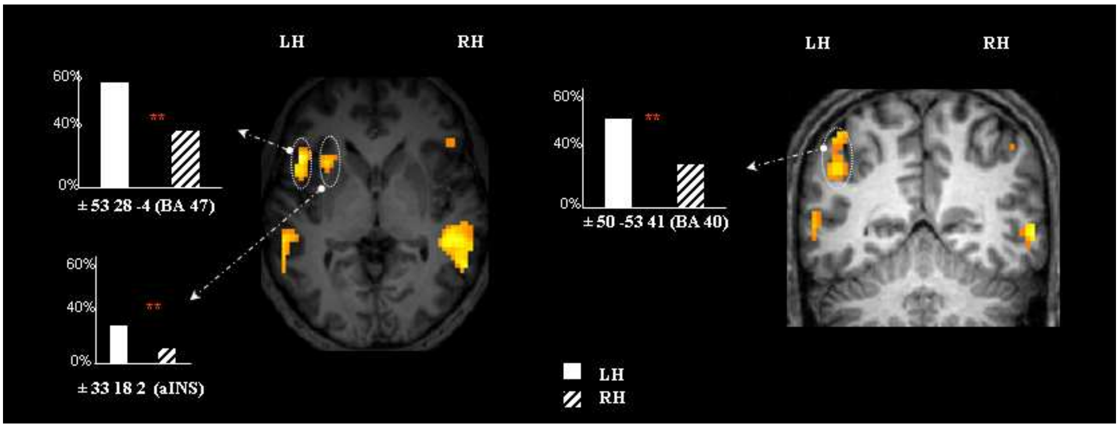

Figure 2: *Graphic representation of left-right hemisphere difference for each ROI (p value in Table 3). Significant LH predominance was obtained for the inferior frontal (BA 47) and supramarginal (BA 40) gyri and anterior insula (BA 13). ** = p < .05.*