

# An fMRI study of the silent production of agent deixis via prosody or syntax

Hélène Lævenbruck†, Monica Baciu‡ and Christoph Segebarth§

† Institut de la Communication Parlée, UMR CNRS 5009, INPG, Univ. Stendhal, Grenoble, France

‡ Laboratoire de Psychologie et Neurocognition, UMR CNRS 5105, Univ. P. Mendès-France, Grenoble, France

§ Unité Mixte INSERM / UJF 594, LRC CEA 30V, Grenoble, France

E-mail: loeven@icp.inpg.fr, monica.baciu@upmf-grenoble.fr, Christoph.Segebarth@ujf-grenoble.fr

## ABSTRACT

Deixis, or verbal pointing, plays a crucial role in language acquisition and speech communication. The aim of this fMRI study is to determine the neural correlates of the production of utterances involving agent deixis through prosody, syntax, or both. Sixteen subjects were examined. A common pattern of activation was found for the three deixis conditions including the left inferior frontal gyrus (LIFG), the left insula and the bilateral premotor (BA 6) cortex. Prosodic deixis additionally activated the left anterior cingulate gyrus (BA 24, 32), the left supramarginal gyrus (LSMG, BA 40) and Wernicke's area (BA 22). Our results suggest that the LIFG is involved in agent deixis, and that the LSMG and Wernicke's area are required in prosody-driven deixis only. These findings are consistent with observations on temporo-parieto-frontal coupling in auditory/visual-motor integration. Once grammaticalized, deixis would be handled solely by the LIFG, without the LSMG and Wernicke's area.

## 1. INTRODUCTION

Deixis, or the ability to draw the listener's attention to an object or person – gradually acquired, first by pointing with the eye, then the finger, then by pointing with intonation and finally by syntax –, is crucial in speech communication. In French, agent deixis –verbal pointing at the agent of an action [1] – can be conveyed by syntax (using syntactic extraction such as « it's x who »), or by prosody (using a prosodic contour bearing a focus on the agent pointed at). The aim of this fMRI study is to determine the neural correlates of the production of utterances involving agent deixis through either prosody or syntax or both.

Broca's region (left inferior frontal gyrus, LIFG; Brodmann Areas BA44, 45, 47) has traditionally been associated with linguistic processing, from sentence- to syllable-parsing [2-4]. It has also been associated with action analysis [5]. Therefore, we hypothesize that the role of the LIFG may be the monitoring of action in general, and that this role may be particularly well adapted to linguistic tracking of thematic roles. This action parser supports the attentional monitoring of thematic roles handled in morphosyntactic analysis and is involved in the spatial and temporal indexing of predicates (actions) and

their arguments (patient, agent). If the LIFG is involved in action parsing, then agent deixis which requires thematic-role monitoring, should activate the LIFG. The aim of this fMRI study was to test the hypothesis that the LIFG may be involved during the production of utterances involving agent deixis.

## 2. MATERIALS AND METHODS

### 2.1 SUBJECTS

Sixteen healthy, male, right-handed (Edinburgh Handedness Inventory) native speakers of French were examined. The study was performed in accordance with the institutional review board regulations.

### 2.2 STIMULI

The stimuli consisted of short sentences in French, visually presented on a projection screen. Four isosyllabic sentences were presented, one for each condition:

- **baseline condition:** "Madeleine m'amena" (*Madeleine brought me around*).
- **prosodic deixis condition:** "MADELEINE m'amena" (*MADELEINE brought me around*), contrastive focus on the agent.
- **syntactic deixis condition:** "C'est Mad'leine qui m'am'na" (*It's Mad'leine who brought me 'round*).
- **combined deixis condition (prosodic and syntactic):** "C'est MAD'LEINE qui m'am'na" (*It's MAD'LEINE who brought me 'round*).

The number of syllables in the sentence was maintained equal to 6, using schwa deletion. Each sentence was presented for 3 seconds at the beginning of the corresponding condition. Then a fixation mark, alternating every 3 seconds between a '+' and a 'x' sign, appeared in the middle of the screen. This alternation was aimed at triggering the silent repetition (14 times per condition) of the sentence presented.

### 2.3 PARADIGM AND TASKS

Before entering into the magnet, the subjects were positioned in front of a computer screen, instructed and trained to execute the tasks, first in overt mode, then in covert mode. Pre- and post-scan audio DAT recordings were carried out to estimate the subjects' task performance during the fMRI scan. Subjects were prompted by exactly the same script as during the scans. They produced each of the sentences 4 times. For the post-scan recording, the instruction was to speak aloud and to reproduce the intonation patterns mentally produced during the scans.

Three functional scans were performed during each fMRI session. A block paradigm was used. A scan comprised 8 epochs (each condition was repeated once) of 42 seconds each. The order of presentation of the four conditions varied between scans and between subjects. Subjects were instructed to silently read the sentence presented at the beginning of each condition and to repeat it, using inner speech, at each alternation of the fixation cross.

## 2.4 MR ACQUISITION

Functional MR imaging was performed on a 1.5T imager (Philips NT) with echo-planar (EPI) acquisition. Twenty-five adjacent, axial, slices (5mm thickness each) were imaged 10 times during each epoch. The imaging volume was oriented parallel to the bi-commissural plane. An EPI MR pulse sequence was used. The major MR parameters were: TR = 3700ms, TE = 45ms, pulse angle = 90°, acquisition matrix = 64x64, reconstruction matrix = 128x128, field-of-view = 256x256mm<sup>2</sup>. Between the first and second functional scans, a high-resolution 3D anatomical scan was obtained.

## 2.5 DATA PROCESSING

Data analysis was performed using the SPM-99 software (Wellcome Department of Cognitive Neurology, London). First, motion correction was applied. All images within a functional scan were realigned by means of a rigid body transformation. Then, the anatomical volume was spatially normalized into a reference space using the Montreal Neurological Institute template. The normalization parameters were subsequently applied to the set of functional images. Finally, to conform to the assumption in SPM that the data are normally distributed, and to allow for some inter-subject variability during group analysis, the functional images were spatially smoothed.

## 2.6 STATISTICS

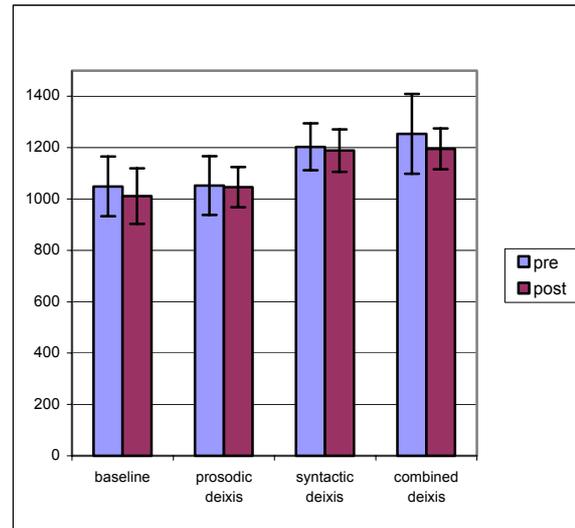
Contrasts between conditions were determined pixelwise using the General Linear Model. Statistical significance threshold for individual pixels was established at  $p = 0.001$ . Clusters of activated pixels were then identified, based on the intensity of the individual responses and the spatial extent of the clusters. Finally, a significance threshold of  $p = 0.05$  (corrected for multiple comparisons) was applied for identification of the activated clusters. The results of the fixed effect group analysis are reported here.

# 3. RESULTS

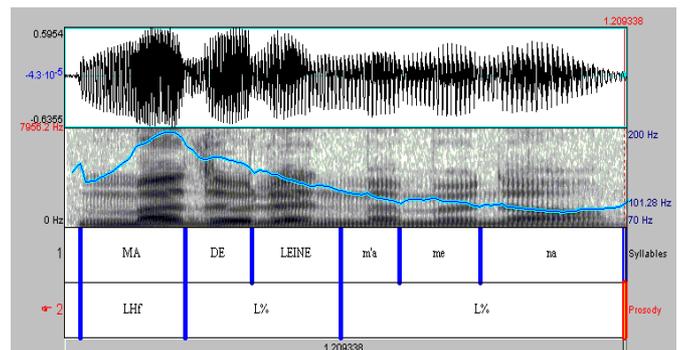
## 3.1 AUDIO RESULTS

The mean sentence duration (16 subjects, 4 repetitions of each of the 4 conditions) was 1139 ms ( $\pm 159$  ms) before and 1108 ms ( $\pm 129$  ms) after the scans. The mean sentence durations for each condition are shown in Figure 1. No significant variations were found. In addition, subjects were consistent in their realizations of the focused constituents before and after the scans. Different subjects made different choices as to the syllable bearing the high pitch accent (LHf, see [6]) in the prosodic and combined deixis conditions, but they maintained their choices. In the prosodic deixis condition, three syllables (/ma.də.lɛn/)

were possible slots for the high pitch accent. In the combined deixis condition, 2 slots were available (/ma.dlɛn/).



**Figure 1:** Pre- and post-scan mean sentence durations (in ms) for the 4 conditions, and for the 16 subjects.



**Figure 2:** Acoustic analysis of one repetition of the prosodic deixis utterance by speaker DB. The same F0 and duration pattern is observed across the 8 repetitions.

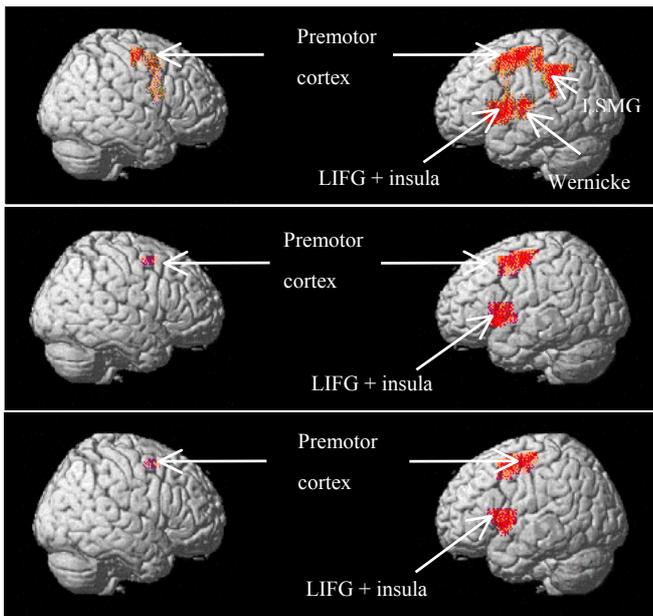
Overall, no significant intra-speaker variability was observed between recordings. For instance, in the 4 repetitions of the prosodic deixis condition, 5 subjects put a high pitch accent on the first syllable (/ma/), 5 subjects promoted the second syllable (/də/), 4 subjects promoted the last syllable (/ɛn/) and 2 subjects alternated between the second and third syllables. But, for each subject, the association between pitch accent and syllable did not vary between recordings. Figure 2 shows the acoustic analysis of a typical repetition of the prosodic deixis utterance by speaker DB. As can be seen on the F0 trace superimposed on the spectrogram, the first syllable of the focused constituent bears a high pitch accent. This pattern is observable in all 8 repetitions of the utterance, before and after the scans. Overall, the subjects' performances as measured by the audio recordings indicated that their production varied neither in rhythm nor in intonation between recordings.

### 3.2 FMRI RESULTS

Table 1 lists the activated regions and their corresponding stereotaxic Talairach coordinates. Figure 3 represents the functional activations obtained for the main effects.

Region	Talairach Coord. (mm)			Z score
	x	y	z	
<b>Prosodic deixis - baseline</b>				
Left insula	-32	4	9	> 8
L. insula	-36	-11	10	6.5
L. anterior cingulate (BA 24)	-12	5	18	5.1
LIFG (BA 47)	-32	20	-5	> 8
Wernicke's area (BA 22)	-48	-16	10	6.5
L. medial frontal gyrus (BA 6)	-28	2	46	7.3
L. anterior cingulate gyrus (BA 32)	-20	10	41	7.2
L; SMG (BA 40)	-44	-37	34	6.6
Right SMA (BA 6)	4	-9	56	6.4
R. SMA (BA 6)	16	-9	56	6.1
<b>Syntactic deixis - baseline</b>				
L. insula	-32	8	9	7.0
LIFG (BA 45)	-28	20	8	5.2
LIFG (BA 47)	-40	16	-1	4.9
L. superior frontal g. (BA 8)	-20	14	50	6.4
L. medial frontal gyrus (BA 6)	-24	3	51	6.0
L. medial frontal gyrus (BA 6)	-24	-9	56	5.2
<b>Combined deixis - baseline</b>				
L. insula	-36	4	9	6.1
LIFG (BA 45)	-28	16	8	6.0
L. SMA (BA 6)	-20	10	50	6.1
L. medial frontal gyrus (BA 6)	-20	-16	61	5.6
L. medial frontal gyrus (BA 8)	-20	14	41	5.5
<b>Prosodic deixis - syntactic deixis</b>				
L. post. sup. temporal g. (BA 22)	-40	-35	6	7.0
L. SMG (BA 40)	-40	-33	29	6.4
L. SMG (BA 40)	-40	-33	48	6.2

**Table 1:** Activated regions in the deictic tasks. LIFG, Left Inferior Frontal Gyrus; SMA, Supplementary Motor Area; SMG, Supramarginal Gyrus.



**Figure 3:** Activations obtained in the prosodic deixis (top), syntactic deixis (middle) and combined deixis (bottom).

The pattern of activations common to the three deixis conditions (each compared to the baseline) included Broca's region (BA 45, 47), the left insula and the premotor cortex (BA 6) bilaterally. Prosodic deixis additionally activated the left anterior cingulate gyrus (BA 24, 32), the left supramarginal gyrus (LSMG, BA 40) and the left postero-superior temporal gyrus (Wernicke's area, BA 22). The (prosodic deixis - syntactic deixis) contrast yielded significant activation in the left posterosuperior temporal gyrus and the LSMG.

### 4. DISCUSSION

This fMRI study shows activation of Broca's region in all the deixis conditions compared with the baseline. The LIFG was therefore activated during verbal pointing at the agent of the action, through prosody, syntax or both.

This activation is consistent with functional neuroimaging studies on complex syntactic processing ([7], [3]). These studies have shown the involvement of the LIFG in plausibility judgments about syntactically complex constructions (with cleft-object sentences, or sentences with center-embedded clauses), which require intricate tracking of thematic roles. Our findings are also in line with studies on the observation and mental imagery of action which show LIFG activation during action tracking ([8], [5], [9], [10]). Taken together, these observations support our claim that the role of the LIFG is that of an action-structure parser, which, in morphosyntactic encoding and decoding, handles the parsing of the predicate and its arguments, or the attentional monitoring of "who does what to whom".

The left insula was also found activated in all the (deixis - baseline) contrasts. The involvement of the left precentral gyrus of the insula in articulatory planning during speech has already been shown [11]. Prosody has acoustic and articulatory correlates ([12], [13], [14]). The production of prosodic focus may require more accurate planning of the movements of the tongue and jaw, which could explain why the prosodic deixis condition yields significant activation of the left insula when compared with the baseline (same words to articulate, but a more stringent prosody). Similarly, the syntactic deixis condition (compared with the baseline) likely requires more accurate articulatory planning, given the larger number of consonant clusters involved (due to schwa deletion).

The activation of the LSMG and of Wernicke's area in the prosodic deixis condition alone suggests that, when deixis is encoded by syntax, no additional recruitment of the inferior parietal lobule and Wernicke's area is necessary. A number of studies ([15], [16], [17], [18]) suggest that the inferior parietal regions in both hemispheres function as sensory integrators which form representations necessary in the organization of motor actions, such as (linguistic or non-linguistic) pointing at targets. The left hemisphere would have a linguistic predominance. A left temporo-parieto-frontal network might be recruited in the organization of verbal motor actions from auditory

representations. Our results, with the activations of the LSMG, the LIFG and Wernicke's area in prosodic deixis, are in line with this hypothesis. Like visually-guided manual pointing, prosodic pointing may need integrated representations (auditory, articulatory) to be formed via superior temporal and inferior parietal regions to organize articulation and phonation in an adequate pattern.

We therefore suggest that non-grammaticalized deixis recruits the temporo-parieto-frontal network and that grammaticalized deixis (syntactic deixis with or without supplementary prosody) is handled solely by the LIFG.

## 5. CONCLUSION

While "basic" linguistic information is considered to recruit the left hemisphere, prosody is often seen as being handled by the right hemisphere (e. g. [19], [20], [21]), a view reflecting the conception of prosody as a well adapted subordinate to syntax and semantics. Several recent neuroimaging studies do provide data supporting this view. When aspects of prosody associated with melody processing are studied, right hemisphere activation is found indeed (e.g. [22], [23]). Recent works have shown that prosody is a "complex grammatical (phonological) structure that must be parsed in its own right", however [24]. Prosody, therefore, should recruit the left hemisphere, just like syntax and semantics. Interestingly, a recent review of the literature [25] shows that the processing of prosody in general (affective and linguistic) is not strictly localizable to the right hemisphere. More specifically, this review quotes studies on the production and perception of emphasis (which is related to prosodic focus) showing that left-damaged patients are more strongly impaired than right-damaged patients. Recent neuroimaging studies also found left hemisphere activation in prosodic tasks ([26], [27]). We consider that these results are consistent with our two conjectures: Broca's region being a parser of action structure, particularly well adapted to agent deixis and the left temporo-parieto-frontal network functioning as an interface between auditory and articulation/ phonation processes, required in prosody-driven deixis.

## ACKNOWLEDGEMENTS

This research project was fostered by Christian Abry. We are very grateful to Véronique Aubergé, Pascal Perrier Cécile Bricchet, Christophe Savariaux, Chafika Rabeih & Albert Rilliard. This work was supported by the CNRS grant "Aide à Projets Nouveaux" # 29031.

## REFERENCES

- [1] Levinson S. (1983). *Pragmatics*, C.U.P., Cambridge, England.
- [2] Grodzinsky Y. (2000). The neurology of syntax: Language use without Broca's area. *B. Brain Sciences*, 23 (1), 1-21.
- [3] Caplan D., Alpert N., Waters G. & Olivieri A. (2000). Activation of Broca's area by syntactic processing under conditions of concurrent articulation. *Hum. Brain Mapp.*, 9, 65-71.
- [4] Poldrack R. A., Wagner A. D., Prull M. W., Desmond J. E., Glover G. H. & Gabrieli J. D. E. (1999). Functional specialization for semantic and phonological processing in the left inferior prefrontal cortex. *NeuroImage*, 10, 15-35.
- [5] Rizzolatti G., Fogassi L., Gallese V. (1997). Parietal cortex: from sight to action. *Curr. Opin. Neurobiol.*, 7 (4), 562-567.
- [6] Jun S.-A. & Fougerson C. (2000). A phonological model of French intonation. In A. Botinis (ed.) *Intonation: Analysis, modeling and technology*. Dordrecht : KAP, 209-242.
- [7] Just M. A., Carpenter P. A., Keller T. A., Eddy W. F. & Thulborn K. R. (1996). Brain activation modulated by sentence comprehension. *Science*, 274, 114-116.
- [8] Grafton S. T., Arbib M. A., Fadiga L. & Rizzolatti G. (1996). Localization of grasp representations in humans by positron emission tomography. 2. Observation compared with imagination. *Exp. Brain Res.*, 112 (1), 103-111.
- [9] Iacoboni M., Woods R. P., Brass M., Bekkering H., Mazziotta J. C. & Rizzolatti G. (1999). Cortical mechanisms of human imitation. *Science*, 286, 2526-2528.
- [10] Binkofski F., Amunts K., Stephan K. M., Posse S., Schormann T., Freund H.-J., Zilles K. & Seitz R. (2000). Broca's region subserves imagery of motion: a combined cytoarchitectonic and fMRI study. *Hum. Brain Mapp.*, 11, 273-285.
- [11] Dronkers N. F. (1996). A new brain region for coordinating speech articulation. *Nature*, 384, 159-161.
- [12] Beckman M. E., Edwards J. & Fletcher J. (1992). Prosodic structure and tempo in a sonority model of articulatory dynamics. *Papers in Laboratory Phonology II; Gesture, segment, prosody*. G. J. Docherty & D. R. Ladd (eds.), CUP. 68-86.
- [13] Fougerson C. & Keating P. A. (1997). Articulatory strengthening at edges of prosodic domains. *J. Acoust. Soc. Am.* 101 (6), 3728-3740.
- [14] Løvenbrück H. (1999). An investigation of articulatory correlates of the accentual phrase in French. *Proceedings of the XIVth Int. Congress of Phonetics Sciences*, San Francisco, CA, 1, 667-670.
- [15] Vallar G., Guariglia C., Nico D. & Pizzamiglio L. (1997). Motor deficits and optokinetic stimulation in patients with left hemineglect. *Neurology*, 49 (5), 1364-1370.
- [16] Lacquaniti F., Perani D., Guigon E., Bettinardi V., Carrozzo M., Grassi F., Rossetti Y. & Fazio F. (1997). Visuomotor transformations for reaching to memorized targets: a PET study. *Neuroimage*, 5 (2), 129-146.
- [17] Hickok G. & Poeppel D. (2001). Towards a functional neuroanatomy of speech perception. *T. I. C. S.*, 4 (4), 131-138.
- [18] Iacoboni M., Koski L. M., Brass M., Bekkering H., Woods R. P., Dubeau M.-C., Mazziotta J. C. & Rizzolatti G. (2001). Reafferent copies of imitated actions in the right superior temporal cortex. *Proc. Natl. Acad. Sci. USA*, 98 (24), 13995-13999.
- [19] Ross E. D. (1981). The aprosodias: functional-anatomic organization of the affective components of language in the right hemisphere. *Arch. Neurol.* 38, 561-569.
- [20] Brådvik B., Dravins C., Holtås S., Rosén I., Ryding E. & Ingvar D. (1991). Disturbances of speech prosody following right hemisphere infarcts. *Acta Neurologica Scandinavica*, 84, 114-126.
- [21] Dronkers N. F., Pinker S. & Damasio A. (2000). Language and the Aphasias. *Principles of neural science*, E. R. Kandel, J. H. Schwartz & T. M. Jessell (eds.), McGraw-Hill. 1169-1187.
- [22] Zatorre R. J., Evans A. C., Meyer E. & Gjedde A. (1992). Lateralization of phonetic and pitch discrimination in speech processing. *Science*, 256, 846-849.
- [23] Meyer M., Alter K., Friederici A. D., Lohmann G. & von Cramon D. Y. (2002). fMRI reveals brain regions mediating slow prosodic modulations in spoken sentences. *Hum. Brain Mapp.*, 17, 73-88.
- [24] Beckman M. E. (1996). The parsing of prosody. *Language and Cognitive Processes*, 11 (1/2), 17-67.
- [25] Baum S. R. & Pell M. D. (1999). The neural bases of prosody: insights from lesion studies and neuroimaging. *Aphasiology*, 13 (8), 581-608.
- [26] Astésano C., Alter K. & Besson M. (2002). Processing of semantic and prosodic information during spoken language comprehension: an ERP investigation. *Proceedings of the ISCA Workshop on the Temporal Integration in the Perception of Speech*, Aix-en-Provence, France, 8-10 April 2002, 74.
- [27] Mayer J., Wildgruber D., Riecker A., Dogil G., Ackermann H. & Grodd W. (2002). Prosody production and comprehension: converging evidence from fMRI studies. *Proceedings of Speech Prosody 2002*, Aix-en-Provence, France, 487-490.