The neural correlates of grammatical gender decisions in Spanish

Arturo E. Hernandez,[CA] Sonja A. Kotz,[1] Juliane Hofmann,[1] Vivian V. Valentin,[2] Mirella Dapretto[3] and Susan Y. Bookheimer[3]

Department of Psychology, University of Houston, 126 Heyne Bldg., Houston, TX 77204-5022, USA; [1]Max Planck Institute for Cognitive Neuroscience, Germany; [2]University of California, Santa Barbara; [3]University of California, Los Angeles, USA

[CA]Corresponding Author: aehernandez@uh.edu

Received 8 December 2003; accepted 8 January 2004

DOI: 10.1097/01.wnr.0000119452.05850.8c

In the current study, nine participants were asked to make gender decisions for a set of Spanish nouns while being scanned with functional MRI (fMRI). Words were chosen in which a direct mapping between ending and gender ("transparent" items such as carro$_{fem}$ or casa$_{masc}$) is present and those in which there is not a direct relationship ("opaque" items such as fuente$_{fem}$ or arroz$_{masc}$). Direct comparisons between opaque and transparent words revealed increased activity in left BA44/45, and BA44/6 as well as bilateral activation near BA 47/insula and the anterior cingulate gyrus. These results reveal activity in areas previously found to be devoted to articulation of the determiner and to morphological processing. Taken together they support the notion that gender decisions for opaque items requires deeper and more effortful processing during the retrieval of lexical and syntactic information. *NeuroReport* 15:863–866 © 2004 Lippincott Williams & Wilkins.

Key words: Cognitive neuroscience; fMRI; Language; Spanish; Syntax

INTRODUCTION

Grammatical gender is a pervasive phenomenon in many of the world's languages. However, this gender is not conceptual in nature. For example, the French word for ocean (mer) is feminine, while the Italian (mare) and the Spanish (mar) can be either masculine or feminine in Spanish. This clearly shows that gender markings are not completely systematic across languages and do not rely solely on conceptual information. Why does grammatical gender exist? What is it for? Some have suggested that gender helps listeners to keep track of the referents in a sentence, much like uniform numbers indicate the identity of players on a football field [1]. For example, a Spanish speaker will say something like 'pasameLA', pass it$_{fem}$ to me. This allows one to cut the number of potential referents in half. Furthermore, gender marked nouns have to agree with determiners and adjectives. Hence, gender plays a role both at the lexical as well as syntactic level.

Recent discussion in the neuroimaging literature has considered the nature of syntactic processing across a variety of tasks [2,3]. These studies revealed a mixture of results potentially due to a variety of tasks such as sentential tasks [4,5], phrasal [6] and single word tasks [7]. However, all these results have shown increased activity in a set of areas which include BA 44 and 45 for syntactic tasks. Recent work by Miceli and colleagues has also found a similar locus for gender decisions of single nouns compared to phoneme and semantic decision tasks [8]. However, Miceli and colleagues did not explore, opacity, a crucial distinction in Italian. In Spanish, as in Italian, gender can be marked both in a transparent manner (-o for masculine, -a for feminine) and in an opaque manner (in which items can end in e,l,n,r,s,t and z which tend to be more irregular). Previous work has found that processing of opaque items results in longer reaction times [9]. However, to date no published study has investigated the neural correlates associated with the processing of opaque items.

What brain areas will reveal increased activity for opaque items relative to transparent items? Recent work in computational linguistics suggests that the gender of a single word can be computed by word endings [10]. Whereas transparent items involve a one-to-one correspondence between word and ending, opaque items require more complex lexical processing in order to match a particular ending with a gender. Studies using fMRI in German have confirmed the finding that overt generation of the determiner for a noun results in increased activity in BA 44 near BA 6 [11]. Activity in this area has been associated with phonological retrieval [12,13]. If gender decisions for opaque items require more complex phonological retrieval, increased activity in superior BA 44 should be observed. Second, one would also predict that gender decisions should lead to increased activity in BA 44/45 in an area proximal to that observed by Miceli and colleagues. It remains to be seen if this area shows increased activity for opaque items relative to transparent items.

METHODS AND MATERIALS

Subjects: Nine participants (four female) with a mean ($\pm$ s.d.) age of 27.3 $\pm$ 0.82 (range 21–23) years participated in the current experiment. All were native speakers of Spanish who live in the Santa Barbara area, but had not spent more than two years in the United States at the time of testing. None had any past medical history or had used medication. All were right-handed as assessed by our internal handedness questionnaire and reported no left-handed members in their immediate family. Informed consent was obtained from all participants and the current protocol was approved by both the UCLA and UCSB Human Subjects Committees.

Apparatus and procedure: fMRI data were acquired with a General Electric 3.0 T magnetic imager equipped with echo-planar imaging (EPI) from Advanced NMR. Using an EPI gradient echo sequence (TR = 3000 ms; TE = 25 ms; a 64 $\times$ 64 scan matrix with a 24 cm FOV) 108 images were obtained for each subject over 19 slices (4 mm thick/1 mm gap). According to the atlas of Talairach and Tournoux [14], the most inferior and superior slices approximately corresponded to z = −24 and z = +65, respectively. A set of co-planar high-resolution EPI structural images (TR = 4000 ms; TE = 65 ms; matrix size 128 $\times$ 128; FOV = 20 cm) were also collected at the same time to later allow for spatial normalization of each subject's data into a standard coordinate system.

Design and materials: A set of 96 nouns were used in the present experiment. Half of these items were transparent (where gender was marked with an -a or an -o ending), and half the items were opaque (where gender is not marked and words end in e,l,n,r,s,t and z). These were further subdivided into four sets (two opaque and two transparent) which were presented in four separate blocks (see below). Across all four sets, items where matched on length, frequency, imageability, and age of acquisition which are known to influence visual word recognition.

Each scanning session consisted of four activation blocks of 48 s, which alternated with five rest blocks of 24 s each. Before each block participants were shown the cue 'M o F' (masculine or feminine) to indicate that they would be making a gender judgement during the experimental portion of the run. In each activation block, 24 words were presented visually through a set of goggles composed of non-magnetic materials. Stimuli were presented at the rate of 1 every 2 s. Each stimulus remained visible to the participant for 1 s. Behavioral data were acquired via response box for each subject during the fMRI sessions. Male/female judgments were indicated via button press with the middle or index finger. The finger press associated with each judgment was counterbalanced across subjects.

Data analysis: The functional images for each subject were preprocessed using automated image registration (AIR) [15,16] which includes realignment, spatial transformation into Talairach space [14] and smoothing using an 6 mm FWHM isotropic Gaussian kernel to increase the signal-to-noise ratio. Statistical fixed effect analyses were done using Statistical Parametric Mapping Program, 1999 (SPM 99; Wellcome Department of Cognitive Neurology, Institute of Neurology, London, UK) [17]. For activation *vs* rest images we used a correction of $p < 0.001$. For direct comparisons images were corrected for height using the false discovery rate [18] value of $p < 0.05$ and an additional corrected spatial extent threshold of $p < 0.05$. For direct comparisons between opaque and transparent items activation *vs* rest was used as a mask. Statistically significant areas were superimposed on individual brain anatomy in Talairach space using SPM routines. Areas of increased activity in BA 44 were interpreted using the probabilistic maps developed by Tomaiuolo *et al.* [19]. Behavioral data for reaction time and percent correct of the responses was gathered during the scanning session. In addition, we entered reaction time as a covariate. The analyses reported here include comparisons in which reaction time was regressed out for each subject.

RESULTS

Results from mean error rates for all subjects revealed no significant effects (transparent 95%, opaque 95%). Comparisons between transparent and opaque items revealed an effect of opacity for gender decisions (F = 125.32, $p < 0.001$, MSE = 166.97; transparent 882 ms, opaque 962 ms).

For the fMRI data, comparison between opaque gender and rest revealed activity in BA 44, 45, 47, BA 6, the anterior cingulate gyrus and lingual gyrus as well as portions of the anterior STG, and the insula. Comparisons between transparent gender and rest revealed increased activity in many of the same areas (Table 1). Direct comparisons between opaque and transparent items revealed increased activity for opaque items in the left inferior frontal gyrus in BA 44/45, a more superior locus near BA 44/6. Bilateral activity was observed in the insula near BA 47 and the anterior cingulate gyrus (Table 1; Fig. 1). There were no areas of increased activity for transparent items relative to opaque items.

DISCUSSION

The current study was designed to investigate the neural bases of gender decisions using fMRI. Behavioral findings were in line with previous studies which showed that gender decisions were faster and more accurate for transparent than for opaque items [9]. fMRI results revealed increased activity for opaque items in the left inferior frontal gyrus in BA 44/45, a more superior locus near BA 44/6 and the bilateral insula near BA 47. Increased activity for opaque items was also observed in the anterior cingulate gyrus.

Many of these areas parallel those seen in previous studies. BA 44/6 has been observed across a wide range of studies which involve articulation and has been posited to be involved in phonological encoding and retrieval [20]. Furthermore, a recent study in gender production used fMRI to investigate activity when participants generated the article of a noun in German [11]. Articulation of the picture name resulted in activity in a number of areas including the inferior frontal gyrus (BA 44 and BA 45), the anterior insula, the fusiform gyrus and the inferior temporal gyrus. Interestingly, generation of the determiner resulted in increased activity in superior BA 44 in an area which we also observed in the current study. In addition, a locus of activity in the bilateral insula (near BA 47) was also observed in current study, a region also known to be involved in articulation [21]. Finally, damage to the anterior cingulate gyrus has been associated with a reduced drive to

Table I. Areas of increased activity during gender decision.

Region		Transparent *vs* rest					Opaque *vs* rest					Opaque *vs* transparent				
		Voxels	x	y	z	t	Voxels	x	y	z	t	Voxels	x	y	z	t
IFG																
BA 44/6	L	34	−40	9	25	6.3*	694	−46	7	24	12.9[b]	328	−44	2	33	4.8
	L		−42	7	20	6.9*										
	R	39	44	5	31	7.2	85	44	5	31	10.5					
	R	43	46	18	32	5.6*	85	48	15	31	8.1[c]					
	R															
BA 44/45	L												−51	18	14	5.1
	L												−46	13	20	5.2
BA 44	R	56	38	20	14	5.2*										
BA 47	L	23	−53	14	−4	6.2*		−53	13	−4	10.4[b]	154	−50	15	−2	2.8
	L		−42	11	−4	5.8*										
	R															
Insula	L												−40	10	3	2.9
	L	10	−40	10	−4	2.9*	70	−42	18	−4	9.04		−34	17	−4	7.4
	R	15	32	13	−4	2.5*	139	30	21	−6	7.7	236	26	20	3	5.6
	R							34	22	6	7.2		48	5	−7	5.3
BA 47	R												42	17	−6	5.3
MFG																
BA 46	R						185	34	38	15	8.4					
BA 10	R							28	51	7	7.8					
BA 6[a]	L	73	−51	6	38	10.3	90	−51	8	36	8.9					
	L		−42	−2	37	8.0		−44	0	35	11.1					
	L		−48	7	24	8.6										
BA 9	R							42	27	30	7.8[c]					
ACG																
	L	243	−6	10	44	10.9	384	−6	4	46	13.4					
	L		−6	2	50	10.1										
	L		−6	15	34	9.0										
	R						243	−2	23	25	5.9*		325	−2	32	26
	R						384	2	18	40	10.4		89	4	25	37
STG														2	25	30
BA 22	L	361	−55	10	−2	10.2		−57	6	0	10.0[b]					
BA 38	L		−51	13	−7	9.3		−54	14	−4	4.7*					
LG																
BA 18	L	262	−4	−76	−11	10.0		160	−4	−76	−13	11.1				
	R		6	−74	−10	10.2			6	−74	−11	9.93				

IFG, inferior frontal gyrus; MFG, middle frontal gyrus; ACG, anterior cingulate gyrus; STG, superior temporal gyrus; LG, lingual gyrus.
[a]This area of activity crossed into the precentral gyrus. It has been listed as middle frontal gyrus since only a small part of the activity was in the precentral gyrus.[b,c]These three peaks of activity were part of the same cluster but extended into different areas of the brain.
*Areas of activity were there was significant activity with a reduced statistical threshold.

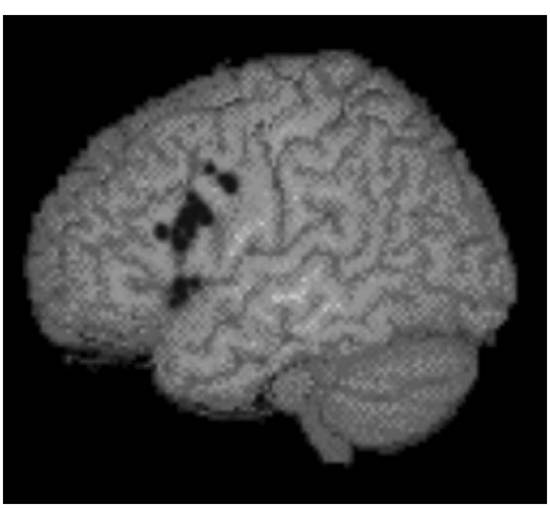

Fig. 1. Areas of increased activity for direct comparison between opaque and transparent items.

speak [22]. Taken together these results suggest that gender decision for opaque items requires increased demands on brain areas involved in articulation, phonological processing and speaking. Increased activation for opaque items was also seen in an area which includes BA 44/45 and is very close to the peak activity reported by Miceli and colleagues when comparing gender decisions to semantic processing using fMRI [8]. Miceli and colleagues suggest that this region has to do with processing grammatical category information, a result which has been supported in other fMRI studies [5–7,23]. Hence, gender decisions for both transparent and opaque items requires increased morphological processing. Our results extend this finding by suggesting that gender decision for opaque items may require additional morphological processing relative to transparent items. So far our data have found activity in areas that have previously been observed in other studies which have investigated the neural bases of grammatical gender. Our interpretation has centered on suggesting that processing of opaque items reveals increased processing of grammatical category information which relies on deeper phonological processing and articulation. Earlier we alluded to one possible strategy that could be used in order to retrieve gender at the single word level: generation of the determiner (el/la). Heim *et al.* [11] actually asked participants to generate the determiner and found that this led to activity in superior BA 44 (near BA 6). Miceli and colleagues found that after debriefing most participants were found to solve the gender decision task by silently generating the determiner and the noun. Post experimental interviews in the current study also found a similar strategy. Interestingly, subjects did not recognize that they were being tested on opaque and transparent items. However, they would mention that they generated the determiner and noun for opaque items such as 'arroz'. However, for transparent items like 'carro' they did not report such a strategy. In short, it appears that in all these studies participants subvocally produce a short noun phrase. That is, participants may be generating a small syntactic phrase in order to retrieve the information. Furthermore, the generation of this small syntactic phrase is more likely to occur for opaque items than for transparent items. While speculative at best, one interpretation is that it is the generation of these syntactic phrases which leads to activity in BA 44/45 for single word gender tasks. However, future studies are needed to more precisely study this. In summary, the current results shed light on the differences in accessing the gender of transparent and opaque items. Opaque nouns required more complex retrieval of grammatical information. This resulted in increased activity in areas involved in articulation, morphological processing, and effortful processing. These findings are consistent with the view that opacity plays a role in the recruitment of neural areas necessary for the retrieval of noun gender.

REFERENCES

1. Bates E, Devescovi A, Hernandez A and Pizzamiglio L. Gender priming in Italian. *Percept Psychophys* **58**, 992–1004 (1996).
2. Vigliocco G. Language processing: the anatomy of meaning and syntax. *Curr Biol* **10**, R78–R80 (2000).
3. Bookheimer S. Functional MRI of language: new approaches to understanding the cortical organization of semantic processing. *Annu Rev Neurosci* **25**, 151–188 (2002).
4. Moro A, Tettamanti M, Perani D, Donati C, Cappa SF and Fazio F. Syntax and the brain: disentangling grammar by selective anomalies. *Neuroimage* **13**, 110–118 (2001).
5. Dapretto M, Bookheimer S and Mazziotta J. Form and content: dissociating syntax and semantics in sentence comprehension. *Neuron* **24**, 427–432 (1999).
6. Kang AM, Constable RT, Gore JC and Avrutin S. An event-related fMRI study of implicit phrase-level syntactic and semantic processing. *Neuroimage* **10**, 555–561 (1999).
7. Friederici AD, Opitz B and Cramon DYv. Segregating semantic and syntactic aspects of processing in the human brain: an fMRI investigation of different word types. *Cerebr Cortex* **10**, 698–705 (2000).
8. Miceli G, Turriziani P, Caltagirone C, Capasso R, Tomaiuolo F and Caramazza A. The neural correlates of grammatical gender: an fMRI investigation. *J Cogn Neurosci* **14**, 618–628 (2002).
9. Bates E, Devescovi A, Pizzamiglio L, D'Amico S and Hernandez AE. Gender and lexical access in Italian. *Percept Psychophys* **57**, 847–862 (1995).
10. Eddington D. Spanish gender assignment in an analogical framework. *J Quant Ling* **9**, 49–75 (2002).
11. Heim S, Opitz B and Friederici AD. Broca's area in the human brain is involved in the selection of grammatical gender for language production: evidence from event-related functional magnetic resonance imaging. *Neurosci Lett* **328**, 101–104 (2002).
12. Burton MW, Small SL and Blumstein SE. The role of segmentation in phonological processing: an fMRI investigation. *J Cogn Neurosci* **12**, 679–690 (2000).
13. Zatorre RJ, Meyer E, Gjedde A and Evans AC. PET studies of phonetic processing of speech: review, replication, and reanalysis. *Cerebr Cortex* **6**, 21–30 (1996).
14. Talairach J and Tournoux P. *Co-planar Stereotaxic Atlas of the Human Brain: A 3-Dimensional Proportional System. An Approach to Cerebral Imaging*. Stuttgart: Thieme Medical; 1988.
15. Woods RP, Dapretto M, Sicotte NL, Toga AW and Mazziotta JC. Creation and use of a Talairach-compatible atlas for accurate, automated, nonlinear intersubject registration, and analysis of functional imaging data. *Hum Brain Mapp* **8**, 73–79 (1999).
16. Woods RP, Mazziotta JC and Cherry SR. Automated image registration. In: Uemura K *et al.* (eds). *International Congress Series, No. 1030, Quantification of brain function: Tracer kinetics and image analysis in brain PET; Proceedings of Brain PET '93, Akita, Japan, May 29–31, 1993*. Amsterdam: Elsevier; 1993, pp. 391–398.
17. Friston KJ. Commentary and opinion: II. Statistical parametric mapping: ontology and current issues. *J Cerebr Blood Flow Metab* **15**, 361–370 (1995).
18. Genovese CR, Lazar NA and Nichols T. Thresholding of statistical maps in functional neuroimaging using the false discovery rate. *Neuroimage* **15**, 870–878 (2002).
19. Tomaiuolo F, MacDonald JD, Caramanos Z, Posner G, Chiavaras M, Evans AC and Petrides M. Morphology, morphometry and probability mapping of the pars opercularis of the inferior frontal gyrus: an *in vivo* MRI analysis. *Eur J Neurosci* **11**, 3033–3046 (1999).
20. Wise RJ, Greene J, Büchel C and Scott SK. Brain regions involved in articulation. *Lancet* **353**, 1057–1061 (1999).
21. Dronkers NF. A new brain region for coordinating speech articulation. *Nature* **384**, 159–161 (1996).
22. Taubner RW, Raymer AM and Heilman KM. Frontal-opercular aphasia. *Brain Lang* **70**, 240–261 (1999).
23. Tettamanti M, Alkadhi H, Moro A, Perani D, Kollias S and Weniger D. Neural correlates for the acquisition of natural language syntax. *Neuroimage* **17**, 700–709 (2002).

Acknowledgements: This material is based upon work supported by the National Science Foundation Grants 'fMRI studies of language and task switching' (BCS0092043) and 'Neural correlates of grammatical gender processing' (INT0202686).