Neural processing of a whistled language

A rare surrogate of Spanish highlights the adaptability of the brain's language regions.

Silbo Gomero is a whistled language that is a rare and endangered surrogate of Spanish, used by shepherds on the island of La Gomera in the Canary Islands for communication over long distances on difficult terrain. Here we show that areas of the brain normally associated with spoken-language function are also activated in proficient whistlers, but not in controls, when they are listening to *Silbo Gomero*. Our findings demonstrate that the language-processing regions of the human brain can adapt to a surprisingly wide range of signalling forms.

The traditionally recognized 'language' areas in the left temporal and inferior frontal lobes of the brain are not exclusive to speech processing — for example, they are engaged in the perception of visual–gestural linguistic signals in sign languages used by the deaf[1] and in non-linguistic acoustic signals[2,3]. We have investigated which areas of the brain are activated in users of *Silbo Gomero*, henceforth *Silbo*, during their comprehension of this whistled language.

Silbo reduces the full phonemic inventory of Spanish to two phonologically contrasting vowels and four consonants[4]. Whistled 'words' are formed by recoding the vowels and consonants of individual Spanish words into whistles that vary along a pitch dimension (high to low) and which differ with respect to the character of the melodic line (continuous or interrupted). Although this leads to phonological mergers and hence potential ambiguities, in practice users rely on repetition and context for the communication of short and simple, routine messages. The compositional, formant-like glides of *Silbo* can therefore function as a form of linguistic communication, provided that listeners know the rules of the whistled codification and can interpret the semantic content in the shared cultural context.

We acquired functional neuroimaging data while users (*Silbadores*) and non-users (controls) of *Silbo* were exposed to comprehension tasks (for details, see supplementary information). The first task involved listening passively to *Silbo* and to Spanish sentences against a baseline condition of digitally reversed *Silbo*. In the second task, participants were asked to monitor cycles of *Silbo* 'words' and Spanish words intermixed with silent periods.

Our results show that the temporal regions of the left hemisphere that are usually associated with spoken-language function[5–7] are engaged during the processing of *Silbo* in experienced *Silbadores* (Fig. 1). Passive-listening and active-monitoring tasks produce a common activation in the left superior posterior temporal gyrus, near the temporal–parietal junction (Fig. 1c); activation of the right-hemisphere superior–midtemporal region is also evident across both the *Silbo* and Spanish speech conditions (Fig. 1a, d).

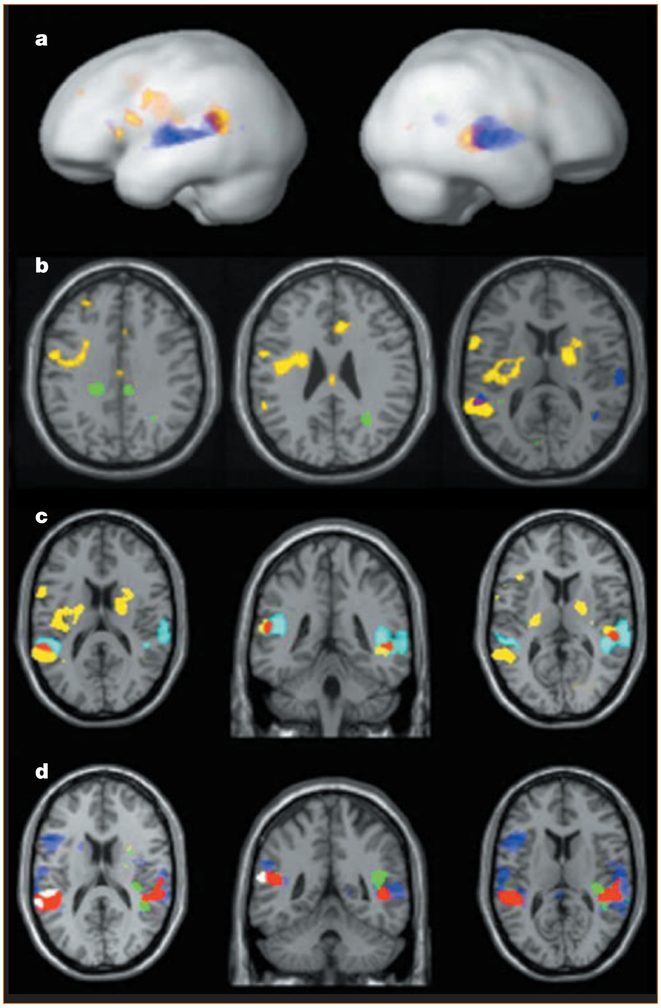

Figure 1 Colour-coded brain-activation patterns from functional neuroimaging of *Silbadores* and non-whistler controls, produced in response to tasks in *Silbo Gomero* and in Spanish. **a,** Surface rendering of each side of the brain, and **b,** axial sections of a normalized brain, showing sites of activation by passive listening to sentences in *Silbo* and in Spanish. **c, d,** Axial and coronal (centre) sections showing sites of activation for **c,** *Silbadores* in *Silbo* passive-listening and *Silbo*-monitoring tasks; and for **d,** *Silbadores* and non-whistlers in all *Silbo* and all Spanish-spoken tasks. Voxel coloration for activation response: yellow, *Silbadores* to *Silbo* sentences (**a–c**); green, non-whistlers to *Silbo* sentences (**b**) and to all *Silbo* tasks (**d**); dark blue, all subjects to Spanish sentences (**a, b**) and to spoken Spanish tasks (**d**); light blue, *Silbadores* to *Silbo*-monitoring tasks; white, *Silbadores* to all *Silbo* tasks; and red, common activations in *Silbadores* for *Silbo* and Spanish (**a, b, d**) and for the two *Silbo* tasks in **c**. The left side of the axial and coronal images corresponds to the left side of brain.

Activity increases in the right temporal lobe in response to non-linguistic pitch changes, tones and complex sounds[8,9], but the same regions may also be associated with linguistic processing tasks — particularly at the sentence level[10]. However, we identified no common cortical language areas for *Silbo* and for speech in non-whistlers (Fig. 1a, b). Group analysis indicated that the areas activated during both Spanish and *Silbo* processing in *Silbadores* differ significantly from those in non-whistlers (Fig. 1d, and see supplementary information). A time-series analysis of the region of interest for each subject verified that *Silbo* modulates cortical activity only in the *Silbadores* and not in the controls (see supplementary information).

How is this pattern of activation for whistle processing in experienced users of *Silbo* (Fig. 2) explained? On the one hand, whistled speech relies upon changes in pitch and melodic form to create distinctive acoustic patterns; on the other, it serves a communicative function. Our results indicate that, in this situation, it is the temporal-lobe regions implicated in language processing that respond, even though the signal is a whistle and the language an unusual speech surrogate.

Left-hemisphere temporal and parietal regions may provide complementary pathways for language processing[5–7,11]. It has been proposed that an anterior–ventral system is used for analysing and mapping complex acoustic sounds, such as speech, onto lexical representations and that a posterior–dorsal system processes the articulatory–gestural representation of speech[8]. We saw less ventral–anterior temporal activation during *Silbo*-processing than during speech-processing tasks, perhaps because this simple whistled system has only a limited number

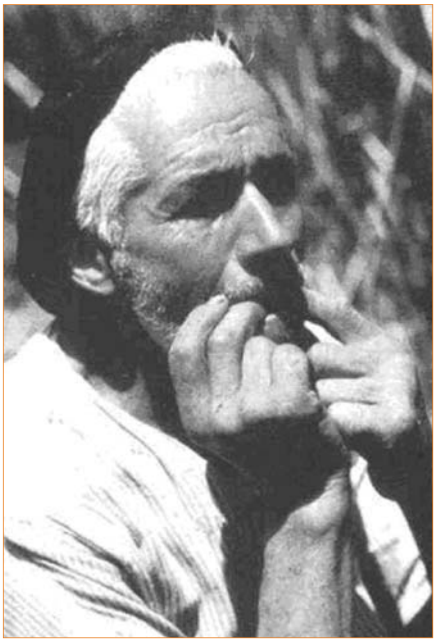

Figure 2 *Silbador* from La Gomera in the Canary Islands using the whistled language *Silbo Gomero* as a means of remote communication. The language recodes the vowels and consonants of individual Spanish words into whistles.

of uniquely specified phonological contrasts that need to be analysed. But for both speech and *Silbo* processing, the posterior temporal cortex is activated in a region that is involved in articulatory–gestural representations[12,13]. The presence of premotor activation (tongue and lip representation) that is involved during *Silbo* communication is consistent with this interpretation.

Manuel Carreiras*, Jorge Lopez†, Francisco Rivero*, David Corina‡
**Departamento de Psicología Cognitiva, Universidad de La Laguna, La Laguna, Tenerife, 38205, Spain*
e-mail: mcarreir@ull.es
†IMETISA, Hospital Universitario de Canarias, La Laguna, Tenerife, 28320, Spain
‡Department of Psychology, University of Washington, Seattle, Washington 98195–1525, USA

---

1. Petito, L. A. *et al. Proc. Natl Acad. Sci. USA* **97,** 13961–13966 (2000).
2. Joanisse, M. F. & Gati, J. S. *NeuroImage* **19,** 64–79 (2003).
3. Giraud, A. L. & Price, C. J. *J. Cogn. Neurosci.* **13,** 754–765 (2001).
4. Trujillo. R. *El Silbo Gomero: Análisis Lingüístico* (Canaria-Andrés Bello, Tenerife, 1978).
5. Hickok, G. & Poeppel, D. *Trends Cogn. Sci.* **4,** 131–138 (2000).
6. Binder, J. R. *et al. Cereb. Cortex* **10,** 512–528 (2000).
7. Scott, S. K. & Johnsrude, I. S. *Trends Neurosci.* **26,** 100–107 (2003).
8. Specht, K. & Reul, J. *NeuroImage* **20,** 1944–1954 (2003).
9. Warren, J. D. & Griffiths, T. D. *J. Neurosci.* **23,** 5799–5804 (2003).
10. Kircher, T. T. J., Brammer, M., Andreu, N. T., Williams, S. C. R. & McGuire, P. K. *Neuropsychologia* **39,** 798–809 (2001).
11. Belin, P. & Zatorre, R. J. *Nature Neurosci.* **3,** 965–966 (2000).
12. Hickok, G., Buchsbaum, B., Humphries, C. & Muftuler, T. *J. Cogn. Neurosci.* **15,** 673–682 (2001).
13. Hickok, G. & Poeppel, D. *Cognition* **92,** 67–99 (2004).

Supplementary information accompanies this communication on *Nature*'s website.

Competing financial interests: declared none.

Environment

Early ant plagues in the New World

The identity and origin of the West Indian plague ants of the early sixteenth and late eighteenth centuries have long been a mystery[1]. By reviewing historic accounts with an analysis of the present-day Caribbean ant fauna, I have narrowed the list of suspects to two species and their insect symbionts.

During, or soon after, 1518–19, a plague of stinging ants hit the fledgling Spanish settlements on Hispaniola, the second largest island in the Greater Antilles. According to an eyewitness account by the premier colonial historian Bartolomé de Las Casas[2], the insects destroyed crops over a substantial portion of the island and invaded dwellings. During 1760–70, similar ant plagues spread through the Lesser Antilles, reducing sugar-cane fields to "a state of the most deplorable condition"[3].

What were the plague ants, and why did they multiply to such proportions? I investigated these questions during field work on the historic plague islands, paying particular attention to species that might be descendants of the plague ants. I also combed contemporary accounts of the ants and fitted together information concerning their appearance and habits, which I matched against that of the now reasonably well-known modern ant fauna. By a process of elimination, I narrowed the list of fauna to candidates with all of the available defining traits.

The Hispaniolan plague ant is easily characterized from the first-hand account of Las Casas[2]. The ant he described was very aggressive; it had a painful sting; it occurred in dense populations in the root systems of shrubs and trees; it did not cut above-ground vegetation yet somehow damaged the root systems; and it was also a pest in houses and gardens. The only species also present in the modern West Indian ant fauna that has all these qualities is the tropical fire ant, *Solenopsis geminata.* This inference is strengthened by the fact that another fire-ant species, *S. invicta*, attained plague proportions in the Gulf states in the 1940s, following its introduction from the La Platte region of Brazil and northern Argentina[4].

The 1760–70 plague ants of the Lesser Antilles had the same traits as *S. geminata* save two: in the several accounts of these species, including details from an eye-witness on Grenada[5], there is not a single mention of defensive aggression or of stinging by the ants. An attack by swarms of fire ants is unavoidable if an intruder nears their nests, and would surely have been mentioned by anyone who had experienced it. And a fire-ant sting contains a venom that burns, creating a small, itching welt, which would presumably also have been reported.

There is one possible clue: on Barbados in the mid-1600s there was an ant that was a serious house pest. Unlike fire ants, its workers lifted and carried large food items, such as cockroaches, in an unusually coordinated fashion. This feature points to the ant genus *Pheidole.* Among the many species known from the West Indies[6], only two are candidates: *P. jelskii*, a native species, and *P. megacephala*, which is of African origin. The evidence favours *P. megacephala*, a global, invasive ant that has caused similar problems in other tropical countries[7].

A puzzle remains: only the attine leafcutter ants of the New World are known to attack vegetation as an important source of food, yet entire plantations on Hispaniola were wiped out "as though fire had fallen from the sky and scorched them", records Las Casas[2]. Sugar cane in the fields of the Lesser Antilles likewise disappeared in the 1760s (ref. 3).

The only viable hypothesis is that the ants had a symbiotic relationship with insects that attack plants directly. The two plague-ant suspects, *S. geminata* and *P. megacephala*, heavily attend sap-sucking coccids, mealy bugs and other insects of the Homoptera group[7]. The ants protect these insects in exchange for their abundant excrement, which is rich in sugar and amino acids. The Spanish, not recognizing the role of the homopterous sap-suckers in the midst of the myriad kinds of insect teeming around their crops, would understandably put the blame on the stinging ants. It was not until the late eighteenth century, on Grenada, that naturalists began to suspect the involvement of homopterans in the West Indian ant plagues[5].

Edward O. Wilson
Museum of Comparative Zoology, Harvard University, 26 Oxford Street, Cambridge, Massachusetts 02138-2902, USA
e-mail: ewilson@oeb.harvard.edu

---

1. Wheeler, W. M. in *Translation of* Histoire des Fourmis *(de Réaumur, R. A. F., unpublished, 1742–43)* 232–239 (Knopf, New York, 1926).
2. de Las Casas, B. in *Historia de las Indias III, Capítulo CXXXVIII,* 270–271 (Impr. de M. Ginesta, Madrid, 1875–1876).
3. Schomburgk, R. H. in *History of Barbados* 640–643 (Longman, Brown, Green and Longmans, London, 1848).
4. Lofgren, C. S. & Vander Meer, R. K. (eds) *Fire Ants and Leaf-cutting Ants: Biology and Management* (Westview, Boulder, Colorado, 1986).
5. Castles, J. *Phil. Trans. R. Soc. Lond.* **16,** 688–694 (1804).
6. Wilson, E. O. *Pheidole in the New World: A Dominant, Hyperdiverse Ant Genus* (Harvard Univ. Press, Cambridge, Massachusetts, 2003).
7. Hölldobler, B. & Wilson, E. O. *The Ants* (Belknap, Harvard Univ. Press, Cambridge, Massachusetts, 1990).

Competing financial interests: declared none.

brief communications arising **online**
www.nature.com/bca

Human behaviour: Egalitarian motive and altruistic punishment
J. H. Fowler, T. Johnson, O. Smirnov
(doi:10.1038/nature03256)
Reply: E. Fehr, S. Gächter (doi:10.1038/nature03257)