Language rhythms in baby hand movements

Hearing babies born to deaf parents babble silently with their hands.

The vocal babbling sounds universally uttered by healthy babies at around 7 months of age are fascinating, and have been interpreted as reflecting both the origins of language production in humans[1] and the vestiges of the evolutionary origins of language in our species[2]. Here we study the hand movements of hearing babies born to profoundly deaf parents and find that these children produce a class of hand activity that is distinct from other uses of their hands and which contains the specific rhythmic patterns of natural language ('silent' babbling). Our findings support the idea that babies are sensitive to rhythmic language patterns and that this sensitivity is key to launching the process of language acquisition.

The biological basis of babbling has been debated for decades. One possibility is that babbling, as in modern accounts of the origins of human language, is a purely non-linguistic motor activity that results from the opening and closing of the mouth and jaw[3–6]. Alternatively, babbling could be a linguistic activity that reflects babies' sensitivity to specific patterns at the heart of human language and their capacity to use them[7–9] — particularly the rhythmic patterns that bind syllables, the elementary units of language, into baby babbles, and then into words and sentences.
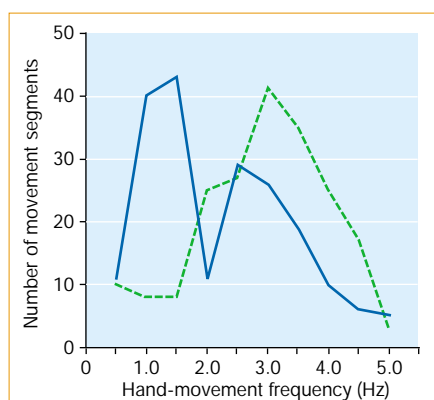

Figure 1 Hand-movement frequencies calculated for the rhythmic hand activity of sign-exposed (full line) and speech-exposed (dashed line) babies across all ages; for each group, 400 movement segments (200 per group) were randomly selected. Only sign-exposed babies had a bimodal distribution of movement frequencies: the first mode (left peak) falls at around 1 Hz (range, 0.5–1.5 Hz) and the second mode (right peak) falls at around 2.5 Hz (range, 2.0–3.0 Hz). In contrast, hand-movement frequencies of speech-exposed babies were unimodal, falling at around 3.0 Hz (range, 2.5–3.5 Hz). Comparison of the two groups further revealed that the pattern of movement frequencies produced by sign-exposed babies was significantly different from that of speech-exposed babies at the same age (20, $n = 200$; $\chi^2 = 389.65$, $P < 0.001$); χ^2 was calculated at 21 quarter-intervals and is shown here at half-intervals for clarity.

To test the motor and linguistic hypotheses, we studied three hearing babies who received no systematic exposure to spoken language and who instead saw only signed language from their profoundly deaf parents, and three hearing babies who were exposed to spoken language. We previously compared the capacity of hearing and deaf babies to babble in another study, in which group differences may have resulted from the babies' different sensory experiences[10].

The two hearing baby groups were equal in all developmental respects, with the only difference being in the form of language input they received (by hand or mouth). Because hearing babies exposed to sign language do not use their mouth and jaw to learn speech, the motor hypothesis predicts that their hand activity should be fundamentally similar to that of hearing babies acquiring spoken language. If, however, babies are born with sensitivity to specific rhythmic patterns that are universal to all languages, even signed ones, then the linguistic hypothesis predicts that differences in the form of language input should yield differences in the hand activities of the two groups.

We recorded all babies' hand activity in three dimensions using Optotrak, an opto-electronic position-tracking system. The hand activity was carried out during presentation with objects and during game-playing in 60-min experimental sessions conducted when the babies were aged about 6, 10 and 12 months. Optotrak sensors accurately measure the trajectory and location over time of light-emitting diodes on the babies' hands with a 0.1-mm precision. Optotrak computations were carried out blind to videotape recordings of the positions of the babies' hands, which on their own are a subjective way to analyse hand movements[11]. Online videotapes were made of all babies independently for post-Optotrak analysis.

Optotrak analyses revealed that sign-exposed babies showed a significantly different type of low-frequency rhythmic hand activity from speech-exposed babies, as well as another type of high-frequency rhythmic hand activity that speech-exposed babies also showed and used almost exclusively (Fig. 1).

The low-frequency hand activity of sign-exposed babies was mainly generated within a tightly restricted space (Fig. 2), corresponding to the obligatory 'sign-phonetic' space in front of a signer's body that binds all linguistic expression in signed languages (82%); high-frequency hand activity was mainly outside this space (73%). Speech-exposed babies produced most of their high-frequency hand activity

Figure 2 Learning language: a class of hand movements made by babies with profoundly deaf parents have a slower rhythm than ordinary gestures and are restricted to space in front of the body.

outside the crucial linguistic space (92%). Quantitatively, the low-frequency hand activity corresponds to the rhythmic patterning of adult sign-syllables[12]. We also discovered, after lifting the blind on videotape recordings, that only these low-frequency movements had the qualitative properties of silent linguistic hand babbling[10].

Remarkably, and without relying on the mouth, this silent linguistic babbling was conveyed by babies' hands in a different class of movement from non-linguistic hand activity. These linguistic and motor movements are differentiated by their distinct rhythmic frequencies, which could only result if babies are able to use the specific rhythmic patterns that underlie human language.

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1. Locke, J. L. *The Child's Path to Spoken Language* (Harvard Univ. Press, Cambridge, Massachusetts, 1993).
2. Lieberman, P. *Human Language and Our Reptilian Brain: The Subcortical Bases of Speech, Syntax, and Thought* (Harvard Univ. Press, Cambridge, Massachusetts, 2000).
3. MacNeilage, P. F. & Davis, B. L. *Science* **288**, 527–531 (2000).
4. Locke, J. L. *Science* **288**, 449–451 (2000).
5. Studdert-Kennedy, M. G. in *Cognition and the Symbolic Processes: Applied and Ecological Perspectives* (eds Hoffman, R. R. & Palermo, D. S.) 38–58 (Erlbaum, Hillsdale, New Jersey, 1991).

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6. van der Stelt, J. M. & Koopmans-van Beinum, F. J. in *Precursors of Early Speech* (eds Lindblom, B. & Zetterstrom, R.) 163–173 (Stockton, New York, 1986).
7. Pinker, S. & Bloom, P. in *The Adapted Mind: Evolutionary Psychology and the Generation of Culture* (eds Barkow, J. H. *et al.*) 451–493 (Oxford Univ. Press, New York, 1992).
8. Jusczyk, P. W. *The Discovery of Spoken Language* (MIT Press, Cambridge, Massachusetts, 1997).
9. Vihman, M. M. *Phonological Development: The Origins of Language in the Child* (Blackwell, Cambridge, MA, 1996).
10. Petitto, L. A. & Marentette, P. F. *Science* **251,** 1493–1496 (1991).
11. Meier, R. P. & Willerman, R. in *Language, Gesture, and Space* (eds Emmorey, K. & Reilly, J. S.) 391–409 (Erlbaum, Mahwah, New Jersey, 1995).
12. Petitto, L. A. *et al. Proc. Natl Acad. Sci. USA* **97,** 13961–13966 (2000).

Spectrographic imaging

A bird's-eye view of the health of coral reefs

Almost three-quarters of the world's coral reefs are thought to be deteriorating as a consequence of environmental stress. Until now, it has been possible to evaluate reef health only by field survey, which is labour-intensive and time-consuming. Here we map live coral cover from the air by remote imaging, a technique that will enable the state of shallow reefs to be monitored swiftly and over large areas.

It is predicted that coral reefs will suffer mounting stress associated with a global increase in atmospheric carbon dioxide over the coming decades[1,2] and from local disturbances such as overfishing[3] and disease[4]. The most obvious effect of such stress is a decline in living coral cover, so a temporal change in cover is a good indicator of the state of health of a coral reef. However, the measurement of coral cover by field survey[5] is impractical on the scale of hundreds to thousands of square kilometres.

Measurements of the reflected light spectra of reef biota and substrata indicate that the dominant groups can be distinguished *in situ*[6–10], but until now it has not been clear whether such spectral differences can be detected remotely from the air or from space. We acquired high-spatial-resolution ($1\,m \times 1\,m$), multispectral images from the air of two reefs in the lagoon of Rangiroa Atoll, French Polynesia, by using a compact spectrographic imager. We carried out this imaging in November 1998 because coral populations had suffered significant mortality after the extreme El Niño/Southern Oscillation that occurred in the austral summer of 1997–98 (ref. 11). At the same time, we carried out detailed *in situ* surveys of coral populations on each reef.

The first reef was dominated by large live and dead colonies of *Porites*, the remotely sensed spectra of which were readily distinguishable on the basis of their first spectral derivatives (rate of change of reflectance versus wavelength[12]) in the wavelength region 506–565 nm, as expected from *in situ* measurements[8].

The habitat of the second reef was highly heterogeneous and we used the imager to estimate the percentage cover of all substrata in ten plots of $25\,m^2$ each. Although within-plot estimates of the cover of dead *Pocillopora* coral, coralline red algae and sand varied by as much as 25–29%, estimates of live coral never differed from field data by more than 10% (Table 1). At a whole-reef (interplot) scale, estimates of the mean cover of all major benthic categories differed by less than 8%, and the cover of both live and dead coral was estimated to within 3%. There were no significant differences in estimates of mean habitat cover at the 95% confidence level (paired *t*-tests).

The video surveying methods currently used by scientific divers on the Great Barrier Reef are estimated to have a 95% probability of detecting a 10% change in live coral cover from one year to the next[13]. Power analysis of our data indicates that 22 plots of $25\,m^2$ each would need to be surveyed by remote sensing, compared with 20 equivalent-sized plots by video camera, to achieve the same level of statistical resolution on the reefs surveyed (that is, similar sample sizes for field and remote methods). However, spectographic images can be acquired over areas that are many times larger than those that can be surveyed underwater.

We anticipate that the application of multispectral remote sensing will significantly improve estimates of coral cover and changes in coral cover over time. It took us 1 hour to acquire images over $92,500\,m^2$ of reef, which represents 3,700 plots of $25\,m^2$ each, compared with 3 days to survey 10 such plots underwater. Moreover, remote images are acquired as numerical data, which can be rapidly processed electronically, reducing the time needed to generate estimates of surface cover.

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1. Pittock, A. B. *Am. Zool.* **39,** 10–29 (1999).
2. Kleypas, J. A. *et al. Science* **284,** 118–120 (1999).
3. Hughes, T. P. *Science* **265,** 1547–1551 (1994).
4. Harvell, C. D. *et al. Science* **285,** 1505–1510 (1999).
5. English, S., Wilkinson, C. & Baker, V. *Survey Manual for Tropical Marine Resources* (Australian Inst. Mar. Sci., Townsville, 1997).
6. Holden, H. & LeDrew, E. *Remote Sensing Environ.* **65,** 217–224 (1998).
7. Myers, M. R., Hardy, J. T., Mazel, C. H. & Dustan, P. *Coral Reefs* **18,** 179–186 (1999).
8. Clark, C. D., Mumby, P. J., Chisholm, J. R. M., Jaubert, J. & Andrefouet, S. *Int. J. Remote Sensing* **21,** 2321–2327 (2000).
9. Hochberg, E. J. & Atkinson, M. J. *Coral Reefs* **19,** 164–171 (2000).
10. Lubin, D., Li, W., Dustan, P., Mazel, C. H. & Stamnes, K. *Remote Sensing Environ.* **75,** 127–137 (2001).
11. Mumby, P. J. *et al. Mar. Biol.* **139,** 183–189 (2001).
12. Tsai, F. & Philpot, W. *Remote Sensing Environ.* **66,** 41–51 (1998).
13. Carleton, J. H. & Done, T. J. *Coral Reefs* **14,** 35–46 (1995).

Immune recognition

A new receptor for β-glucans

The carbohydrate polymers known as β-1,3-D-glucans exert potent effects on the immune system — stimulating antitumour and antimicrobial activity, for example — by binding to receptors on macrophages and other white blood cells and activating them. Although β-glucans are known to bind to receptors, such as complement receptor 3 (ref. 1), there is evidence that another β-glucan receptor is present on macrophages. Here we identify this unknown receptor as dectin-1 (ref. 2), a finding that provides new insights into the innate immune recognition of β-glucans.

We screened a RAW264.7 complementary DNA retroviral expression library using the β-glucan-rich particle zymosan[3]

Table 1 Estimates of substrate cover for live and dead reefs

	Cover (%)		Mean disparity (%)	Maximum disparity (%)	Minimal detectable disparity of means (%)
	Field survey	Imagery			
Live *Porites*	11.5 (2.7)	8.8 (2.9)	− 2.7	− 9	5.6
Recently dead *Porites*	7.8 (1.6)	6.8 (3.1)	− 1.0	18.9	10.6
Dead *Pocillopora*	32.5 (8.3)	37.2 (12.6)	4.7	28.9	17.3
Red coralline algae	21.9 (2.4)	15.2 (4.8)	6.6	− 25.7	14.3
Sand	18.9 (6.0)	26.8 (9.1)	7.9	27.2	12.1
Halimeda	3.9 (1.6)	5.1 (2.1)	1.2	− 9.7	8.3

Field and remote estimates of substrate cover are shown for comparison (standard errors shown in parentheses). Results of pairwise *t*-test comparisons for each habitat were non-significant ($P < 0.05$). Minimal detectable difference represents the smallest disparity in mean cover between field and image estimates that would result in a significant *t*-test with 90% power. These values provide a worst-case scenario for the accuracy of remote sensing to predict mean habitat cover; actual disparities were considerably lower. Compact airborne spectrographic imager (CASI) data (10 bands) were corrected for depth variation (1–7 m) using image-derived attenuation coefficients. Substrata were predicted from unsupervised classification of spectral data and were categorized using independent field data. Each plot was identified on CASI images by triangulation to white plastic markers ($4\,m^2$) and mapped *in situ* with a resolution of $0.01\,m^2$.