Elephants are capable of vocal learning

Two animals coin unexpected sounds as a surprising form of social communication.

There are a few mammalian species that can modify their vocalizations in response to auditory experience[1] — for example, some marine mammals use vocal imitation for reproductive advertisement, as birds sometimes do. Here we describe two examples of vocal imitation by African savannah elephants, *Loxodonta africana*, a terrestrial mammal that lives in a complex fission–fusion society[2]. Our findings favour a role for vocal imitation that has already been proposed for primates, birds, bats and marine mammals: it is a useful form of acoustic communication that helps to maintain individual-specific bonds within changing social groupings[3,4].

In the first case, we recorded imitations of truck sounds made by Mlaika, a ten-year-old adolescent female African elephant living in a semi-captive group of orphaned elephants in Tsavo, Kenya. Trucks were sometimes audible (Fig. 1a) from Mlaika's night stockade, which lay 3 km from the Nairobi–Mombasa highway. Mlaika emitted truck-like sounds (Fig. 1b; audio file in supplementary information) for several hours after sunset, the optimal time for the transmission of low-frequency sound in African savannahs[5].

Comparisons of durations and of minimum and maximum fundamental frequencies show that Mlaika's truck-like calls differ from normal African adult, adolescent and calf calls (Fig. 2a; Mann–Whitney *U*-test, $P < 0.002$). Mlaika's truck-like calls do not differ significantly from the truck sounds (Fig. 2a; Mann–Whitney *U*-test, $P > 0.1$). For comparisons that used Mlaika's calls or truck sounds, ten samples were randomly selected from the appropriate data set (for methods and further details, see supplementary information).

The individual means for the three acoustic parameters of these calls (Fig. 2b) also show that Mlaika's truck-like calls differ from the normal calls of African elephants[6] and are similar to the recorded truck sounds. Mlaika's truck-like calls are no more similar to the sounds of trucks recorded at the same time than they are to truck sounds recorded at other times (*t*-test, $P > 0.6$), suggesting that Mlaika used the general features of truck sounds as a model.

A second case of imitation by an African elephant involves the chirping sounds[7] typically produced by Asian elephants, *Elephas maximus,* though not by African elephants. Calimero is a 23-year-old male African elephant who spent 18 years with two female Asian elephants at the Basel Zoo in Switzerland. The spectrogram in Fig. 1c shows a typical series of chirps from one of the Asian elephants and Fig. 1d shows the similar

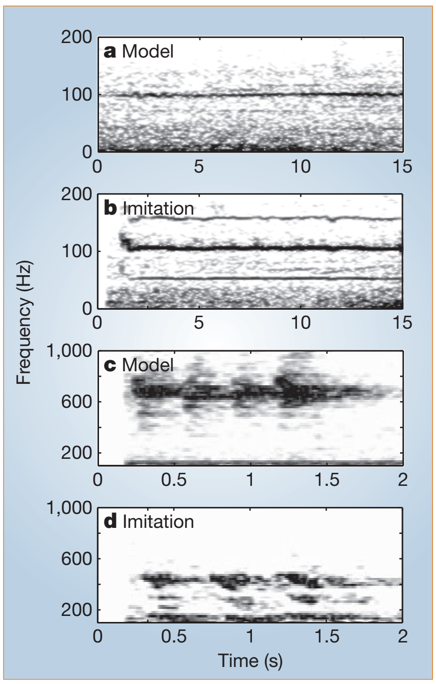

Figure 1 Spectrograms showing examples of models and sound imitations by two African elephants, Mlaika and Calimero. **a,** Sound of a distant truck recorded from within Mlaika's night stockade; **b,** Mlaika's truck-like call. **c,** Chirps emitted by Asian female elephants living in captivity with Calimero, and **d,** the chirp-like calls emitted by Calimero. (For details and audio files, see supplementary information.)

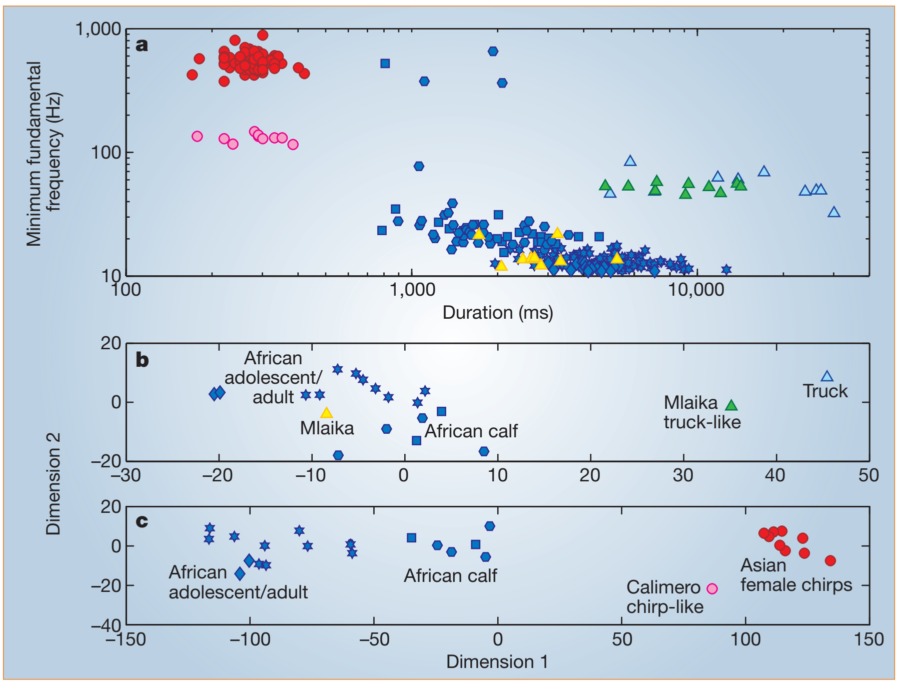

Figure 2 Imitation of sounds by the African elephants Mlaika and Calimero. Mlaika's imitations (green triangles) are similar to truck sounds (light-blue triangles) and differ from her normal calls (yellow triangles), which are similar to the sounds made by other African elephants (dark blue symbols: stars, adult female; diamonds, adult male; squares, female calf; hexagons, male calf). Calimero makes chirp-like sounds (pink circles) similar to the chirps of the Asian elephants (red circles) who lived with him. **a,** Scatterplot of frequency versus duration for ten calls from each source. **b,** Multidimensional scaling plot of means for each source in **a,** apart from the chirp sounds. **c,** Multidimensional scaling plot of individual means from chirps of nine female Asian elephants and Calimero's chirp-like calls. Dimension numbering represents different combinations of acoustic features; for methods and further details, see supplementary information.

chirp-like calls made by Calimero, who seldom makes any other sounds.

Using the same statistical analysis as that applied to Mlaika's calls, we find that Calimero's chirp-like calls do not significantly differ in duration from the chirping calls of Asian elephants ($P > 0.46$) and differ in all parameters from mean adult, adolescent and calf African elephant calls ($P < 0.002$; Fig. 2a). Multidimensional scaling confirms that Calimero's chirp-like calls differ from the normal calls of African elephants and are similar to the chirps of female Asian elephants (Fig. 2c).

The evolution of vocal imitation in humans, some birds, bats and dolphins may result from the need to use acoustic signals to maintain individual-specific bonds when animals separate and reunite[1,3]. If so, then vocal learning should occur in other species in which long-lived social bonds are based upon individual-specific relationships and involve fluid group membership, and where vocal communication is used to maintain contact and individual or group recognition. Our finding that an African savannah elephant matched the calls of Asian elephants with whom he lived follows a pattern commonly seen in species that are capable of vocal learning, in which calls converge as the animals form social bonds[3].

Vocal learning enables a flexible and open communication system in which animals may learn to imitate signals that are not typical of the species, as demonstrated by the elephant that imitated trucks. To our knowledge, this discovery in elephants is the first example of vocal imitation in a non-primate terrestrial mammal. It strengthens the idea that there is a primary selection pressure for vocal learning that involves the communicative demands of maintaining social relationships in fluid societies.

Joyce H. Poole*, Peter L. Tyack†, Angela S. Stoeger-Horwath‡, Stephanie Watwood†

**ElephantVoices, Amboseli Trust for Elephants, PO Box 15135, Langata 00509, Nairobi, Kenya*

†Biology Department, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543, USA

e-mail: ptyack@whoi.edu

‡Institute of Zoology, University of Vienna, 1090 Vienna, Austria

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Meteorology

Dusty ice clouds over Alaska

Particles lofted into the atmosphere by desert dust storms can disperse widely and affect climate directly through aerosol scattering and absorption. They can also affect it indirectly by changing the scattering properties of clouds and, because desert dusts are particularly active ice-forming agents, by affecting the formation and thermodynamic phase of clouds. Here I show that dust storms that occurred in Asia early in 2004 created unusual ice clouds over Alaska at temperatures far warmer than those expected for normal cirrus-cloud formation.

Although the direct light-scattering effects of dust storms are readily observed from satellites[1], their indirect effects on clouds are difficult to quantify. Knowledge about the effects of desert dusts on clouds has come from polarization lidars (detection systems that work on radar principles but use laser light), which can identify both non-spherical aerosols and the phase of clouds[2]. The evidence suggests that, even after great transport distances, aerosols from both the Asian and Saharan deserts affect cirrus and supercooled water clouds[3–6]. It has long been known that desert dusts are highly effective as nuclei on which ice crystals form heterogeneously[7].

From late February to mid May 2004, ruby (0.694 μm wavelength) polarization-lidar observations[8] from the University of Alaska at Fairbanks (64.86 °N, 147.84 °W) regularly detected elevated dust layers, which were tracked back to a series of Asian dust storms. In many cases, the dust layers sporadically developed embedded ice-crystal clouds. This phenomenon is illustrated in Fig. 1 by the backscattered laser power and linear depolarization ratio (δ, which is the ratio of the powers in the planes of polarization orthogonal and parallel to that transmitted). Figure 1 shows two hours of lidar display over a range of heights. Aerosols are particularly apparent in stratified layers at between about 4.5 and 6.5 km of height because of their enhanced backscattering (an increase in display brightness) and depolarization (values of δ, 0.1–0.2) compared with that produced by molecular scattering. Also prominent is the embedded ice cloud centred at 5.5 km at about 20:30 GMT, which displays even stronger backscattering and depolarization. This cloud had a minimum temperature of −36 °C and a maximum relative humidity (with respect to ice) of 103% (according to the bracketing local radiosonde data).

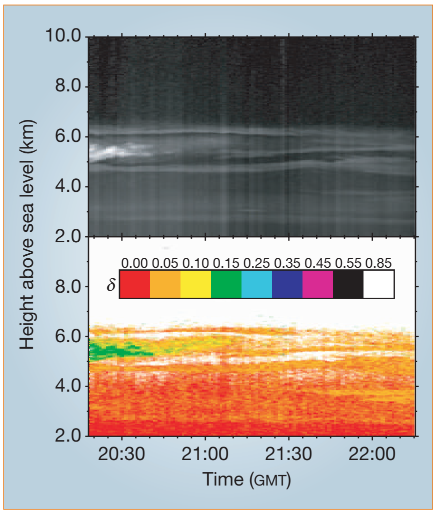

Figure 1 Polarization-lidar height against time display, showing ice-cloud formation in an elevated desert-dust aerosol layer. Displays of backscattered laser power (top; logarithmic grey scale) and linear depolarization ratio (colour scale; δ is the ratio of the powers in the planes of polarization orthogonal and parallel to that transmitted) are given for a two-hour period on 29 February 2004, as debris from an Asian dust storm drifted over the interior of Alaska.

Similar mixed dust and ice layers were observed with cloud-top temperatures between about −15 °C and −40 °C: these are abnormally warm compared with those of cirrus clouds, which form by the homogeneous nucleation of haze particles[8]. The corresponding relative humidities indicate an almost ice-saturated environment, which also contrasts with the high supersaturations needed for cirrus formation[9]. In laboratory experiments, dust particles needed ice supersaturations of only 10–15% to nucleate ice crystals directly from the vapour[10].

Although there have been previous indications that desert dusts alter clouds[3–6], to my knowledge this is the first time that they have been shown to serve as deposition ice nuclei in the atmosphere and to create ice clouds at modest supersaturations and temperatures. Desert dust storms are a natural part of our world, but we must be wary in case human activities in arid lands, or climate change itself, are increasing aerosol amounts and so further altering climate by affecting distant clouds.

Kenneth Sassen

Geophysical Institute, University of Alaska Fairbanks, Fairbanks, Alaska 99775, USA

e-mail: ksassen@gi.alaska.edu

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