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Spontaneous human speech mimicry by a cetacean

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Although dolphins (*Tursiops truncatus*) have been trained to match numbers and durations of human vocal bursts [1] and reported to spontaneously match computer-generated whistles [2], spontaneous human voice mimicry has not previously been demonstrated. The first to study white whale (*Delphinapterus leucas*) sounds in the wild, Schevill and Lawrence [3] wrote that "occasionally the calls would suggest a crowd of children shouting in the distance". Fish and Mowbary [4] described sound types and reviewed past descriptions of sounds from this vociferous species. At Vancouver Aquarium, Canada, keepers suggested that a white whale about 15 years of age, uttered his name "Lagosi". Other utterances were not perceptible, being described as "garbled human voice, or Russian, or similar to Chinese" by R.L. Eaton in a self-published account in 1979. However, hitherto no acoustic recordings have shown how such sounds emulate speech and deviate from the usual calls of the species. We report here sound recordings and analysis which demonstrate spontaneous mimicry of the human voice, presumably a result of vocal learning [5], by a white whale.

After seven years in our care (see the Supplemental Information), a white whale called NOC began, spontaneously, to make unusual sounds. We interpreted the whale's vocalizations as an attempt to mimic humans. Whale vocalizations often sounded as if two people were conversing in the distance just out of range for our understanding. These 'conversations' were heard several times before the whale was identified as the source. The whale lived among a group of dolphins and socialized with two female white whales. The whale was exposed to speech not only from humans at the surface — it was present at times when divers used surface-to-diver communication equipment (see Supplemental Information). The whale was recognized as the source of the speech-like sounds when a diver surfaced outside this whale's enclosure and asked "Who told me to get out?" Our observations led us to conclude the "out" which was repeated several times came from NOC.

As soon as NOC was identified as the source of these sounds, we recorded his speech-like episodes both in air and underwater (Supplemental Information). Recordings revealed an amplitude rhythm similar to human speech. Although there was variation, vocal bursts averaged about three per second (Figure 1). The rhythm of vocal bursts also reminded us of human speech. Intervals between bursts were generally of 0.05 to 0.5 seconds. Fundamental frequencies were in the range of 200 to 300 Hz — similar to human speech and several octaves lower than the whale's usual sounds [4]. Spectral characteristics with multiple harmonics were unlike usual whale sounds but not unlike those of the human voice. The greatest energy in each burst was seldom in the fundamental but usually in the second to fourth harmonic. Unlike echolocation clicks, ordinary pulse bursts, and whistle-like sounds, the production of speech-like sounds involved marked inflation of first one and then the other vestibular sac. This was readily observed on the surface of the whale's head and may have been necessary to emphasize lower frequencies of the speech-like sounds. In usual white whale sounds, such extreme inflation of these sacs is not evident.

White whales make sounds by pressurizing the nasal cavities [6]. The evidence for this has come from whales and dolphins trained to accept rapid response pressure catheters (Supplemental Information) into the nasal cavities and sacs. With catheters in place, animals performed a task that required them to echolocate to detect a target in the environment. When targets were detected, the animal vocalized to indicate detection. During the task, nasal cavity pressure could be leaked by variable opening of the catheter. With large leaks in the nasal cavity,

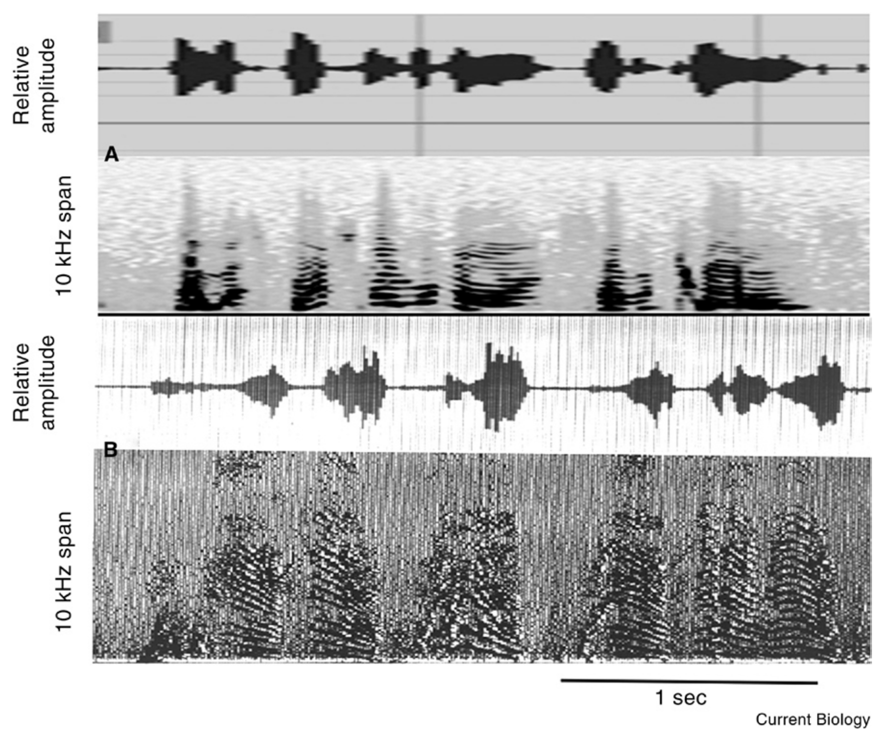

Figure 1. Acoustic record of human speech and whale speech-like sound.
(A) Human speech from a tape recorded voice track analyzed with Audacity (an on-line open source sound editor). (B) Whale speech-like sounds recorded with a B&K microphone in air and displayed in water-fall mode on the SD 350 digital spectrum Analyzer (Scientific Atlanta).

air rushed out through the catheter. Air pressure could not drive the phonic lips and no sound could be produced [6]. One set of phonic lips sits atop each nasal cavity [7]. Passing pressurized air from the nasal cavities through phonic lips causes vibrations in the lips resulting in sounds including echolocation clicks, pulse bursts and fast vibrations called whistles [8].

After recording several epochs of speech-like sounds, we decided to put the behavior on signal. After a trainer's signal the whale was rewarded for making the speech-like sounds. This allowed us to study the mechanism of speech-like sound production. The whale accepted pressure catheters [6] into his vestibular sacs above and into the nasal cavity below the phonic lips [7]. With catheters in place, the whale was signaled to 'speak'. Pressure increases preceded each vocal episode. As each vocal burst ended pressure fell (see Supplemental Figure S1). Pressure increases in the nasal cavities ranged from 200 to 500 mmHg; pressure in the vestibular sacs was under 200 mmHg. Harmonic intervals indicated that the humanoid sounds resulted from modulation of a pulse rate [9]. Helium breathing experiments have shown that dolphin sounds are produced by pulse rate variation [8]. Because of the similarity of nasal and phonic lip structure between white whales and dolphins [7], we conclude the same mechanism applies. Our whale mimicked human sounds by varying his nasal tract pressure and making concurrent muscular adjustments of the vibrating phonic lips while over-inflating vestibular sacs.

The speech-like behavior subsided after about four years. After the whale matured, we no longer heard speech-like sounds. However, NOC remained quite vocal. He produced typical echolocation pulses with peak frequencies between 60 and 120 kHz, whistles with fundamental frequencies of 2 to 10 kHz and various pulse burst sounds previously described as "squawks, rasps, yelps or barks" [4].

Vocalizations reminiscent of human speech have been observed for white whales in the wild [3]. The human brain is quick to recognize words [10]. Even partial or garbled words are identified. Reports of animal mimicry based solely on hearing vocalizations must be viewed skeptically. We do not claim that our whale was a good mimic compared to such well-known mimics as parrots or mynah birds. However, the sonic behavior we observed is an example of vocal learning [5] by the white whale. It seems likely that NOC's close association with humans played a role in how often he employed his human voice, as well as in its quality.

Supplemental Information

Supplemental Information includes experimental procedures, one figure, and a sound file and can be found with this article online at http://dx.doi.org/10.1016/j.cub.2012.08.044.

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Niche construction drives social dependence in hermit crabs

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Organisms can receive not only a genetic inheritance from their ancestors but also an ecological inheritance, involving modifications their ancestors made to the environment through niche construction [1]. Ecological inheritances may persist as a legacy, potentially generating selection pressures that favor sociality. Yet, most proposed cases of sociality being impacted by an ecological inheritance come from organisms that live among close kin and were highly social before their niche construction began [2]. Here, I show that in terrestrial hermit crabs (*Coenobita compressus*) — organisms that do not live with kin and reside alone, each in its own shell — niche-construction drives social dependence, such that individuals can only survive in remodeled shells handed down from conspecifics. These results suggest that niche construction can be an important initiator of evolutionary pressures to socialize, even among unrelated and otherwise asocial organisms.

Niche construction is a process of organism-driven environmental modification in which ecological changes brought about by organisms' behaviors can potentially feed back over evolutionary time, altering natural selection pressures on the organisms, their descendants or other species [1]. Niche construction appears ubiquitous [2], and it may have been a powerful force in the evolution of highly social animals. However, few examples show whether niche construction could drive the early origins of sociality, for instance by instigating strong selection for a reliance upon unrelated conspecifics and their associated niche-constructed products. Here, I examine the consequences of a niche construction behavior in terrestrial hermit crabs, involving modification of gastropod shell architecture.