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PULSE SEQUENCE AND WHISTLE PRODUCTION BY TWO CAPTIVE BEAKED WHALES, *MESOPLODON* SPECIES

Two beaked whales, *Mesoplodon* species, were found stranded alive at Ocean Beach in San Francisco, CA on 24 August 1989. They were rescued by staff from the California Marine Mammal Center and transported to Marine World Africa USA in Vallejo, CA for rehabilitation efforts by the staff of the two facilities. Both whales died. One of the whales, Nicholas, was identified as Hubb's beaked whale, *M. carlhubbsi,* by skull characteristics (Stephen F. Bailey, personal communication, 1991). The species of the other whale has yet to be determined but is assumed to be the same. The attempted rehabilitation of these whales provided a unique opportunity to observe behavior and record concurrent vocalizations. Two hundred ninety-six pulse sequences and six whistles were recorded. In this note we report temporal and spectral parameters of these vocalizations.

The two male beaked whales, Nicholas and Alexander, were estimated to be very young based on suckling response and size. Nicholas weighed 293 kg and measured 298.6 cm from rostrum to end of fluke. Alexander weighed 204 kg and measured 287.0 cm. Nicholas died 8 September 1989, after 16 d in captivity. Alexander died on 17 September 1989, after 25 d. While there was no definitive cause of death, the whales apparently suffered from suppressed immunological systems and additional medical complications: Alexander had a mild case of pneumonia and Nicholas suffered from a subcutaneous emphysema primarily on his left dorsal side from behind the blowhole to the peduncle, preventing him from submerging (Gage 1990).

During the rehabilitation effort the whales were kept in a 9.7 m diameter by 2.7 m deep pool filled with artificial sea water. The whales received medical treatment and were fed a high calorie formula three to four times a day (Gage 1990). At these times the water level was dropped from 2.0 m to about 0.5 m. The rehabilitation pool was on a separate filter system and was acoustically and physically isolated from other dolphin pools in the vicinity, precluding the possibility of acoustic contamination.

We are not certain whether both whales were vocalizing; however, we believe most, if not all, of the vocalizations recorded were produced by Alexander. We have positive identification of Alexander producing all patterns of pulses. In these cases we could identify the source because we were either in the pool with Alexander and could hear the sounds coming from the whale or we observed bubbles released concurrent with sound production. After Nicholas' death we continued to record pulse sequences showing the same characteristics as those previously recorded. It is unclear whether Nicholas' inability to submerge or subcutaneous emphysema in the blowhole region precluded him from producing sounds.

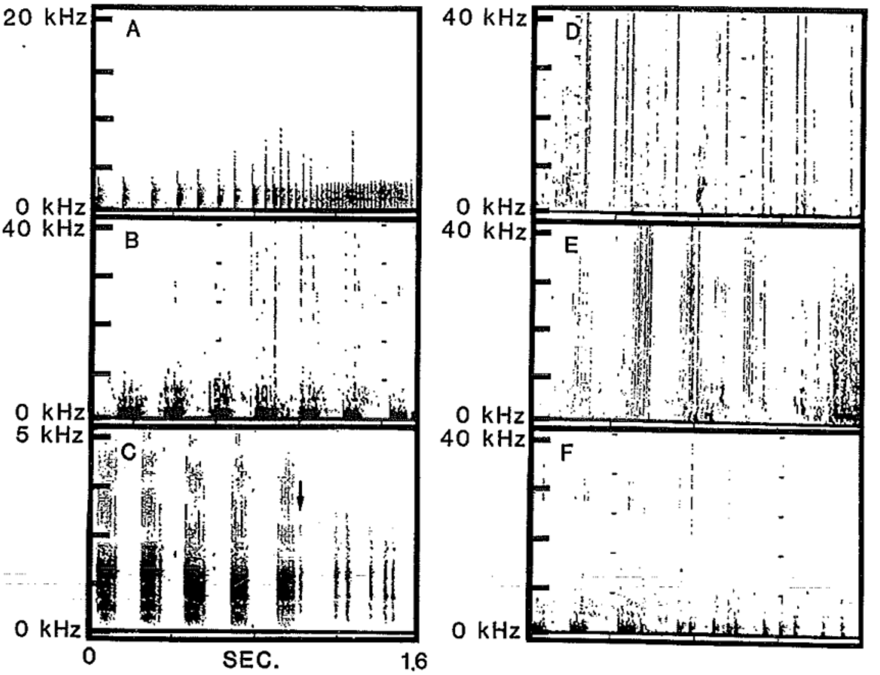

Figure 1A–F. Examples of pulsed vocalizations recorded. (A) An example of a sequence of lower frequency (type 1), ungrouped pulses. Most of the energy below 2 kHz. (B) An example of a sequence of lower frequency (type 1), grouped pulses showing stereotypical rhythmicity. Note the weaker high frequency components apparent in some of the pulses. (C) The low frequency components (to 5 kHz) of a sequence of lower frequency (type 1) pulses. Note that the sequence starts with grouped pulses and ends with ungrouped pulses. The arrow indicates a final offset pulse. (D) An example of a sequence of broader band (type 2), ungrouped pulses. (E) An example of a sequence of broader band (type 2), grouped pulses showing sterotypical rhythmicity. Note the more equal distribution of energy throughout the frequency spectrum of the pulses. (F) An example of a lower frequency (type 1) pulse sequence beginning as grouped pulses and ending as individual, ungrouped pulses. Note the weaker high frequency components apparent in some of the pulses.

Seven and one-half hours of recordings were made yielding a total of 296 sequences of pulsed vocalizations. Two hundred fifty-five of these sequences were recorded with a Labcore 76 hydrophone and preamplifier, with a level frequency response to 20 kHz, used with two tape recorders: a Wollensak 6250 and an Akai 1730 D-SS, both with a frequency response from 35–20,000 Hz ($\pm$3 dB) at a recording speed of 7.5 ips. Ampex Grand Master 456 tape was used with both the Akai and Wollensak recorders. Unfortunately, due to a malfunction in the preamplifier, these two systems often cut off near 8 kHz and the 255 sequences recorded with these two systems were used only in the analysis of temporal parameters, not in the spectral analysis. The remaining 41 pulsed sequences, used in both the spectral and temporal analyses, were recorded using

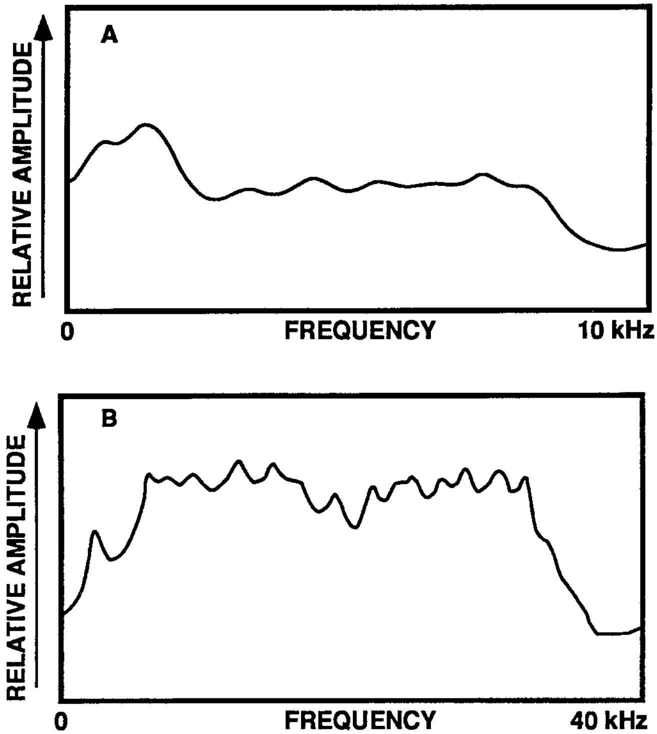

Figure 2A, B. Linear Predictive Coefficient of (A) a lower frequency (type 1) pulse signal with the major energy located around 2 kHz, and (B) a broader band (type 2) pulse signal with the energy spread more equally throughout the spectrum. Time = 10 msec.

a Hewlett Packard 3968-A instrumentation recorder, with a frequency response from 70–60,000 Hz (±3 dB) at 15 ips, Ampex 797 15DW11 tape, and a Magnavox Sonobuoy hydrophone with a level frequency response to 40 kHz. A Multigon Uniscan II model 4600 FFT Sonogram Spectral Display was used to measure the spectral and temporal parameters of the vocalizations, accurate to 6 msec at 40 kHz. Linear Predictive Coefficients were made with a G. W. Instrument's MacADIOS II spectrum analyzer with a resolution of 0.1 sec at 40 kHz.

The 41 pulse sequences recorded with the Hewlett Packard system ranged in frequency from 300 Hz to 40 kHz (the peak flat response of our recording system) though there was indication of energy beyond this limit when the recordings were played back at one quarter speed (3.25 ips).

We categorized the pulses into two types according to power spectra. Type 1 signals were predominantly lower frequency pulses with some wide band components extending beyond the range of our recording/analysis system (40 kHz). The majority of the energy was confined to a narrow bandwidth between 300 Hz and 2 kHz (73%, 30/41 sequences; Fig. 1A, 1B, 1C, 1F, and 2A).

Table 1. Measurements of grouped pulses independent of spectral type.

	No. pulses per group	Duration of group[a] (msec)	Interval between groups[a] (msec)	Repetition rate[b] (no. pulses/sec)	No. groups per sequence	Offset interval: Initial pulse[a] (msec)	Offset interval: Final pulse[a] (msec)
Mean	7	90	142	80	4.2	32	37
SD[c]	2	29	35	16	2.3	10	15
Min. value	2	16	44	38	1	22	19
Max. value	14	219	294	129	13	52	91
n[d]	380	389	283	380	129	11	50

[a] Calculations involving temporal measurements are ±6 msec.

[b] Repetition rates were obtained by dividing the number of pulses in the group by the duration of the group.

[c] Though the standard deviations appear large, the units are in milliseconds and the signals sound rhythmic to the human ear.

[d] Calculations were performed on all groups for which the relative information was obtainable. The sample size indicates the number of pulse groups involved in the calculation, not the number of pulsed sequences.

Type 2 signals were broader band pulses, with energy from 300 Hz to beyond the 40 kHz limit of our recording/analysis system (27%, 11/41 sequences; Fig. 1D, 1E, and 2B), similar in structure to the echolocation signals produced by many small toothed whales in which the energy is more equally distributed throughout the frequency spectrum (Kamminga 1988). Pulse sequences were composed entirely of either lower frequency or broader band signals; the two types did not occur within the same sequence.

We further classified the signals into two temporal patterns: grouped pulses, in which individual pulses were emitted in sequences of groups, averaging seven pulses per group and four 90 msec groups per sequence, with a low variability in both interpulse and intergroup duration, producing a rhythmic pattern to the human ear (Fig. 1B, 1E and Table 1); and ungrouped pulse sequences with a variable repetition rate (Fig. 1A and 1D).

Both the lower frequency (type 1) and broader band (type 2) pulses were found in grouped and ungrouped temporal patterns. Seventy-three percent (30/41) of the sequences contained lower frequency, grouped pulses (Fig. 1B). Twenty-four percent (10/41) of the sequences contained lower frequency, ungrouped pulses (Fig. 1A). Twenty-seven percent (11/41) of the sequences contained broader band, grouped pulses (Fig. 1E). Twelve percent (5/41) of the sequences contained broader band, ungrouped pulses (Fig. 1D). The preceding percentages add up to more than 100 because they include sequences which are combinations of the grouped and ungrouped temporal patterns. Such sequences were thus counted twice, once for grouped pulses and once for ungrouped pulses.

In the grouped sequences composed of lower frequency (type 1) signals the

Table 2. The spectral and temporal parameters of all whistles recorded, as shown in Figure 3.

Figure	Frequency range (kHz)	Duration[a] (msec)	Max. frequency (kHz)	Min. frequency (kHz)
3A	1.8	200	7.8	6.1
3B	2.6	312	8.2	5.6
3C	1.0	187	3.5	2.6
3D	7.0	450	10.7	3.7
3E	3.4	262	7.0	3.7
3F	5.3	156	8.6	3.4
Mean	3.5	261	7.7	4.2
SD	2.3	108	2.4	1.4

[a] ±6 msec.

mean number of pulses per group was 5.8 (n = 63 groups). The mean number of pulses per group for the broader band (type 2) sequences was 7.0 (n = 16 groups). Using a Mann-Whitney U test we found a significantly higher number of pulses per group for the broader band (type 2) sequences than for the lower frequency (type 1) sequences (df = 77, P = 0.003). However, group duration (time from onset of initial pulse to onset of final pulse), interval between groups, repetition rate, and number of groups per sequence were not found to differ significantly across the two pulse types (df = 77, P = 0.139; df = 51, P = 0.455; df = 75, P = 0.085; df = 31, P = 0.131 respectively).

The grouped and ungrouped temporal patterns often occurred within the same sequence (Fig. 1C and 1F). Combination grouped and ungrouped pulse sequences comprised 53% (156/296) of the sequences recorded. Twenty-four percent (71/296) of the sequences contained only ungrouped pulses. The remaining 23% (69/296) of the sequences contained only grouped pulses. Typically, the combination sequences began with grouped pulses (63%, 98/156 sequences) and ended in ungrouped pulses (88%, 137/156 sequences).

Approximately 14% of the grouped pulse sequences contained groups in which the initial or final pulse was temporally "offset" from the rest of the group (Table 1 and Fig. 1C, arrow indicates offset pulse). Using a Mann-Whitney U test we found no significant difference between the mean interval for initial versus final-pulse offsets (df = 59, P = 0.157). Offset pulses were only found in the lower frequency (type 1) grouped pulses.

Six whistles were recorded (Table 2 and Fig. 3). The frequencies range of the whistles was 2.6 to 10.7 kHz and the duration ranged from 156 to 450 msec. The dynamic range of individual whistles varied from 1 to 7 kHz. Each whistle occurred discretely, not as part of a sequence of pulses or other whistles.

The context of "humans in pool" *vs.* "whales alone" was noted for 294 of the 296 pulse sequences recorded. Ninety-eight percent (288/294 sequences) of the pulse sequences occurred when humans were in the pool. There were only six sequences recorded when the whales were alone in the pool.

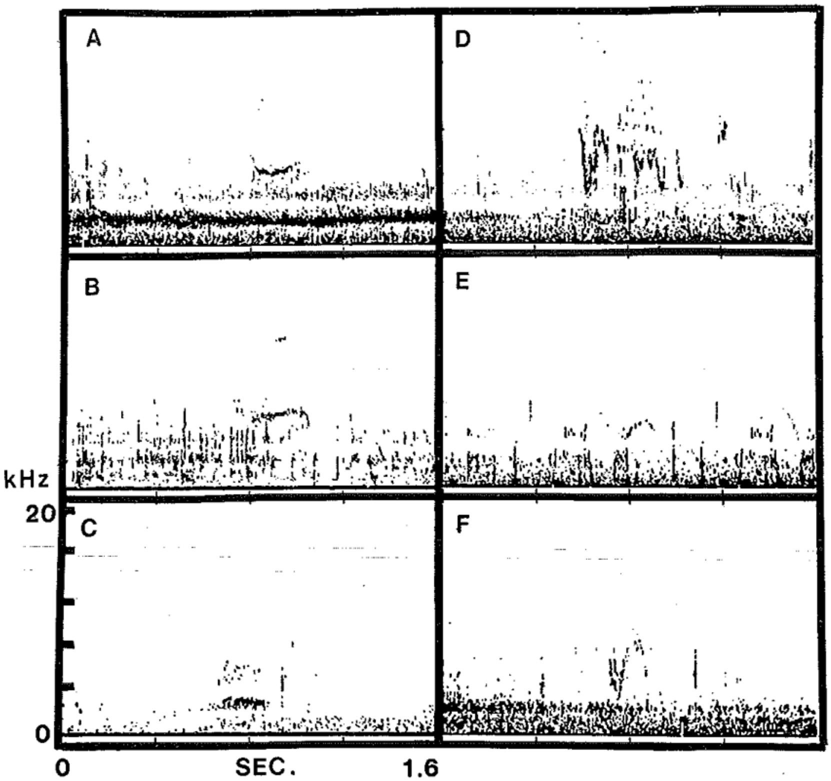

Figure 3A–F. Sonagrams of all whistles recorded. Refer to Table 2 for measurements. (A) Context unknown. (B) Whales separate from each other, one being handled. (C) Whales alone in pool. (D) Both whales being fed, separate from each other. (E) Whales being fed and medically examined. (F) Whales separate from each other, one whale being fed while the other is medically examined. The other signals shown in this figure are not vocalizations produced by the whales, but rather noise produced by objects or people in the environment.

The signals described in this study were emitted by very young animals. The frequency and temporal characteristics of the signals may not be representative of adult signals. Other studies have demonstrated age-related differences in the pulsed/click signals of cetaceans and other species. Recordings of stranded sperm whale (*Physeter macrocephalus*) calves in captivity and older calves in the wild (Watkins *et al.* 1988) revealed that younger calves produced "noisier" clicks with tonal components, which were "interpreted as the result of improperly formed clicks." In addition, the use of patterned adult-like clicks (codas) increased with age. Previous studies reported that in bottlenose dolphins, *Tursiops truncatus,* (Reiss 1988) and various species of bats (Brown and Grinnel 1980), young produce lower frequency, longer duration pulses than the adult echolocation signals.

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