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ヒトと動物の関係を科学する新分野の創造
—応用動物科学がもたらす豊かな社会—
I．人との関わりによるバンドウイルカ（*Tursiops Truncatus*）鳴音の増加

The new field of science for human-animal interaction
— Healthy society with animal science —
I. Increased number of whistle of Bottlenose dolphins, Tursiops Truncatus, arising from interaction with people

坂田亮一，太田光明，田中智夫，デニス・ターナー

麻布大学大学院獣医学研究科

Ryoichi Sakata, Mitsuaki Ohta, Toshio Tanaka, Dennis C. Turner

Azabu University Graduate School of Veterinary Medicine

Abstract. The acoustic mode is the most reasonable means for social animals such as dolphins to maintain contact in the underwater habitat, and has been developed since they moved to the sea. This study investigates variations in dolphin vocalizations under the following conditions in a captive environment: 1) before feeding (Pre-feeding), 2) during feeding (Feeding), 3) during free time without the presence of people (Free), 4) during interaction with people located upon a float (Float), 5) during interaction with people in the water (Water). During the experiments, a total of 2642 whistles were extracted from sonogram data using a spectrogram. About 44 % of the total whistles were observed during Pre-feeding (1171/2642), and the number recorded during Free, when people were absent, was the smallest. The acoustic contours of dolphin whistles differed in different situations: convex, wave, and trill whistles were made repeatedly during Pre-feeding, thereby being more common at this time than at other times. The situation of Feeding saw an increased number of Upsweeps, which might be related to the use of echolocation. The lower frequencies were recorded during Pre-feeding, reflecting the emotion related to the dolphin's hunger. The results of this study indicate that dolphins increase their vocalization during interaction with people, suggesting that interactions with dolphins provide an effective treatment for human health problems, which is discussed with a reference article in this study. Vocal data obtained during contact with humans might serve as an important index for the dolphin-assisted therapy.
Key words: bottlenose dolphin, captive environment, dolphin-human interaction, vocalization

1．目　的

Bottlenose dolphins, *Tursiops truncatus*, are kept in many aquaria and marine facilities throughout the world. They have a wide distribution and inhabit almost every ocean. The brain of the bottlenose dolphin is heavier than that of the human brain, and the bottlenose dolphin's brain index {brain weight / (body size)2/3}, which is the ratio of brain size to body size, is the second-largest (0.64) of all mammals after humans (0.89); this value is more than twice that of chimpanzees (0.30) [16]. Dolphins have developed a complex social structure [8] and make use of tools [13]. Several experiments that target cognitive mechanisms have demonstrated dolphins' capabilities in terms of learning, memory, and communicative language [11].

Most marine-derived dolphins form communities, called pods, and are considered to mutually communicate. They often use characteristic vocalizations for communication rather than touch and breaching [24]. The dolphin has developed a means of sound communication that can carry a wide range and send myriad messages rapidly through water. Dolphins gather information through hearing. Their sophisticated communication system improves their efficiency in searching for food, reproduction, and protection; thereby enhancing their adaptation to the environment [6].

Dolphins produce sounds in the range 10 Hz to 160 kHz [10], which are categorized as either pulse or non-pulse sound. Clicks (pulses) commonly extend into the ultrasound region for the purpose of echolocation, and last for only a few tens or hundreds of microseconds. The other pulses, burst pulse sounds, seem to be related to the dolphin's emotional state [3, 7]. Whistles are non-pulse, have a narrow frequency band below 20 kHz, and are of long duration. Whistles appear to serve an important role in communication among dolphins [19]. Individual dolphins identify themselves using a signature whistle: dolphins use the whistle to identify and call their calves and other group members [20].

Wild dolphins adapt to their natural environment, changing behavior and sense appropriately. Captive dolphins also adapt to their respective environments and show simpler behavior and fewer calls than wild dolphins. In contrast, long-term captive seals show poor variation in vocalization [21].

Dolphins change behavioral patterns according to their captive environment. The main difference between natural and captive environments might well be the presence of humans; consequently, any association with humans would be expected to result in a change in the dolphin's behavior. Following this theme, the present study investigates variations in dolphins' whistles under different conditions within a captive environment.

2. 方　法

Animals: The three captive bottlenose dolphins, *Tursiops truncatus*, were used in this study included one male and two females of 5–8 years of age. They were housed together in a sea pen (20 x 60 m, 6–10 m depth) at a facility in Muroto, Kochi, Japan. Two of the dolphins had been kept since 6 August 2003 and the other female since 28 February 2004. The dolphins are fed and trained four times daily, including two sessions where they are fed by guests. Their health condition is regularly monitored by two veterinarians with a good knowledge of dolphins. A program through which disabled persons could come in contact with the dolphins was conducted during the summer (June–November) of 2004.

Data collection and analysis: Whistles of the studied dolphins were recorded together using a Whale Phone (Oki Electric Industry Inc., Shizuoka, Japan) with a hydrophone, a digital audio tape recorder (TCD-D10, Sony Corp., Tokyo, Japan), and a portable mini-disk recorder (MZ-N10, Sony Corp.). Microphones were set 3 m under the platform in the sea pen, and the system had a frequency response of 20 Hz to 20 kHz.

The whistles of three dolphins, but not individually, were collected for 10–15 minutes during various daily situations: 1) immediately before feeding (Pre-feeding), 2) during feeding (Feeding), 3) during free time without the presence of people (Free), 4) during interaction with people upon a float (Float), and 5) during interaction with people in the water (Water).

Data recorded on six different days during the 5 months of observations were converted into sonograms using a free software package (Spectrogram; Richard Horne), and shown as the numbers per 10 minutes.

Whistle contours were classified as one of seven types (Fig. 1): Constant, Upsweep, Downsweep, Concave, Convex, Wave, and Trill, using a modified version of Bazua-Duran and Au's [5], six-part classification. The different types of whistle contours are defined as follows:

I. Constant: A contour in which the frequency

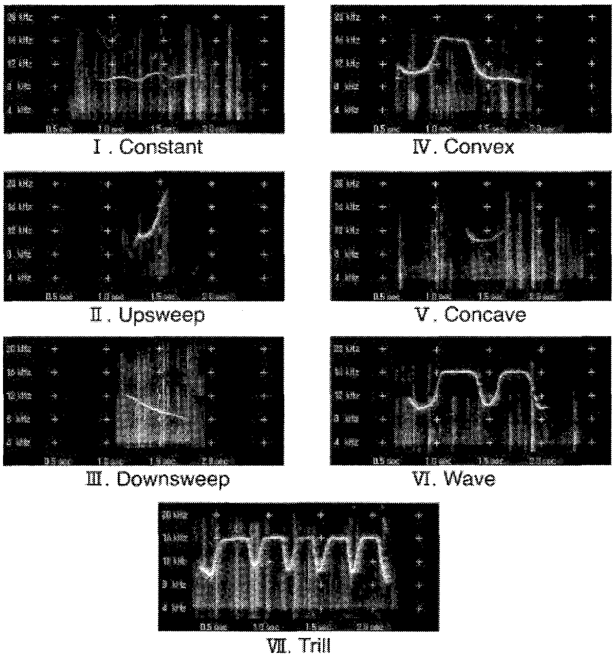

Fig. 1. The seven types of whistle contours (I-VII) converted into sonograms.

changes by less than 1000 Hz.

II. Upsweep: A contour in which the frequency is mainly ascending.

III. Downsweep: A contour in which the frequency is mainly descending.

IV. Convex: A contour with at least one inflection point at which the frequency is first mainly ascending and then mainly descending.

V. Concave: A contour with at least one inflection point at which the frequency is first mainly descending and then mainly ascending.

VI. Wave: A contour with two inflection points at which the frequency is first mainly ascending, then mainly descending, or vice versa (termed 'Sine' in Bazua-Duran and Au [5]).

VII. Trill (the original whistle contour in this study): A contour with more than three inflection points in which the frequency is repeated for the entire duration of the whistle.

The frequency resolution was set to 86.1 Hz and the time resolution to 5 msec. Six parameters were extracted from the sonograms of each whistle following the method of Wang et al. [22] and Bazua-Duran and Au [5]: 1) beginning frequency, 2) end frequency, 3) maximum

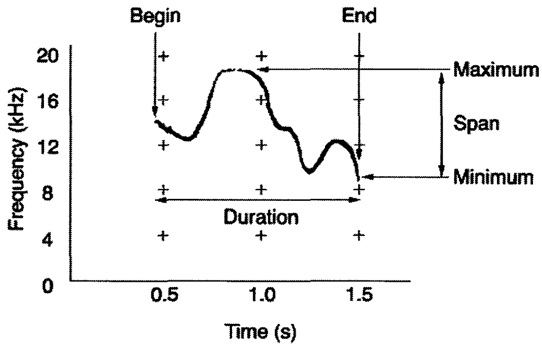

Fig. 2. The six parameters of beginning frequency, end frequency, maximum frequency, minimum frequency, frequency span, and duration measured from each whistle contour.

frequency, 4) minimum frequency, 5) frequency span, and 6) duration (Fig. 2). The frequency span is the difference between the maximum and minimum frequency, while the duration is the difference between the beginning and end times of the whistle.

The differences in the numbers of whistles between Free and the other situations, and the comparison of the five main situations of daily life (Free, Pre-feeding, Feeding, Float and Water) with the six parameters of whistle components (Begin, End, Minimum, Span, and Duration) were tested using one-way ANOVA as well as the multiple-comparison post hoc tests.

3. 結果と考察

RESULTS

A total of 2642 whistles were extracted from the records. The frequency span was 6.54 ± 2.56 kHz (mean ± SD, $N = 2642$): 73 % of the whistles were in the range 5–10 kHz and 4.2 % were < 1 kHz. The whistle durations were 1.25 ± 0.91 sec: 41 % were less than 1 sec and 10 % were longer than 5 sec.

About 44 % of the total whistles were observed during Pre-feeding, whose number (mean ± SD, 195.2 ± 57.5) was significantly different from that during Free (42.7 ± 4.9, $P < 0.01$; Dunnett's multiple-comparison test) (Fig. 3, Table 1). The numbers of whistles also increased during Feeding, Float and Water, although they were not statistically significant, compared to the number recorded during Free, which was without people. The lowest number of Float on the first observation might be due to

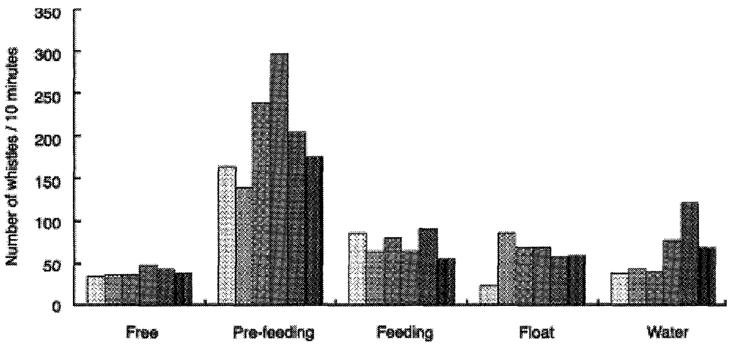

Fig. 3. The numbers of whistles per 10 min on six different days during the 5 months of observations. The columns of the five situations are placed according to the order of experiments.

Table 1.

Whistle categories	Free	Pre-feeding	Feeding	Float	Water	Total
Constant	32	58	38	46	57	231
Upsweep	32	44	100	63	43	281
Downsweep	11	23	17	15	15	81
Convex	63	465	131	75	78	812
Concave	3	9	12	6	2	32
Wave	38	205	40	48	33	363
Trill	77	368	126	134	136	842
Total	256	1171	464	387	364	2642

Comparison of the total numbers of whistle contours in five situations.

the dolphin's landing on the float, in which the sound was not recorded (Fig. 3).

The recorded numbers of each whistle type varied among the five situations (Table 1). The numbers of whistles during Free were lowest for all types of whistle contours. Convex, wave, and trill whistles were commonly repeated during Pre-feeding, and thus appeared much more in this situation than in others. The numbers of upsweep, convex, and trill whistles increased during Feeding, as did the number of trill whistles during Float and Water. Little difference was apparent in the numbers of constant, downsweep, and concave whistle contours among different situations.

Table 2 shows descriptive statistics (mean, standard deviation, and highest and lowest values) of the six parameters of whistle components for the five main situations of the daily life of the dolphins. The beginning frequency was higher than the end frequency during Pre-feeding, but all the others show larger values in the end frequency. The frequency span was the widest during Pre-feeding, and the whistle duration was longest during Water (1.83 ± 1.49 sec).

DISCUSSION

The captive bottlenose dolphins analyzed in this study showed changes in the number of whistle contours in several of the situations of daily life. Delphinids produce different sounds related to their behavioral context according to changes in feeding, sexual play, aging, etc [12, 14, 23]. The whistles of the studied dolphins during Free, without interaction with people, occurred at the lowest levels for all contour types, whereas whistles during others situations occurred in greater numbers. The large numbers of whistles in Pre-feeding were due to repeated Convex, Wave, and Trill whistles.

The pod sizes of several dolphin species increase during feeding events [15]. Dusky porpoises produce greater numbers of characteristic calls or a greater number of total

Table 2.

	Discriptive Statistics	Frequency (kHz)					Time(sec)	
		Begin	End	Minimum	Maximum	Span	Duration	*N*
Free	Mean	12.13 [a]	12.51 [egh]	10.85 [i]	16.41 [mn]	5.56 [q]	1.40 [u]	256
	S.D.	2.77	3.66	2.38	3.62	2.82	1.21	
	Highest	20.03	20.11	18.39	21.06	11.71	6.90	
	Lowest	1.15	4.18	4.18	4.44	0	0.05	
Pre-feeding	Mean	11.57 [b]	9.67 [f]	9.10 [j]	16.26 [mn]	7.18 [r]	1.13 [v]	1171
	S.D.	1.96	2.22	1.37	2.66	2.57	0.48	
	Highest	17.69	19.60	16.24	20.28	18.13	3.82	
	Lowest	1.22	0.71	1.68	3.23	0	0.02	
Feeding	Mean	11.35 [b]	11.96 [eh]	9.86 [k]	15.84 [m]	5.98 [q]	1.07 [v]	464
	S.D.	2.69	4.00	2.49	3.42	2.84	0.88	
	Highest	19.60	20.97	18.30	21.32	14.47	9.26	
	Lowest	1.15	1.02	1.15	4.18	0	0.02	
Float	Mean	12.17 [a]	12.89 [g]	10.93 [i]	16.69 [n]	5.75 [q]	1.48 [u]	387
	S.D.	2.49	3.73	2.32	3.26	2.84	1.27	
	Highest	21.06	21.15	18.99	21.49	13.61	8.57	
	Lowest	1.24	3.57	3.57	5.73	0	0.06	
Water	Mean	11.37 [b]	11.83 [h]	9.90 [k]	15.86 [m]	5.97 [q]	1.83 [w]	364
	S.D.	2.57	3.06	2.06	3.44	2.73	1.49	
	High	19.25	20.03	16.24	20.72	17.36	8.15	
	Low	5.38	5.64	1.63	5.64	0	0.07	

Comparison of the descriptive statistics (mean, standard deviation, highest and lowest values) of six parameters of the whistles component in five situations of daily life. Value followed by different alphabet within each column are significant at $P = 0.01$ (Tukey's multiple-comparison test).

calls in order to recruit individuals to feeding events [25]. The whistles of bottlenose dolphins are also more numerous among feeding groups than non-feeding groups [1]. The large increase in the number of whistles during Pre-feeding recorded in our study might reflect the timing of feeding events, suggesting a demand for food. In dogs, acoustic communication via barking has multiple meanings in defense, play, display, attention, and caution. Excitement caused by the frequency of barking has been found to correlate with the degree of tension [9]. The sound is said to be sent correctly to the target of the call by repeating a limited repertory of signals to make it easily understood. In our case, reiteration of the whistle during Pre-feeding appears to arise during a state of tension when seeking food.

The situations of Feeding, Float, and Water also led to increases in the numbers of whistles, except the first of serration during Float (Fig. 3). The only difference between Free and other situations including Pre-feeding was interaction with people, including dolphin trainers. Antonioli and Reveley [2] documented that animal-facilitated therapy with dolphins is an effective treatment for mild to moderate depression, and suggested that healing properties are derived from the emotions raised by interaction with dolphins and the sounds of the dolphins, including the echolocation system. In the present study, the situations that involved human–dolphin interaction were characterized by increased sounds, especially Trill whistle contour.

The minimum frequency during Pre-feeding showed the lowest level of all situations, as with the end frequency. In humans, a definite relation exists between the acoustic characteristics of vocalization and emotion [17]. Characteristically, the mean of the fundamental frequency is high for the emotions of happiness and amazement and is low for sadness [18]. The low levels of whistle frequency recorded during Pre-feeding might reflect the emotion of sadness related to the dolphins' hunger.

The whistle duration of bottlenose dolphins in nature is less than 1 sec [22], whereas the mean duration in the present study is longer than 1 sec in all situations, even up to 8 sec for Water. Bazúa-Durán [4] reported for spinner dolphins that their whistle duration depended on the group size and different general behavioral states: social, travel, or rest. The Water situation is different from other states in that people are close to the dolphins. The behavior of the dolphins during Water implies that the dolphins attempt to communicate with people who are in the water with them.

Repeatedly vocalizations by dolphins during Pre-feeding resemble types of Convex whistles such as Wave and Trill contours that change shape at the end of the inflection, suggesting the emotions of hunger or demand. The characteristic contour during Feeding is the upsweep. The increased frequency of the Upsweep contour might be related to echolocation, as cetaceans produce sounds during foraging because they use echolocation clicks to detect and pursue prey [3].

During the situation of Free time, when the aquarium was free of people, the dolphins fell silent. Incidentally, the whistles became more numerous and longer when a dolphin interacted with a new person than those when interacting with a familiar person. A greater variety of whistles were produced when a greater number of people were in the water. Further research is required to explore the possibility that dolphins seek to actively communicate with humans as well as the differences in individual sound and in gender.

Dolphins increase their vocalization in situations where they interact with people, suggesting an effective treatment for human health via interactions with dolphins. Vocal data obtained during contact with humans might serve as an important index that can be used to improve dolphin–human interactions, especially for the dolphin-assisted therapy.

4. 要　約

水中生活を営むイルカにとって音声によるコミュニケーションは，群れ社会の相互関係を円滑にするため数千万年にわたって高度に発達させた方法であろう。

本研究では，人工飼育下において，1）給餌の前（Pre-feeding），2）給餌のとき（Feeding），3）人のいない自由なとき（Free），4）ふれあい場で人と関わるとき（Float），5）人が水中にいるとき（Water）の5つの状態におけるイルカの鳴音の変化について記録解析した。

記録した音声は，Spectrogramを用いて2642のホイッスルソナグラムに分けた。10分間単位のホイッスル数は，Freeで最も少なく，Pre-feedingで最も多かった。Pre-feedingと同様に人が存在するFeeding, Float，Waterでもホイッスル数は増加した。ホイッスルソナグラムはそれぞれの条件において明らかに異なり，Pre-feedingでは凸型，波形，トリル型が繰り返し出現した。一方，Feedingでは，特徴的な上昇型が多くみられ，エコーロケーションとの関連が示唆された。また，ホイッスルソナグラムの解析から，Pre-feedingにおいて低周波が記録され，空腹と関連する感情表現を推測した。

最近のイルカ介在療法に関する研究および本研究の結果から，イルカが人との関わりで鳴音を増加させ，このことが人の健康に影響を与えるとの仮説についてさらに検討が必要であるが，本研究で得られたイルカ鳴音データはイルカと人の相互作用，特にイルカ介在療法を推進するに際し，重要な指標となる。

文　献

1）Acevedo-Gutiérrez, A. and Stienessen, S. C. 2004. Bottlenose dolphins increase number of whistles when feeding. Aqua. Mamm. 30: 357-362.

2）Antonioli, C. and Reveley, M. A. 2005. Randomised controlled trial of animal facilitated therapy with dolphins in the treatment of depression. Br. Med. J. 331: 1231.

3）Au, W. W. L. 1993. The Sonar of Dolphins. Springer-Verlag, New York.

4）Bazúa-Durán, C. 2001. The whistles of Hawaiian Spinner Dolphins, Stenella longirostoris, description and geographic variations. Ph.D. thesis, University of Hawaii.

5）Bazúa-Durán, C. and Au, W. W. L. 2002. The whistles of Hawai`ian spinner dolphins. J. Acoust. Soc. Am. 112: 3064-3972.

6) Caldwell, M. C. and Caldwell, D. K. 1965. Individual whistle contours in bottlenose dolphins, Tursiops truncatus. Nature 207: 434-435.

7) Caldwell, M. C. and Caldwell, D. K. 1967. Intraspecific transfer of information via the pulsed sound in captive odontocete cetaceans. pp. 879-936. In: Animal Sonar Systems: Biology and Bionics, Laboratoire de Physiologie Acoustique, Jouy-de-Josas, France.

8) Connor, R. C., Heithaus, M. R. and Barre, L. M. 2001. Complex social structure, alliance stability and mating access in a bottlenose dolphin 'super-alliance'. Proc. Biol. Sci. 268: 263-267.

9) Coppinger, R. P. 1991. Why do dogs bark? pp. 119-129. In: Smithsonian Magazine

10) Evans, W. E. 1967. Vocalizations among marine mammals. pp. 159-186. In: Marine Bio-Acoustics (Tavolga, W. N. eds.), Pergamon Press, New York.

11) Herman, L. M. 1986. Cognition and language competencies of bottlenosed dolphins. pp. 221-251. In: Dolphin Cognition and Behavior: A Comparative Approach. (Schusterman, R. J., Thomas, J. and Wood, F. G.. eds.), Lawrence Erlbaum Associates, Hilladal.

12) Janik, V. M. 2000. Food-related bray calls in wild bottlenose dolphins, Tursiops truncatus. Proc. Biol. Sci. 267: 923-927.

13) Krützen, M., Mann, J., Heithaus, M. R., Connor, R. C., Bejder, L. and Sherwin, W. B. 2005. Cultural transmission of tool use in bottlenose dolphins. Proc. Natl. Acad. Sci. 25: 8939-8943.

14) McCowan, B. 1995. Maternal aggressive contact vocalizations in captive bottlenose dolphins, Tursiops truncatus: Wide-band, low-frequency signals during mother/aunt-infant interactions. Zoo Biol. 14: 293-309.

15) Norris, K. S. and Dohl, T. P. 1980. Behavior of the Hawaiian spinner dolphin, Stenella longirostris. Fish. Bull. 77: 821-849.

16) Russell, I. S. 1979. Brain size and intelligence: A comparative perspective. pp. 126-153. In: Brain, Behavior and Evolution. (Oakley, D. A. and Plotkin, H. C. eds.) Methuen, London.

17) Scherer, K. R. 1986. Vocal affect expression: A review and a model for future research. Psychol. Bull. 99: 143-165.

18) Scherer, K. R., Banse, R., Wallbott, H. G. and Goldbeck, T. 1991. Vocal cues in emotion encoding and decoding. Motiv. Emot. 15: 123-148.

19) Sjare, B. L. and Smith, T. G. 1986. The vocal repertoire of white whales, Delphinapterus leucas, summering in Cunningham Inlet, Northwest Territories. Can. J. Zool. 64: 407-415.

20) Smolker, R. A., Mann, J. and Smuts, B. B. 1993. Use of signature whistles during separations and reunions by wild bottlenose dolphin mothers and infants. Behav. Ecol. Sociobiol. 33: 393-402.

21) Thomas, J. A. and Kuechle, V. B. 1982. Melt pools as natural experimental arenas for acoustical studies. Antarc. J. 16: 187-188.

22) Wang, D. W., Würsig, B. and Evans, W. E. 1995. Whistles of bottlenose dolphins: comparisons among populations. Aqua. Mamm. 21: 65-77.

23) Weilgart, L. and Whitehead, H. 1990. Vocalizations of the North Atlantic pilot whale, Globicephala melas, as related to behavioral contexts. Behav. Ecol. Sociobiol. 26: 399-402.

24) Würsig, B. and Würsig, M. 1979. Behavior and ecology of the bottlenose dolphin, Tursiops truncatus, in the South Atlantic. Fish. Bull. 77: 399-412.

25) Würsig, B. and Würsig, M. 1980. Behavior and ecology of dusky porpoises, Lagenorhynchus obscurus, in the South Atlantic. Fish. Bull. 77: 871-890.