Aquatic Mammals 1989, **15.2,** 57–63

Respiratory arrhythmia in the hearts of Harbour porpoises (*Phocoena phocoena*)

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Summary

The heart rates of 3 Harbour porpoises (recorded for 26 days) showed individual variation. Electrocardiograms of two of these animals, made while they were on land, showed respiratory arrhythmia. The heart rate dropped when the animals were returned to the water, but the arrhythmia remained.

Introduction

Marine mammals spend a large part of their time underwater and cannot breathe as regularly as terrestrial mammals. In order to be able to stay under water for an extended period of time these animals have developed a number of adaptations, such as an increase of the oxygen storage capacity in blood and muscles, a reduced blood flow to non-vital organs during submersion, a reduced carbon dioxide sensitivity of the brain, and a heart rate that changes during submersion. Not much is known about the way the heart adapts itself to diving.

Few studies have been done on the heart functions of cetaceans. White *et al.* (1953) and King *et al.* (1953) report on the electrocardiogram (ECG) of a harpooned Beluga whale (*Delphinapterus leucas*) and Hamlin *et al.* (1970) on the ECG of Bottlenose dolphins (*Tursiops truncatus*) on land. Kanwisher and Ridgway (1983) describe the ECG of a Common dolphin (*Delphinus delphis*), a Bottlenose dolphin and a Beluga whale. Their recordings were of free-swimming animals, and radio telemetry techniques were used. Meijler and Van der Tweel (1986) report on the ECG of a Killer whale (*Orcinus orca*) at the Harderwijk Park. The animal was trained to beach itself, and 3 electrodes were held against the sides of the animal. So far, an ECG of only one balleen whale has been recorded. Reynolds *et al.* (1986) give an ECG of a free-swimming Humpback whale (*Megaptera novaeangliae*) using a radio telemetry device. The morphology of marine mammals' hearts has also been studied incidentally. The anatomy and morphology of the cardiac conduction system of the following cetaceans has been reported: Sperm whale (*Physeter macrocephalus*) by White and Kerr (1915–1917); Beaked whale (unidentified species) by Reynolds *et al.* (1987); White beaked dolphin (*Lagenorhynchus albirostris*) and Harbour porpoise (*Phocoena phocoena*) by van Nie (1987 and 1988).

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Table 1. The characteristics of the 3 Harbour porpoises

Animal	Sex	Estimated age (yrs)	Weight (kg)
PpSH012	F	0·5	17·5
PpSH013	M	15	37·5
PpSH014	M	6	31·0

As far as could be discovered, no published information exists on the ECG's of cetacean species other than those mentioned above. When in March 1988 three Harbour porpoises beached on the Dutch coast and were sent to the Harderwijk Marine Mammal Park for rehabilitation, the opportunity arose to investigate their cardiac rhythm and record the electrocardiograms of individuals of this species. For this purpose special underwater electrodes were developed.

Materials and Methods

Study animals

The animals used in this study were 3 rehabilitated Harbour porpoises (*Phocoena phocoena*) which had beached on the Dutch coast (Table 1).

Heart rate monitoring

During a period of 26 days the 3 animals were caught and held 1–4 times per day (between 09.00 and 16.00 hrs) for approximately 5 minutes at the surface of the water. Only the blowhole was above the water. The person holding the animal could feel the heart rate with the hand which supported the animal. A second person at the edge of the pool indicated the start and end of a one-minute period.

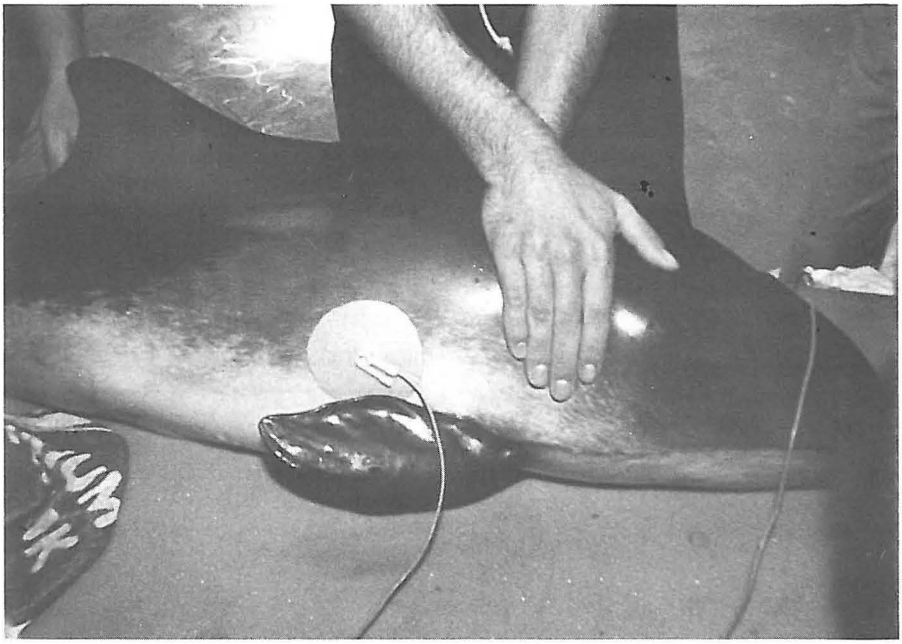

Figure 1. The position of a self-adhesive foam rubber electrode on a Harbour porpoise.

Figure 2. The suction-cup electrode made from a modified suction-cup to transport glass.

Figure 3. The 2 modified glass-carrier electrodes on the Harbour porpoise.

Table 2. The average heart rate of 3 Harbour porpoises

Animal	No. of recordings	Average heart rate (beats/min.)	Standard deviation
PpSH012	24	122	19·0
PpSH013	104	99	21·7
PpSH014	90	129	22·6

ECG recording

First session (4-4-1988)
At first, two animals were taken out of the water and placed on a mattress. Four self-adhesive foam rubber electrodes (used in recordings of human ECG's) were applied to the body. Two electrodes were placed dorsal of the pectoral fins, and 2 on each side of the tailstock (Fig. 1). The electrodes were connected to an ECG recorder by means of wires. The recordings were taped for future analysis. After recordings out of the water, the two animals were put back into the water, with the electrodes still in position and the wires attached. The self-adhesive electrodes, made for human ECG recording, stuck well to Harbour porpoise skin after it had been dried. The quality of the signals made on land was satisfactory. However, because the glue on the electrode pads was water-soluble, they fell off the skin in less than 2 minutes after the animals were put back into the water.

Second session (4-8-1988)
In order to record the ECG of Harbour porpoises in water, it was necessary to develop electrodes that would stick to the dolphin's skin for an extended period of time. Two different types of suction-cup electrodes were tested on False killer whales (*Pseudorca crassidens*). One type was a modified plunger. This type was difficult to use because of the large amount of force needed to fix it to the skin. The other type of electrode was made from a suction-cup usually used to transport glass (Fig. 2). These modified glass-carrier electrodes worked well under water. Even with only one electrode connected to the skin, and the other in the salt water within 10 cm of the animal, a good signal was obtained. The electrodes stuck to the skin during the full 10 minutes of the recording (Fig. 3).

Results

Heart rate
Table 2 shows the average heart rate of the 3 Harbour porpoises. Animals PpSH012 and PpSH014 had a rather similar heart rate. Animal PpSH013 had a significantly lower heart rate than the other two animals. The average heart rate of 2–4 recordings per day during 26 days is shown in figure 4. Animals

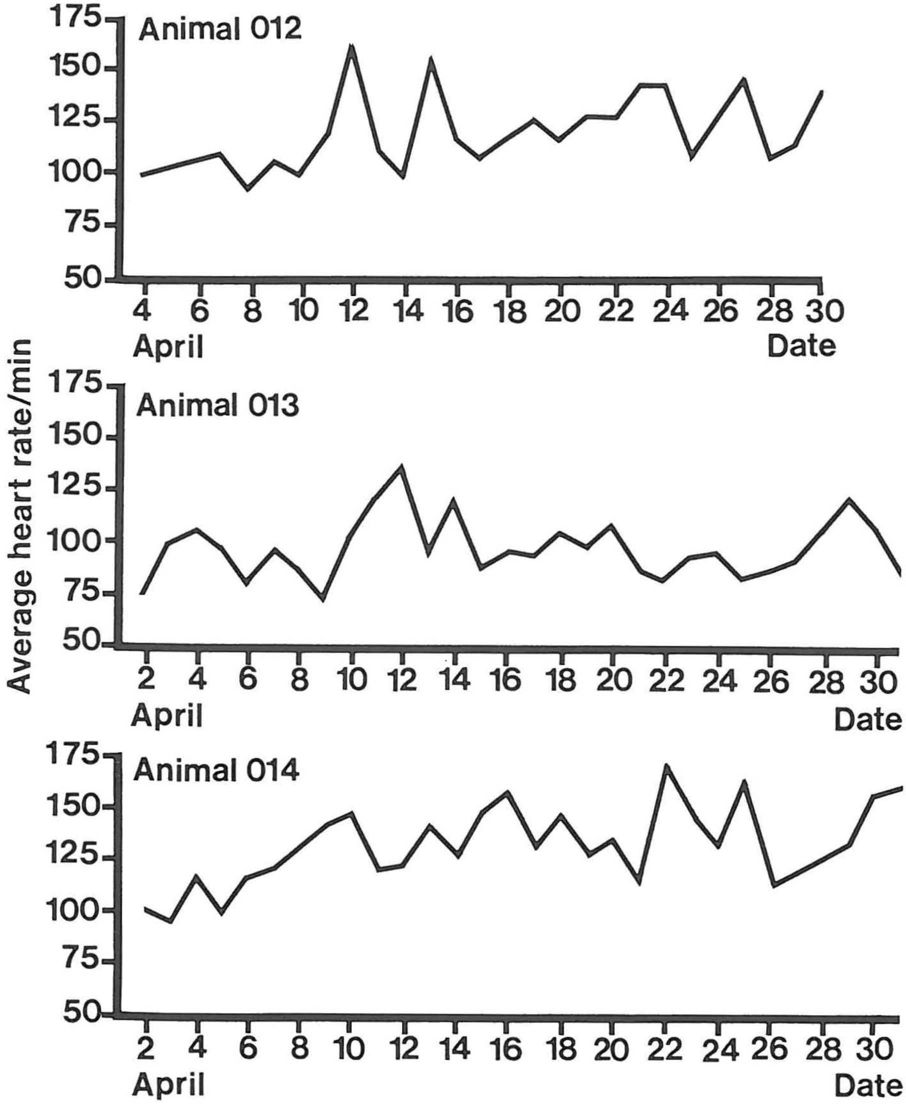

Figure 4. The average daily heart rate of 3 Harbour porpoises recorded during a period of 26 days.

PpSH012 and PpSH014 showed a small increase in average heart rate over time. Animal PpSH013 showed no particular trend in average heart rate over time.

Electrocardiogram (ECG)

In a normal human ECG several waves can be distinguished. The P-wave represents the electrical excitation of the atria. The QRS-complex comes from the more complicated spread of excitation through the ventricles. The T-wave is associated with the electrical recovery of the ventricles; it signifies the return to the resting polarized state.

Animal PpSH014 showed a rapid, but varying, supraventricular rhythm with a frequency of 120 beats per minute during the last 10 seconds before respiration, and about 160 beats per minute during the first 10 seconds after respiration (Fig. 5 and Table 3). This sinus arrhythmia is almost certainly caused by the respiratory cycle. The ECG shows a high voltage P-wave and a relatively long PR-interval (Table 4). The T-vector is opposite to the QRS-vector.

Animal PpSH012 also showed a certain degree of respiratory arrhythmia. It had a supraventricular rhythm of 105 beats per minute during the last 10

Table 3. Heart rates, before and after respiration, of 2 Harbour porpoises in the present study, and of 3 other species of cetaceans (Kanwisher and Ridgway, 1983)

Species	Weight (kg)	Heart rate last 10 sec before respiration (beats/min.)	Heart rate first 10 sec after respiration (beats/min)
PpSH014	31·0	120	160
PpSH012 (on land)	17·5	105	165
PpSH012 (in water)	17·5	90	150
Common dolphin	50	42	100
Bottlenose dolphin	150	42	60
Beluga whale	500	30	60

Table 4. Duration (milliseconds) of ECG deflections and intervals of a Harbour porpoise in the present study and of a Horse, a Bottlenose dolphin and a Beluga whale (Altman and Dittmer, 1971) and of a Killer whale (Meijler and van der Tweel, 1986)

Animal	P-wave	PR-interval	QRS-interval	QT-interval
Horse	195 (170–220)	370 (320–429)	100 (80–120)	520 (440–600)
Beluga	—	320	(90–120)	—
Bottlenose dolphin	82 (60–100)	—	65 (50–80)	257 (210–320)
Killer whale	120	—	120	340
PpSH014	50	120	40–60	220

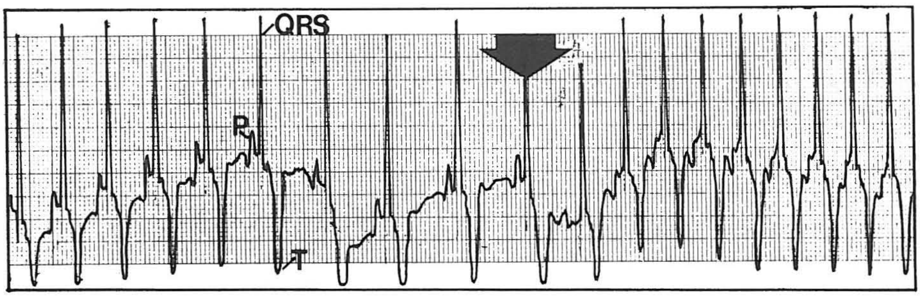

Figure 5. The ECG of animal PpSH014 on land. The arrow indicates a respiration (25 mm = 1 second).

seconds before respiration, and 165 beats per minute during the first 10 seconds after respiration (Fig. 6A and Table 3). The animal also showed a relatively high voltage of the P-top, but a relatively short PR-interval. The T-waves are biphasic. This does not necessarily contradict the findings of animal PpSH014, but could be due to the location of the electrodes.

When the animal was put back into the water, the heart rate dropped (but the arrhythmia remained) and the voltage decreased (Fig. 6B and Table 3). This is probably caused by the short-circuiting effect of the salt water. The PR-intervals remained short, the T-waves became negative.

Discussion and conclusions

The heart rates recorded were possibly higher than those in free-swimming Harbour porpoises, because the animals may have been under stress while held by the researchers. The fact that the heart rate increased over time was probably due to a further increase in health status of these beached animals which became more alert over time. The relatively slow heart rate of

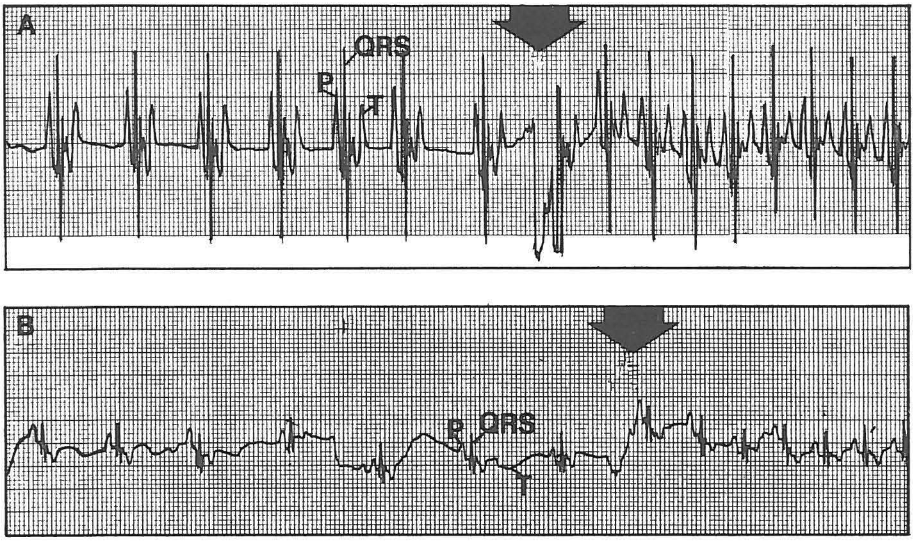

Figure 6. The ECG of animal PpSH012 on land (A) and in the water (B). The arrow indicates a respiration (25 mm = 1 second). Note the loss of voltage which is probably due to the short-circuiting affect of the water.

animal PpSH013 might have been related to an overall low level of metabolism of this animal, since it ate less and swam more slowly than the other two animals. The older age and greater body weight may also account for the lower heart rate of this animal.

There are similarities, but also a difference between the ECG's of the two Harbour porpoises. Similarities: The heart rate dropped and the sinus-arrhythmia remained in all the animals when they were placed in the water. Difference: The direction of repolarisation of animal PpSH014 was opposite to that of the depolarisation. This was not clear for animal PpSH012.

Kanwisher and Ridgway (1983) found a respiratory arrhythmia in 3 other cetaceans (Table 3). The animals of the present study had a higher heart rate than the 3 other species of cetaceans. The heart rate of cetaceans seems to be correlated to the body weight, as in terrestrial mammals. The adjustment for the decrease in specific metabolic rate with increasing body size is entirely taken care of by the decrease in heart rate (Schmidt-Nielsen, 1984).

Ecological significance

Kanwisher and Ridgway (1983) suggest that the accelerated heart rate after inhalation serves to accelerate the oxygen uptake in the blood. This is necessary because a dolphin's lungs partially collapse during deep dives, which probably lowers oxygen uptake (Ridgway and Howard, 1979). So the quickened distribution of the oxygen after respiration is beneficial to the animal. This study shows that ECG recordings of marine mammals may contribute to the understanding of the heart and circulation.

Acknowledgements

We thank head trainer Jan Mosterd for his assistance with the recordings and for testing the underwater electrodes, and also Claes Wassenaar and Wallace Reeder for the ECG recordings. We appreciate the help of Martin Bakker during the first meeting. We also thank Jos Hermens, Suzan Hordijk, Peter van der Weij and Erik Laarakker for recording the heart rate of the animals, Nancy Vaughan for her comments on the text, and Irma Verhoeven for drawing the graphs. The photographs were taken by Henk Merjenburgh.

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