Behaviour and physiological effects of transmitter attachments on a captive harbour porpoise (*Phocoena phocoena*)

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ABSTRACT

A captive harbour porpoise (*Phocoena phocoena*) was monitored for 80 consecutive days, 10 days before attachment of a satellite dive recorder and a VHF-radio tag, 30 days during attachment and 40 days after removal of the transmitters. Dive data recorded by the satellite transmitter was collected during the attachment. Daily food intake was measured and each week the porpoise was taken out of the water for a physical examination. Behavioural observations logged on the handheld computer showed an immediate effect of the tagging in time spent resting at the surface (logging), which was four to six times higher on the day of attachment. Digital video recordings showed a significant increase in the mean duration of rolls at the surface immediately after attachment. The mean duration of dives was shorter before attachment than both after the tagging and after removal of the transmitters. Furthermore the frequency of surfacings farthest away from where the porpoise was taken out of the pool for tagging, was highest the first five days following the tagging. Dive data from the satellite tag showed a semidiurnal diving pattern, with increased mean dive depth in the first 24 hours after attachment. The heart rate was fairly constant during the tagging, but the mean heart rate increased significantly from 161 beats per minute (bpm) to 180 bpm after the first hole in the dorsal fin was made. The body weight of the porpoise increased up to the time of tagging (16 May 2000), after which it decreased until six days prior to release (28 July 2000); this was probably due to the seasonal trend in blubber thickness of harbour porpoises rather than an effect from the tagging. After one month of attachment, a reaction occurred around the frontal pinhole and the transmitters were removed. This reaction was probably due to drag from two tags and seaweed attached to the tags during the last part of the attachment period. After the tags were removed epithelia closed the pinholes after two days.

KEYWORDS: HARBOUR PORPOISE; BEHAVIOUR; PHYSIOLOGY; CAPTIVITY; SATELLITE TAGGING; TELEMETRY

INTRODUCTION

During the past decade, telemetry studies have helped elucidate the behaviour and population structure of cetaceans. Due to the relatively large size of the transmitters, tagging of smaller species, such as the harbour porpoise (*Phocoena phocoena*) has been limited until the recent availability of smaller tags.

Many kinds of tags have been used in studies on cetaceans, including VHF transmitters, satellite tags and dataloggers. Satellite tags in particular are popular since data are transmitted to an earth-based station via a satellite, making retrieval of the tag unnecessary. Several small cetacean species have been followed for long periods using VHF or satellite tags, e.g. white whales (*Delphinapterus leucas*): 30-126 days (Richard *et al*., 2001), 14-104 days (Suydam *et al*., 2001); harbour porpoises: 2-212 days (Read and Westgate, 1997); 50 days (Westgate *et al*., 1998), 6-349 days (Teilmann *et al*., 2003); Dall's porpoise (*Phocoenoides dalli*) 2-378 days (Hanson, 2001); and narwhals (*Monodon monoceros*): 6-145 days (Dietz *et al*., 2001). Dataloggers have also been deployed on small cetaceans, including the harbour porpoise. A datalogger stores high resolution dive data within the instrument usually for a few hours or days (Westgate *et al*., 1995; Otani *et al*., 1998; Schneider *et al*., 1998; Teilmann, 2000; Baird *et al*., 2001; Laidre *et al*., 2002).

Transmitters are attached to smaller odontocetes in several ways. In some cases they are secured to the front or the side of the dorsal fin or the dorsal ridge, usually with two to four nylon, delrin, stainless steel or titanium pins (4-9mm diameter) through the dorsal fin (e.g. Read and Westgate, 1997; Richard *et al*., 2001). Other approaches include the attachment of the transmitters to the dorsal fin or the body using suction cups (Schneider *et al*., 1998); in the case of male narwhals the tags can be secured around the tusk of the animals (Dietz *et al*., 2001). The pins ensure that the tag stays attached for a longer period of time, but boring two to three holes through the dorsal fin may be a stressful procedure for the animal. Furthermore the pinhole wounds are at a potential risk of infection due to their exposure to the water and foreign material. Using suction cups for attachment allows the tag to stay on for only some hours, but there is no risk of infection. However, suction cups can cause localised skin damage (Read *et al*., 1997); after eight hours of attachment blisters developed under the suction cups and they appeared to cause the porpoise much discomfort for several days.

So far there have been no systematic studies on how invasive attachments affect behaviour and physiology of the animals. However, one study did attempt to re-sight tagged animals to evaluate tag attachment and animal condition (Hanson, 2001). The reason for this limited number of studies is due to logistical difficulties associated with following and observing wild cetaceans for longer periods of time, both before and after attachment of transmitters. In general, only small changes in behaviour have been observed (Martin and Smith, 1992; Read and Westgate, 1997; Otani *et al*., 1998). These observations were however undertaken without baseline information, and could only reveal a difference in behaviour immediately after tagging and later; this cannot be interpreted to show that tagging does not change behaviour on a longer-term scale. Tag attachment by pinning through the dorsal fin was found to cause slight behavioural short-term reactions on the Amazon River dolphin (*Inia geoffrensis*; Martin and da Silva, 1998). These reactions were limited to the first few minutes following the tagging.

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This study documents the first systematic record on possible changes in behaviour of a cetacean equipped with a satellite and a VHF radio transmitter. Behavioural observations were focused on changes immediately after tagging and over a longer period. The physiological effects of the transmitters on the animal were also studied.

METHODS

Study site

The experiment was carried out at the Cetacean Rehabilitation and Research Center, Neeltje Jans, The Netherlands, in an outdoor enclosure placed in a harbour in a firth without any boat traffic. Two harbour porpoises were kept in an outdoor floating pen 34×20m wide, with the deepest part varying from 4-7m depending on the tide. Large floating pontoons surrounded the pen, the sides and the bottom were made of net (twine thickness: 3mm) with a stretched mesh size of 9cm, which allowed seawater to continuously flow through the pen. Within the floating pen were two smaller holding pens (3.6 × 2.9m; 1.2m deep) situated at the north end (Fig. 1).

Study animal

Only one of the two harbour porpoises was used in this study. The study animal was a stranded mature female (code PpSH057). It was kept in an indoor pool for rehabilitation at the Netherlands Cetacean Research and Rehabilitation Centre at the Harderwijk Marine Mammal Park, Harderwijk, The Netherlands, approximately 4.5 months prior to the start of the study. After this period the animal was transferred to Neeltje Jans on 12 April 2000, where the experiment was carried out over a period of 80 days. At the time of tagging, the porpoise was 141.5cm long and weighed 39.4kg. Each week the porpoise was taken out of the water for approximately 15 minutes for a physical examination. Blood samples were taken from the fluke and the weight, length and girth of the animal was measured. Furthermore, food intake was measured on a daily basis from 8 May 2000 until the end of the study; the porpoise had unlimited access to fish at each feeding. After rehabilitation, the animal was released into the North Sea on 3 August 2000 (with no tags attached).

Transmitters and attachment

A VHF radio tag (Sirtrack Ltd, New Zealand) and a satellite dive recorder (SDR-T16 with 2 × M1 cells, Wildlife Computers, Seattle, USA) were attached, on each side of the dorsal fin (Fig. 2). The external measurements of the VHF tag were 5.0(l) × 3.7(h) × 0.7(w)cm. The VHF tag was glued (Loctite 414) to a conveyer rubber belt padded with 3mm neoprene in which three holes for the pins were made. The maximum external measurements of the satellite transmitter were 10.0(l) × 6.5(h) × 2.1(w)cm with a triangular pointed tip towards the front (Fig. 2). The satellite transmitter had three holes in the epoxy casting, one in front and two on top of the tag. The back of the transmitter was lined with 3mm neoprene. The total weight of the dorsal pack was 180g in air and 20g in water. A detailed description of how dive data are collected and transmitted by the SDR-

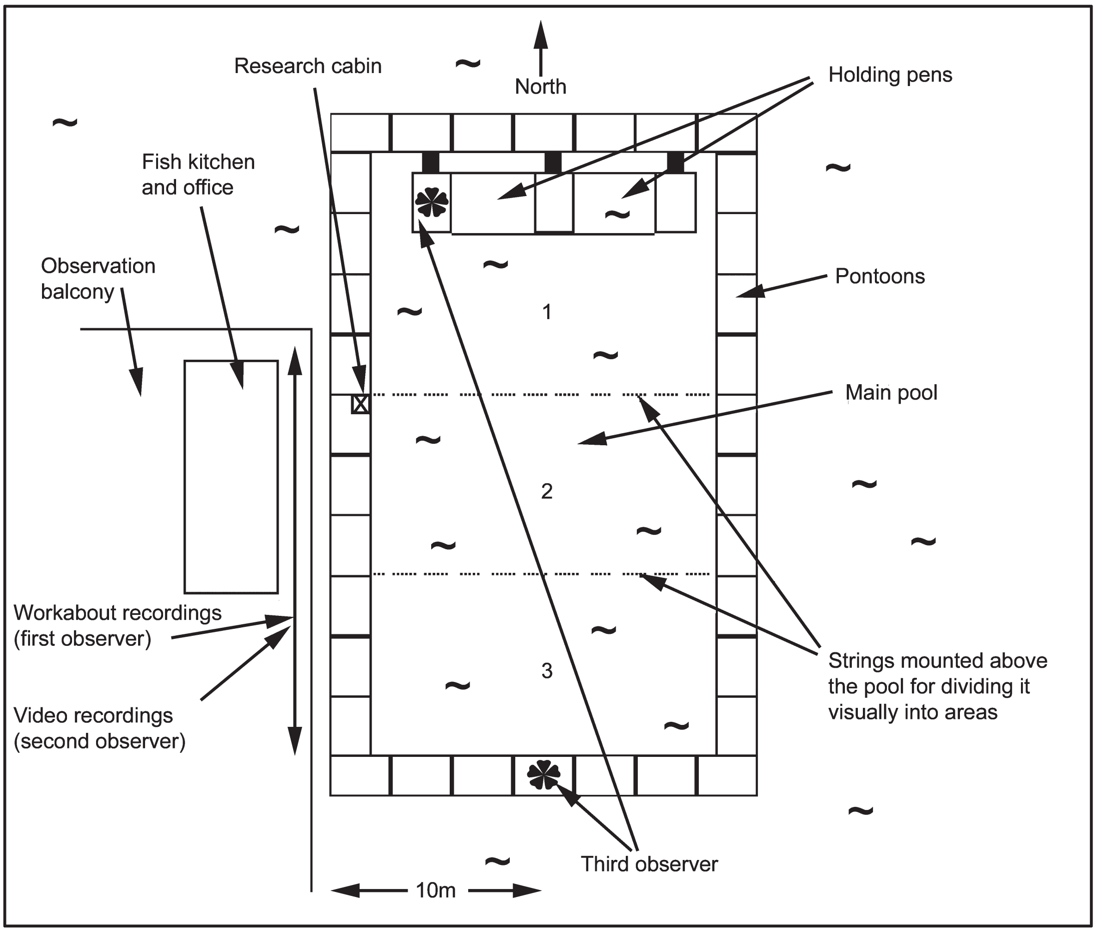

Fig. 1. Schematic view of the pen. The main pool is divided into three areas. The Workabout and video recordings were made from the observation balcony and were recorded by the first and second observer respectively. The third observer followed the animal from one of two different positions (*).

T16 tag can be found in Teilmann (2000). In addition to the transmitted dive data, the tag also stored the depth of the animal every 10 seconds on its internal memory. However the transmitter had to be recovered for downloading of these data to a computer. The pressure transducer had a resolution of 1m with an accuracy of ±1% of the depth reading. The 10 seconds depth readings were recorded continuously for 87 hours after tagging until the memory was full. Two hours of these data were discarded; one hour in the beginning that represented a period before and during tagging, and approximately one hour at the end comprising corrupted data. A total of 85 hours of data, representing 30,600 depth recordings, was available for analysis. The dive data were grouped into one-hour periods, and the mean depth of each hour was used for analysis.

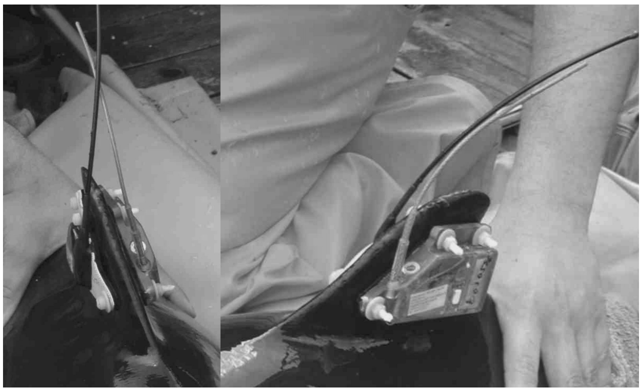

Fig. 2. Pictures of the SDR-T16 satellite tag (transparent) and the VHF tag (black) glued to a piece of conveyer belt and the three pins attaching the tags to the dorsal fin.

Prior to the attachment, the animal was tranquillised with Valium and local anaesthesia was applied to the dorsal fin (Lidocain ointment 5%, and Scandicain 3% injections). Three holes were then bored in the dorsal fin with a 5mm cork borer-type utensil. The transmitters were attached with three pins (polyoxymethylen (POM), 5mm in diameter) sheathed with smooth nylon tubes and coated with antibacterial ointment (Fucidin 2%). The pins were fastened with nylon nuts, but not too tightly so that water could still flow between the neoprene and the skin. During attachment of the transmitters, the harbour porpoise was fitted with a heart rate instrument to monitor the cardiac response to tagging. The heart rate monitor consisted of a Polar transmitter fitted on an elastic belt, and a Polar Vantage NV wrist monitor (Polar Electro). The elastic belt was strapped around the chest of the porpoise just anterior to the pectoral fins. On the inside of the belt two electrodes, connected to the transmitter, measured the electrical potential from the heart and transmitted the data to the wrist monitor via an electromagnetic field (Edwards, 1997). The heart rate was measured in beats per minute (bpm) giving an average value every 5 seconds. By observing the wrist monitor it was possible to closely follow the heart rate while the tagging progressed. After the porpoise was released, the heart rate data were transferred to a computer using a wireless interface (Advantage Interface, Polar Electro).

Observations

One observer measured behavioural changes immediately after the tagging and after removal of the transmitters using a handheld computer (Psion Workabout). A second observer followed the porpoise closely with a Sony digital video camera also immediately following transmitter attachment and after removal, while a third observer monitored the animal regularly for 80 consecutive days focusing on possible behavioural changes before, during and after transmitter attachment.

The first observer collected a total of 15 hours of data on the Workabout, one day before attachment (3.1hrs), two days immediately after attachment (3.9hrs and 5.4hrs, respectively) and the seventh day after the transmitters were removed 16 June 2000 (2.6hrs). The Workabout was programmed to log duration of dives, frequency and duration of surfacings in each of the three areas of the enclosure as well as the number of loggings. A 'logging' was recorded each time the porpoise remained at the surface between two breaths.

One day before tagging, the two days following tagging and on the seventh day after removal of the transmitters, digital video recordings provided data on the exact duration of each roll during the observation period. A roll was defined as a surfacing followed by a single breath, and then a dive (Amundin, 1974). The duration of rolls was measured to give an indication of whether the transmitters had an impact on the swimming pattern of the harbour porpoise. The duration of each roll was calculated by tallying the number of picture frames in the video recordings, starting with the first appearance at the surface and ending when the porpoise disappeared again. One frame represented 0.04 seconds and only fully recorded and clearly visible rolls were analysed. The mean duration of 45-50 rolls was calculated from the afternoon as well as for the morning immediately after tagging.

The third observer followed the porpoise visually while taking notes from either of the two locations marked in Fig. 1. Harbour porpoise behaviour was observed in two periods of 10 minutes (around 10:00 and 14:00 hours) each day, over 80 days, resulting in a total of 26.7 hours of observation. The observation period was divided into four sub-periods, based on when the transmitters were attached. Day 1-10 was the baseline period, before the attachment of the transmitters, day 11-15 was the first five days after attachment, day 16-40 when transmitters were attached, and day 41-80 after removal of the tags. Two types of behaviours were recorded: duration of each dive and distribution of surfacings in the pool. Durations of 4,273 dives were recorded and grouped in 5 second intervals. The pool was divided into three areas to facilitate analysis of the distribution of surfacings (Fig. 1). The area in which the porpoise surfaced following each dive was recorded and the distribution of surfacings among the three areas were compared. Area 1 contains the holding pool where the porpoise was taken out of the water for attachment of the transmitters and for medical examinations.

Data analysis

Animal behaviour software (Observer version 3.0, Noldus, the Netherlands) was used to analyse the data collected on the Workabout. SAS 8.02 (SAS Institute Inc., Cary, NC, USA) was used for statistical analysis. All data proved to be distributed normally and the statistics used were descriptive statistics, one-way ANOVA, Tukey test and chi-square test. The results were considered significant at the 5% level.

RESULTS

The transmitters were attached to the dorsal fin of the animal during a routine weekly physical examination at 08:30-09:00 on 16 May 2000. During the tagging, the porpoise generally reacted as if it had been a normal physical examination, although when the holes were made in the dorsal fin, the porpoise reacted a few times by arching its back. The heart rate measurements showed a relatively constant pulse of 161 bpm (STD=13.1) until the first hole was made. Thereafter the heart rate increased significantly to 180 bpm (STD=10.3, *t*-test, $p<0.0001$, Fig. 3) until the animal was released into the water and the heart rate measurer was removed.

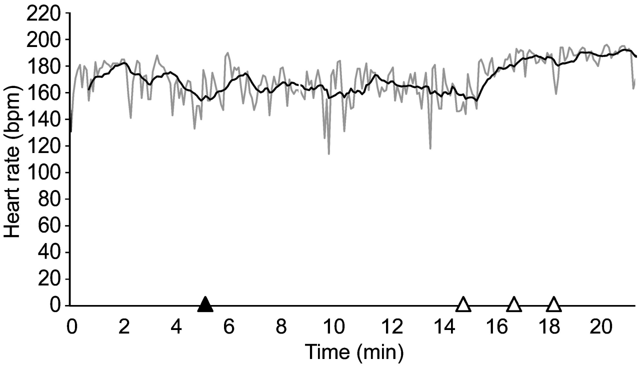

Fig. 3. Heart rate of the porpoise (bpm) during tagging. The black triangle on the x-axis represents when the blood samples were taken and the white triangles represent when the holes were bored in the dorsal fin. The black line is a running average.

Behavioural effects caused by the transmitters

Loggings (Fig. 4)

A total of 15.0 hours of observation on the handheld computer yielded data on 132 loggings. The number of loggings per hour was five to six times higher on the day of tagging, than the day before tagging, the day after tagging and on one day a week after removal of the tags.

Duration of rolls (Fig. 5)

The mean duration of rolls varied significantly (one-way ANOVA: $p<0.0001$, $F=120.65$). There was a significant difference in the duration of rolls during all days of observation, except for the 16 May seven hours after attachment and the seventh day after removal of transmitters (Tukey test, critical value 3.89).

Dive duration (Fig. 6)

Dive duration varied between 1-163s with an overall mean of 22.2s. The mean dive duration whilst the tag was attached (23.8s) was significantly higher than both the mean dive duration before (19.0s) and after removal of transmitters (21.7s; one-way ANOVA: $p<0.01$, $F=6.6$).

Surfacing areas

In the first period after the attachment (day 11-15), the porpoise surfaced more in area 3, the area furthest away from the medical pool (89%) compared to the other three periods (45-56%). Consequently surfacings in area 1 and 2 for the period from day 11-15 were less frequent (area 1=2% and area 2=9.5%) than in the other periods (area 1=15-24% and area 2=28-31%) (Fig. 7). There was a significant difference in the distribution of areas where the porpoise surfaced when comparing the four time periods (chi-square, $p<0.001$).

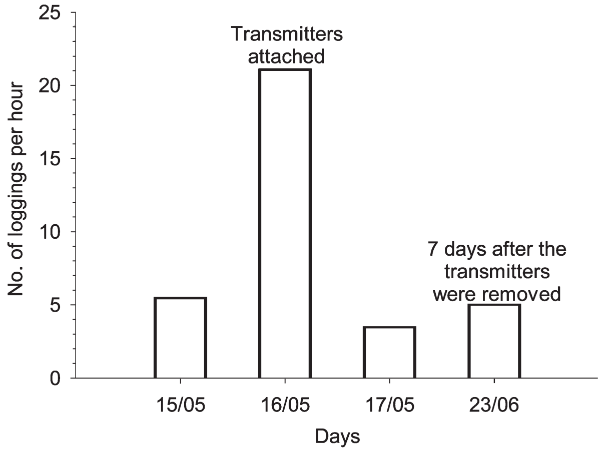

Fig. 4. Frequency of loggings per hour on four days of observation. There were 15 hours of observation in total: 3.1hrs on the day before attachment of the transmitters; 3.9 and 5.4hrs on the two days following attachment; and 2.6hrs on the seventh day after the removal of the transmitters.

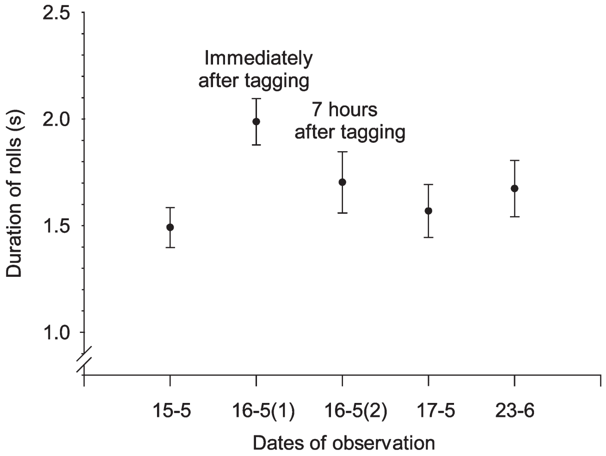

Fig. 5. The mean duration of rolls on four days of observation. All rolls were measured from recordings made between 13:20 and 17:00, except 16-5 (1), where recordings were made between 09:00 and 10:00. The mean duration of rolls each day are represented by dots, while the bars represent one standard deviation.

Depth of dives

A clear semidiurnal dive cycle was evident during the first 85 hours after tagging. Shallower mean depth of dives were recorded around noon and again around midnight (dive depth 0-1m), and deeper mean depth of dives were recorded in a short period around 06:00 and 18:00 (dive depth 1.5-2.2m) (Fig. 8). In the first 24 hours after attachment, the semidiurnal pattern was similar, but with 1-2m deep mean depth during all hours compared to the rest of the experimental period. The tide varied about 3m with high tide around 01:30-3:30 in the morning and 13-15:30 in the afternoon during 16-19 May 2000. There was no obvious connection between dive cycle and tide cycle.

Body weight and food intake of the porpoise

A decrease in body weight from 35 to 33kg was seen for the first two weeks after the porpoise was stranded (4 December 1999). After that, the porpoise steadily gained weight, except for a period between mid-January and late February 2000 when its body mass remained fairly constant (Fig. 9). At the time of transfer to the outdoor enclosure in Neeltje Jans (12 April 2000), the porpoise weighed 38.8kg and in the period up to the tagging (16 May 2000) the body weight

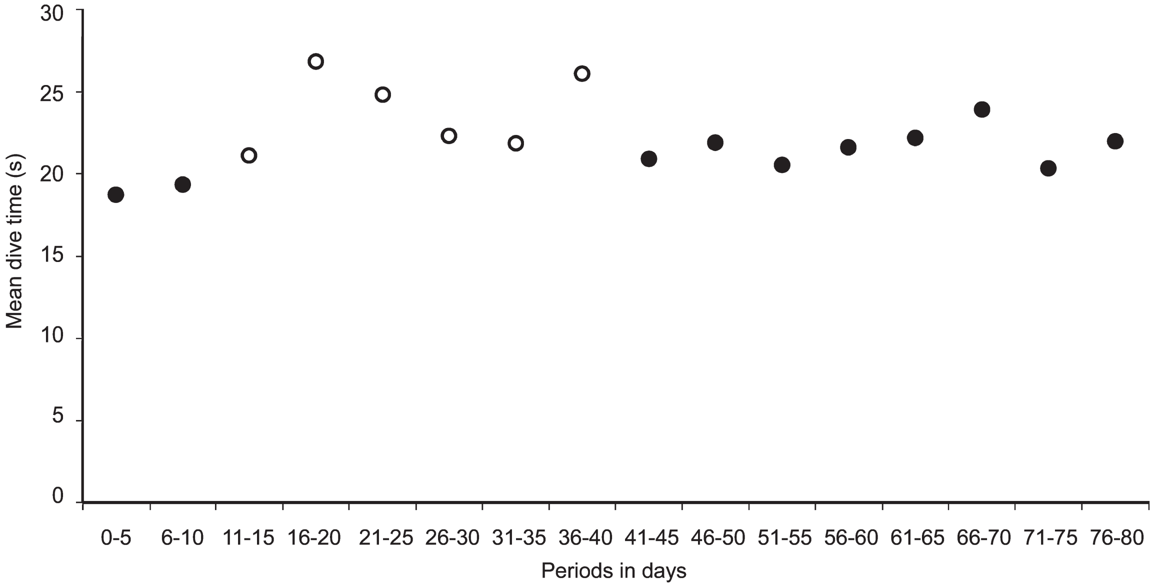

Fig. 6. The mean dive time of 16 five-day periods in seconds. The black dots represent time periods where the porpoise was not tagged and the white dots represent time periods where the porpoise was tagged.

increased to 39.4kg. During transmitter attachment period, the body mass decreased to 37.2kg and after the transmitters were removed the porpoise continued to lose weight until the last week of July, just prior to the release of the porpoise, where the animal gained 1kg. The relative weight loss between mid-May and late July was 7.6% of the total body weight.

The daily food intake decreased from 1.7 to 1.4kg in the week up to the tagging. From the time of transmitter attachment until three weeks after the removal of the transmitters, the daily food intake increased steadily from 1.4kg to 1.9kg. Following that period the food intake increased much more rapidly than previously seen, thus from 6 July 2000 until the end of the study period the daily food intake increased from 1.9kg to 3.5kg (Fig. 9).

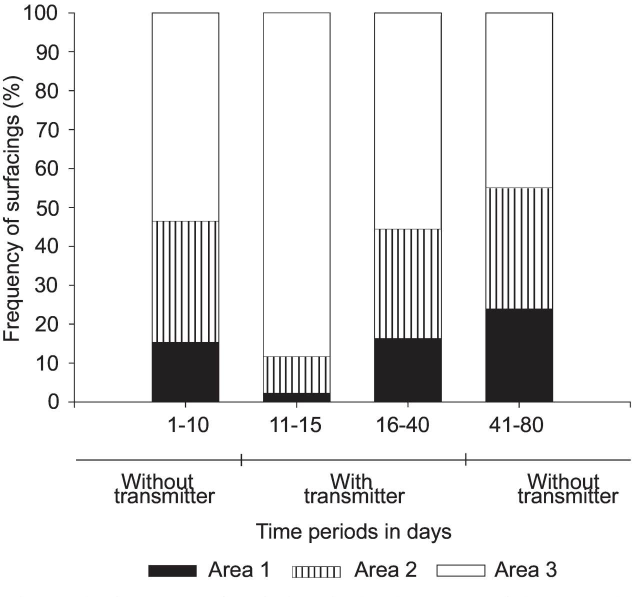

Fig. 7. The frequency of surfacings in the three areas of the pool. The animal was released in area 1 after the tagging on day 11 (see Fig. 1 for areas).

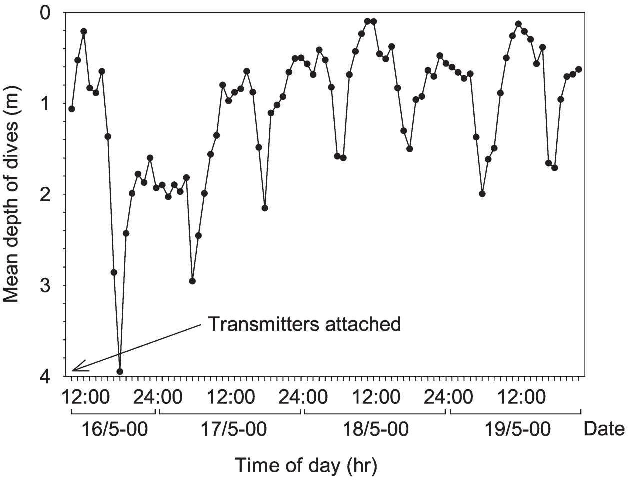

Fig. 8. The mean depth of dives during 85 hours. The depth of the porpoise was measured every 10 seconds and 360 measurements were averaged over 1 hour. The mean depth of each hour is displayed against time of day starting immediately after the attachment of the transmitters. Note the apparent semidiurnal rhythm of diving.

Removal of the tags

Due to a lighter skin colour around the pinholes and a sudden reaction when the front hole was touched, the transmitters were removed on 16 June after one month of attachment. When the pins were removed a reddish exudate was present inside the holes but no swelling was observed. This tissue reaction that apparently emerged after about one month could be due to the additional drag associated with the seaweed that tended to get stuck on the antennas and pins during the last part of the experiment. The animal was often seen with long ‘tails’ of seaweed up to 0.5m in length trailing after it when it swam.

On the second day after transmitter removal, the holes were closed but the porpoise still reacted when the front hole was touched. After seven days all holes were healed, but touching the front hole still caused the animal to react. After 28 days the porpoise did not react to any pressure on the holes.

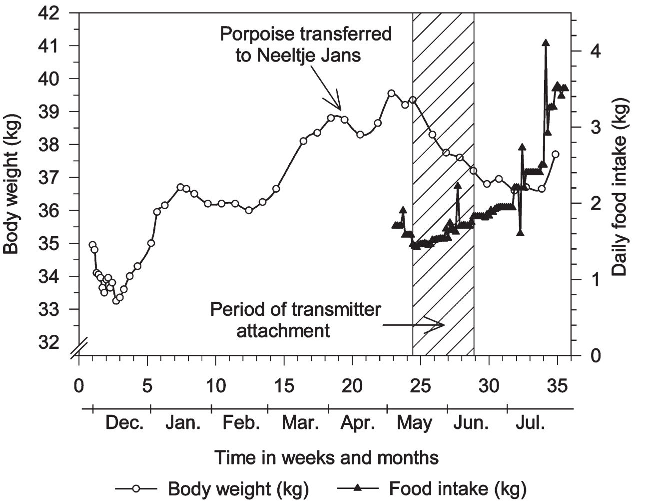

Fig. 9. The variation in body mass (primary y-axis) from 4 December 1999 to 28 July 2000 and the daily food intake (secondary y-axis) from 8 May 2000 to 2 August 2000. The time is given in both weeks after the porpoise stranded and months of the year.

When the transmitters were removed, an imprint of 1mm in depth was observed on the upper and lower part on both sides of the dorsal fin. The colour of the skin at the imprint was lighter than the normal skin. The imprint on the lower part of the dorsal fin was gone after five days, while the one on the upper part did not disappear until 35 days after the transmitters were removed. Several times during these 35 days the skin sloughed at the imprints. The imprints did not seem to cause the porpoise any discomfort.

DISCUSSION

Heart rate measurements

There was no clear effect on the heart rate of the animal when blood samples were taken. However, the mean heart rate increased significantly following the boring of the first hole. Geertsen (2002) presents heart rate data during handling and tagging of 20 harbour porpoises. During nine of these taggings, the time of the boring and blood sampling were recorded. Three of the porpoises experienced a clear and significant increase in heart rate after the first hole was bored. Therefore we suggest that the state of the animal during tagging should be monitored closely, particularly during the boring of the holes through the dorsal fin. Furthermore, measuring the heart rate of the animal during tagging is important for monitoring its wellbeing.

Short-term effects on behaviour

The dramatic increase in logging behaviour we observed has also been documented for a captive adult female harbour porpoise regularly carrying a datalogger attached with suction cups for approximately one hour at a time (Teilmann, 2000). In this experiment, logging increased significantly when the datalogger was attached compared to before and after the attachment. In another study, Otani *et al.* (1998) observed two female harbour porpoises in a small circular tank before and after attachment of a datalogger. Although logging behaviour was not recorded, no changes in either breathing frequency, body weight, swimming or feeding behaviour, were reported after the attachment of the dataloggers. The observed increase in logging in the present study during the first day after tagging was probably a result of the animal acclimatising to the touch of a foreign object on its dorsal fin and the sensation of associated drag during diving. Furthermore, the Valium that was used as a tranquilliser could have had an effect on the animal's behaviour in the first hours after tagging.

Immediately after the attachment, the harbour porpoise made significant longer lasting rolls than on the day before attachment. The mean duration of rolls decreased with time following the period after attachment, but in none of these periods was the mean duration of rolls as low as the day before attachment. Teilmann (2000) recorded the behaviour of a harbour porpoise in captivity before and after a datalogger was attached to the dorsal fin with suction cups. The porpoise was resting (immobile) for 11% of the observation time before and 37% during the attachment of the datalogger (Teilmann, 2000). Furthermore the frequency of breathings that terminated by the porpoise submerging/sinking backwards after resting at the surface increased significantly after the attachment of the datalogger (Teilmann, 2000). The 'sinking backwards' behaviour was not observed in the present study, but in another study also conducted at Neeltje Jans, such behaviour was observed in two different male porpoises tagged with satellite transmitters (Ron Kastelein, unpubl. data). Irvine *et al.* (1982) also observed this behaviour in two out of 10 bottlenose dolphins tagged in the wild with radio tags attached with one pin through the dorsal fin. The slower rolls at the surface and the slow sinking backwards could be an adaptation to reduce the possible discomfort when the tag hits the water surface during a normal roll. The differences in mean duration of dives, before, during and after tagging, show that the porpoise increased its dive duration during tagging. Although the mean dive duration only increased by about 5s, this may also be an adaptation to reduce the number of surfacings and thereby the numbers of impacts with the water surface.

During the first 24 hours after tagging, the mean dive depth was 1-2m deeper than during the following 61-hour period, where the semidiurnal diving pattern was rather constant. Since the dive depth could only be recorded by the satellite tag, it is not known whether the deeper dive depth after tagging was a reaction to the tagging or if the shallower dives recorded after 24 hours was a reaction to the presence of the tag.

In the first period after deployment of the transmitters (day 11-15), the animal surfaced almost exclusively in area 3, compared to the other three periods. This behaviour suggests that the porpoise connected the stressful tagging experience with the holding pen in area 1. Therefore it tended to stay as far away as possible from that end of the pool in the first days following the tagging. A similar behaviour was observed in a satellite tagging study of wild porpoises in Denmark where tagged animals tended to move rapidly away from the tagging location immediately after release but often returning to the same general area after some days (Teilmann, 2000).

The increase in logging behaviour as well as the clear avoidance behaviour towards area 1, suggest a reaction to the tagging experience. However, the results presented in this paper indicate that the change in behaviour may only last a few hours or days. Considering that harbour porpoises exhibit a high degree of individual behavioural variability (Westgate *et al.*, 1995; Read and Westgate, 1997; Teilmann, 2000), and that the experiment in this paper is based on only one animal, the results must be interpreted with caution.

Long-term effects on behaviour

Only a few experiments have succeeded in resighting tagged animals after several days (Martin and Smith, 1992; Read and Westgate, 1997; Hanson, 2001). Read and Westgate (1997) reported resightings seven days after release of a male harbour porpoise deployed with a satellite tag mounted on the front of the dorsal fin, and a VHF transmitter attached to the trailing edge of the dorsal fin. The animal appeared to swim normally, and was in a large group of feeding porpoises. Martin and Smith (1992) were able to observe a tagged white whale on several occasions in the days following the release of the animal. The animal was often seen together with other white whales, and its behaviour appeared normal. Furthermore, a satellite tagged harbour porpoise was resighted in Danish waters in the company of another porpoise for a few hours two months after tagging. There was no apparent difference in behaviour between the two porpoises (Jonas Teilmann, pers. comm.). Hanson (2001) observed a tagged free-ranging harbour porpoise periodically over a 203 day period. Although the porpoise was commonly observed near other porpoises, the animal appeared to log at the surface with greater frequency than its conspecifics (NMML, unpublished data).

Physiological effects

Attaching a satellite tag and/or a VHF transmitter onto small cetaceans using pins through the dorsal fin gives rise to concern about potential adverse impacts associated with the tag and the attachment. The drag from transmitters is a potential problem and has been discussed in relation to both tissue and energetics for several marine animals (Bengtson *et al*., 1993; Watson and Granger, 1998; Hanson, 2001). In small cetaceans, where the tag is attached with pins through the dorsal fin, the drag is transferred from the transmitter to the pins, and ultimately to the adjacent tissue (Hanson, 2001). This may cause tissue degradation around the holes and result in migration of the pins through the fin, resulting in the tag detaching from the animal. Irvine *et al.* (1982) report of several cases of pins migrating through the dorsal fin of bottlenose dolphins deployed with VHF-transmitters. Hanson (2001) found from wind tunnel experiments that positioning a tag on each side of the dorsal fin of a harbour porpoise increased the drag considerably compared to attachment of a single tag onto the side of the dorsal fin. Careful attention to streamlining the design of the tag can probably reduce the drag significantly (Hanson, 2001). Furthermore, the fast closure of the holes suggests that it was only a local reaction and that the ability to regenerate tissue is very fast in the dorsal fin.

During tag attachment and after the transmitters were removed, the porpoise continued to lose weight despite the increase in food consumption. Lockyer *et al.* (2003) reports on clear seasonal fluctuation in both body weight and food intake of a mature male and a mature female captive harbour porpoise kept in a semi-natural outdoor enclosure over a period of five years in Kerteminde, Denmark. The body weight of both porpoises peaked during the winter months, after which it decreased during spring and reached the lowest values in the summer. The daily food consumption declined after January until the end of June where it increased rapidly until late summer or early autumn. The mean weight loss (percent of the total body weight) in the period 1997-2001 was larger for the female than for the male (19.9% and 15.7% respectively, Lockyer *et al*., 2003). The relative weight loss was less pronounced for the porpoise in the present study, but the porpoises in the two studies showed similar patterns in daily food intake. Therefore it is possible that the variations in body weight and daily food intake for the porpoise in this study were due to seasonal fluctuations rather than an effect of the extra drag caused by the transmitters and the seaweed. However, contrary to the hypothesis that the drop in body weight was part of a seasonal body weight cycle, is the fact that the drop was less pronounced after the transmitters were removed. In addition, the female had been housed indoors over the previous winter, and thus did not create an extra thick blubber layer like the porpoises in Kerteminde that live in cold water in the winter.

CONCLUSIONS

Although the results presented in this paper are gathered from one captive harbour porpoise, which did not have to capture its own food, it appears that the attachment of satellite tags had minor long-term effects on the animal's behaviour. Changes in behaviour were evident in the first hours or days after the tagging, but thereafter the animal appeared to behave normally apart from a slight increase in the mean dive duration.

The shape of the tag, antenna and saddle should be carefully designed according to hydrodynamic principles to reduce drag as much as possible (Hanson, 2001). Furthermore we recommend rounding all edges, pins etc., to avoid catching seaweed. New smaller and more hydrodynamic tags have been designed with internal pins (e.g. SPOT2 and SPOT3, Wildlife Computers, Seattle, USA), or recessed nuts (Hanson, 2001) to reduce drag and seaweed attachment. As it is difficult to get quantitative data on the effects of tagging on cetacean species in the wild, we recommend that more long-term captive studies be conducted. These studies should focus on: (1) the effect of various tag designs on the tissue of the dorsal fin; (2) the effect of various pin materials, as well as their size and number used for attachment on the dorsal fin tissue; (3) the effect of various tag designs on the behaviour and energetics of the animal; and (4) developing a reliable release mechanism for long-term deployments that releases the tag when e.g. battery is drained. Such studies will help developing tags and methods of attachment that have the least impact on the animals and thereby increasing the value of the results obtained from animals tagged in the wild and not compromising their well-being.

ACKNOWLEDGEMENTS

We would like to thank the staff at Neeltje Jaans for excellent training and caretaking of the porpoise. Genevieve Desportes and Christina Lockyer provided useful information on various aspects of the physiology of harbour porpoises. We would also like to thank Rune Dietz and Jakob Tougaard for constructive criticism on an earlier draft as well as Bent Jørgensen and Frank Riget for comments on the statistics and Brad Hanson and another external reviewer. This study was financed by the Danish Forest and Nature Agency as a part of the tagging study of wild harbour porpoises in Denmark and by the Danish National Research Foundation.

REFERENCES

Amundin, M. 1974. Functional analysis of the surfacing behaviour in the harbour porpoise, *Phocoena phocoena* (L.). *Sonderdruck aus Z. f. Säugetier Bd.* 39(5):313-8.

Baird, J.W., Ligon, A.D., Hooker, S.K. and Gorgone, A.M. 2001. Subsurface and night time behaviour of pantropical spotted dolphins in Hawaii. *Can. J. Zool.* 79:988-96.

Bengtson, J.L., Croll, D.A. and Goebel, M.E. 1993. Diving behaviour of chinstrap penguins at Sea Island. *Antarct. Sci.* 5(1):9-15.

Dietz, R., Heide-Jørgensen, M.P., Richard, P. and Acquarone, M. 2001. Summer and fall movements of narwhals (*Monodon monoceros*) from Northeastern Baffin Island towards Northern Davis Strait. *Arctic* 54(3):244-61.

Edwards, S. 1997. The heart rate monitor book. *Fleet Feet Press* 9:31.

Geertsen, B.M. 2002. Attaching satellite tags on harbour porpoises (*Phocoena phocoena*): effects on behaviour and physiology and a guideline for estimating stress levels. Master Thesis, Institute of Biology, University of Southern Denmark, Odense. 127pp.

Hanson, M.B. 2001. An evaluation of the relationship between small cetacean tag design and attachment durations: a bioengineering approach. Ph.D. Thesis, University of Washington, Seattle, Washington. 208pp.

Irvine, A.B., Wells, R.S. and Scott, M.D. 1982. An evaluation of techniques for tagging small odontocete cetaceans. *Fish. Bull.* 80(1):135-43.

Laidre, K.L., Heide-Jørgensen, M.P. and Dietz, R. 2002. Diving behaviour of narwhals (*Monodon monoceros*) at two localities in the Canadian High Arctic. *Can. J. Zool.* 80:624-35.

Lockyer, C., Desportes, G., Hansen, K., Labberté, S. and Siebert, U. 2003. Monitoring growth and energy utilisation of the harbour porpoise (*Phocoena phocoena*) in human care. *NAMMCO Scientific Publications* 5:107-20.

Martin, A.R. and da Silva, V.M.F. 1998. Tracking aquatic vertebrates in dense tropical forest using VHF telemetry. *Mar. Technol. Soc. J.* 32:82-8.

Martin, A.R. and Smith, T.G. 1992. Deep diving in wild, free-ranging beluga whales, *Delphinapterus leucas*. *Can. J. Fish. Aquat. Sci.* 49(3):462-6.

Otani, S., Naito, Y., Kawamura, A., Kawasaki, M., Nishiwaki, S. and Kato, A. 1998. Diving behavior and performance of harbor porpoises, *Phocoena phocoena*, in Funka Bay, Hokkaido, Japan. *Mar. Mammal Sci.* 14(2):209-20.

Read, A.J. and Westgate, A.J. 1997. Monitoring the movements of harbour porpoises (*Phocoena phocoena*) with satellite telemetry. *Mar. Biol.* 130:315-22.

Read, A.J., Wiepkema, P.R. and Nachtigall, P.E. (eds.). 1997. *The Biology of the Harbour Porpoise*. De Spil Publishers, Woerden, The Netherlands. 409pp.

Richard, P.R., Heide-Jørgensen, M.P., Orr, J.R., Dietz, R. and Smith, T.G. 2001. Summer and autumn movements and habitat use by belugas in the Canadian high arctic and adjacent areas. *Arctic* 54(3):207-22.

Schneider, K., Baird, R.W., Dawson, S. and Childerhouse, S. 1998. Reactions of bottlenose dolphins to tagging attempts using a remotely-deployed suction-cup tag. *Mar. Mammal Sci.* 14(2):316-24.

Suydam, R.S., Lowry, L.F., Frose, K.J., O'Corry-Crowe, G.M. and Pikok, D., Jr. 2001. Satellite tracking of eastern Chukchi Sea beluga whales in the Arctic Ocean. *Arctic* 54(3):237-43.

Teilmann, J. 2000. The behaviour and sensory abilities of harbour porpoises (*Phocoena phocoena*) in relation to bycatch and gillnet fishery. Ph.D. Thesis, Institute of Biology, University of Southern Denmark, Odense. 219pp.

Teilmann, J., Dietz, R., Geertsen, B.M., Aastrup, P., Larsen, F., Desportes, G., Buholzer, L., Rye, J. and Andersen, L. 2003. Satellitsporing af marsvin (*Phocoena phocoena*) i danske farvande. Technical report from National Environmental Research Institute. 89pp. [In Danish].

Watson, K.P. and Granger, R.A. 1998. Hydrodynamic effects of a satellite transmitter on a juvenile green turtle (*Chelonia mydas*). *J. Exp. Biol.* 201:2,497-505.

Westgate, A., Read, A., Berggren, P., Koopman, H. and Gaskin, D. 1995. Diving behaviour of harbour porpoises (*Phocoena phocoena*) in the Bay of Fundy. *Can. J. Fish. Aquat. Sci.* 52(5):1064-73.

Westgate, A.J., Read, A.J., Cox, T.M., Schofield, T.D., Whitaker, B.R. and Anderson, K.E. 1998. Monitoring a rehabilitated harbor porpoise using satellite telemetry. *Mar. Mammal Sci.* 14(3):599-604.