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An Acoustic Tag for Recording Directional Pulsed Ultrasounds Aimed at Free-Swimming Bottlenose Dolphins (*Tursiops truncatus*) by Conspecifics

Christer Blomqvist and Mats Amundin

Department of Biology, IFM, University of Linköping, S-581 83 Linköping, Sweden, and Research & Education Centre, Kolmårdens Djurpark, S-618 92 Kolmården, Sweden

Abstract

We developed an acoustic tag, called MOSART (MObile Submersible Acoustic Recorder of Transients), for recording directional social pulses produced by a bottlenose dolphin (*Tursiops truncatus*). The tag was attached to the dorsal fin of two dolphins by means of suction cups. Two adult bottlenose dolphins at the Kolmårdens Djurpark, Sweden, were trained to carry the tag comfortably through a desensitising program. The tag included two envelope click-detectors, each with a narrow bandpass filter, centred at 120 and 70 kHz, respectively. The duration of the original pulses and their relative amplitude within the two filter frequency bands was retained. The amplitude differences between the two filter bands reflected changes in the source frequency spectrum and/or the position of the tag hydrophone in the incoming sound beam. The tag recorded "echolocation click trains," "slow and irregular pulses," and "pulse bursts" with varying amounts of energy in both frequency bands. The peak amplitude and duration of clicks in "echolocation click trains" and in "slow and irregular pulses" were logged correctly; however, the tag recorder had more difficulties in handling the complex pulses in the aggressive "pulse bursts," where the duration of the individual pulses could not be determined. Still, the amplitude and the pulse repetition rate could be measured. The possible impact of the tag was investigated by analysing the dolphin's behaviours (12 categories), sounds (3 categories), preferred location in the pool, and respiration intervals. Only four of the behaviours and one preferred location in the pool showed significant differences among pre-tag baselines, tag periods, and post-tag follow-ups, suggesting that the tag had only a minor impact on the dolphin. We describe and discuss the tag and its capacity to record different pulsed sounds.

Key Words: acoustic tag, bottlenose dolphin, *Tursiops truncatus*, click detector, suction cup tag, directional pulse, broadband pulse burst, ultrasound, aggressive sounds

Introduction

The ability of odontocetes to produce pulses has been the subject of numerous studies, and all species investigated so far produce such sounds (Richardson et al., 1995). The majority of these studies focused on pulses used for echolocation in delphinids (see Au, 1997, for a review), but pulsed sounds also are used in intraspecific communication (Amundin, 1991; Busnel & Dziedzic, 1966; Caldwell & Caldwell, 1967; Dawson, 1991; Lang & Smith, 1965; Overstrom, 1983; Ralls et al., 1985; Watkins & Schevill, 1977; Weilgart & Whitehead, 1990).

Echolocation clicks in the bottlenose dolphin (*Tursiops truncatus*) have a very short duration (50 to 150 µs) and are broadband, often having a bimodal power spectrum with two widely separated frequency peaks at 30-60 kHz and 100-120 kHz (Au, 1993). Dolphins can control the source level (SL), as well as the frequency content of these pulses, although very high SLs always seem to be coupled with a high peak frequency (> 100 kHz) in the click power spectrum (Moore & Pawloski, 1990). These outgoing sounds are directional with a –3dB beam width of about 10 degrees in both the vertical and horizontal planes. The frequency spectrum of stronger pulses often has a single peak > 100 kHz close to the beam axis, whereas the more distorted waveforms in the beam periphery have multiple frequency peaks, with the lower ones (30-70 kHz) being more powerful (Au, 1993).

Blomqvist & Amundin (2004) found that pulse burst sounds, which occurred in aggressive interactions, were broadband and directional, similar to sonar clicks (see Au, 1993). In their dolphinarium-based study, a single hydrophone was attached to a netted gate, which was positioned in a narrow channel connecting two pools. This increased the probability of recording within the transmission beam (i.e., in front of and in line with the rostra of dolphins interacting across the gate). Blomqvist & Amundin suggested that the directionality might be used intentionally to address these signals to selected pool mates. To study this aspect further in free-swimming dolphins, the sensing hydrophone needs to follow the interacting animals and either be positioned within the acoustic beam of the transmitter and/or be attached to the potential receiver.

Previous studies on dolphin communication mainly focused on the transmitting individual. Tyack (1985) studied dolphin whistles by attaching a suction cup unit called "vocalight" on the melon of dolphins in human care. The "vocalight" had a hydrophone molded into the suction cup, and it displayed the occurrence of whistles and their relative amplitude on a panel of diodes (LEDs). It would have been possible to adapt the "vocalight" to indicate the emitter of broadband, pulsed sounds instead of whistles; however, identifying the transmitter is not enough for studying the directionality of these sounds and its use in addressing social signals to selected conspecifics. Instead, following a reversed approach, we developed an acoustic tag to be carried by the potential receiver.

The tag was attached to the dorsal fin by means of suction cups. Although the dorsal fin is some distance away from the acoustic window at the lower jaw (Brill et al., 1988; Bullock et al., 1968; McCormick et al., 1970; Norris & Harvey, 1974), it was regarded as an acceptable and practical position for the tag. Suction cups have been promoted as a benign alternative to bolt attachments through the dorsal fin (Hanson & Baird, 1998); the latter sometimes is used in field studies. In our case, working with performing public display animals, bolts were inadmissible; however, previous studies using suction cup tags reported highly variable attachment durations, from minutes to several hours (Akamatsu et al., 2000; Baird, 1998; Hanson & Baird, 1998; Johnson & Tyack, 2003; Madsen et al., 2002), with a maximum of 62 h (Baird et al., 2000). The TracPac® (TracPac Inc., Fort Walton Beach, FL, USA), a commercially available dorsal fin pack, has a very good record of attachment when loaded with small-sized and lightweight electronics (Davis et al., 1996; Nowacek et al., 1998), and it was used as a model for the development of the tag for this study.

Suction cup tags, which are attached to wild cetaceans by using guns or crossbows, have caused an initial startle reaction, but the animals usually returned to an apparently "normal" behaviour within only a few minutes after tagging (Goodyear, 1993; Watkins & Tyack, 1991); however, Schneider et al. (1998) reported a dramatic behavioural change in New Zealand bottlenose dolphins after remote attachment of suction cups. To avoid such a behavioural impact, the dolphins used in this study were subjected to a desensitisation program, using counter-conditioning techniques (see Hurley & Holmes, 1998).

The tag and its recording system are described, and examples of pulsed sounds recorded with it are given. Based on this and concurrent behaviours, the usefulness of the tag for the study of directional social pulsed sounds was assessed.

Materials and Methods

Tag Attachment

The tag, called MOSART (MObile Submersible Acoustic Recorder of Transients), is based on a girdle, shaped to cover the front and sides of the dorsal fin ("front-mount design"; see Figure 1). The tag has suction cups on the inside of the girdle and is secured with a Velcro® strap around the trailing edge of the fin. The girdle was laminated on a cast of a dolphin's dorsal fin, with eight layers of flexible Orthoacryl® and two embedded layers of carbon-fibre-webbing to increase its stiffness (custom made by Otto Bock AB, Norrköping, Sweden). [1]

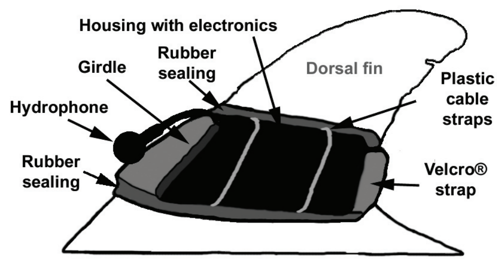

Figure 1. Schematic illustration of the MOSART tag, designed to be attached with suction cups to a dolphin's dorsal fin and secured around its trailing edge with a Velcro® strap. The cylindrical housing contains two Envelope Click Detectors and an MD recorder. A piece of hard rubber, of similar size and weight, was attached to the girdle on the opposite side of the fin, to counterbalance the weight and drag of the housing. The hydrophone is attached at the front edge of the girdle, where it is exposed to sounds coming from all directions, except from below and straight behind.

[1] The dorsal fin cast was made in plaster using a negative mold, produced by wrapping a 3-mm thick sheet of Turbocast® around the dorsal fin of the adult male, Flip. Turbocast® is a medical thermoplastic polycaprolactone and polyurethane mixture, covered with a 0.6-mm layer of foam (T-Tape Company, Putte, The Netherlands). Turbocast® is used as an alternative to plaster in human and veterinary medicine/orthopaedics. When heated to 60° C, it becomes as soft as tissue, and when cooled to room temperature, it stiffens again.

Five soft and flexible silicone suction cup soap holders (78 x 58 mm; Coram Scandinavia AB, Helsingborg, Sweden) were sewn to the inside of the girdle, using a Teflon® thread. Each soap holder has 36 small, 8-mm suction cups on both sides—that is, facing both the dorsal fin and the inside of the girdle. This, and sewing instead of gluing it to the girdle, gave the soap holders the necessary flexibility to allow a perfect fit around most adult dorsal fins and to absorb pulling forces created by the dolphin's movements. Rubber "flaps" were fitted on both the lower and the upper edge of the girdle to prevent the tag from falling off due to water being pressed in between the fin and the girdle during high speed swimming, jumping, etc.

Tag Sound Recording System

A waterproof housing, containing the sound recording electronics and two 9-V batteries, was made of carbon-fibre-reinforced polyester (custom made by Otto Bock AB, Norrköping, Sweden). The housing was attached to the left side of the girdle by means of plastic cable straps (Figure 1). To counterbalance the weight and drag of the housing, a piece of hard rubber of similar size and weight was attached to the right side.

The pulsed sounds were picked up by a 12.7-mm HS/150 ball hydrophone (Sonar Products, now Sonar Research and Development, Ltd, Beverley, East Yorkshire, UK, frequency response 1-130 kHz ± 2 dB; sensitivity –204 dB re 1 V/1 μPa), mounted on the front edge of the girdle (Figure 1). The pulses were fed into two envelope click detectors (ECD-1; NewLeap Ltd, Cardiff, Wales, UK), each with an 8th order band pass filter centred at 70 and 120 kHz, respectively (-3 dB bandwidth 12 and 10 kHz, respectively; Figure 2). There was a 6-dB difference in gain between the two filters, which has been corrected for in the figures presenting the relative amplitude of pulses recorded by the tag. These filters were designed to give selective information on the variations in the high- and mid-portion of the power spectrum of broadband social pulses (cf. Blomqvist & Amundin, 2004) aimed at the dolphin carrying the tag. Differences in the amplitude of pulses in the two filter channels will reflect variations in the source frequency spectrum, but also the differences caused by changes in the position of the tag's hydrophone in the incoming sound beam. A pulse is more distorted in the periphery of the beam, which affects its envelope as well as its power spectrum (Au, 1993). The outputs from the two ECDs were stored separately on a portable stereo digital MiniDisc recorder (SONY; MZ-R55; sampling rate 44.1 kHz). The MD-recorder is designed to optimise the recording time by reducing the frequency resolution in the higher frequencies within the human hearing range. This, however, had no consequence for the present application since no frequency analysis of the ECD output was intended. The analyses were restricted to pulse duration, the relative amplitude, and repetition rate patterns of recorded pulses. The system noise limited the dynamic range of the whole recording system to 62 dB. With the selected preamplifier settings, the maximum received sound pressure level, which could be recorded without overload, was equivalent to 158 dB_{p-p} re 1 μPa in the 70-kHz filter band and 152 dB_{p-p} re 1 μPa in the 120-kHz filter band. The maximum recording time of the MD disc was 74 min.

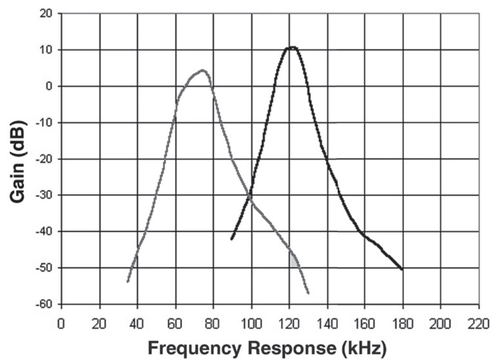

Figure 2. The measured frequency response of the 8th order bandpass filters are incorporated in the Envelope Click Detector boards. Left trace = 70-kHz filter, and right trace = 120-kHz filter. The -3 dB bandwidths of the filters were 12 and 10 kHz, respectively. Note the 6-dB gain difference between the filters. This was compensated for in the subsequent analysis.

Animals and Tag Desensitisation Procedures

Four bottlenose dolphins were selected to participate in this project: Flip, the 38-year-old breeding male, and three adult females, Vicky (age: 28 years), Delphi (age: 19 years), and Sharky (age: 21 years). They were part of a colony of fourteen dolphins kept for breeding and public display at the Kolmårdens Djurpark, Sweden. Seven of the animals were born at the facility, the first in 1983 and the latest 4 months prior to the onset of this study. The indoor pool complex contains two large public display pools, with a holding pool system in between. It has a total water volume of 6,400 m^3 and a total water surface area of 1,950 m^2.

The training objective was to have the selected animals carry the MOSART tag for a period of up to one hour, and remain comfortable enough to engage in social interactions with pool mates, while being unrestricted by human activities. Flip and Vicky served as "test platforms" during the initial phase of the tag development in 1998 and 1999. Based on the experiences with them, a training program was designed for Delphi and Sharky, to make them voluntarily and comfortably accept carrying the tag. They were introduced to this training in September 2000. Delphi and Sharky were socially more active than both Flip and Vicky and, hence, more interesting candidates for the study of social pulsed sounds, which was the main objective for this project. The training procedure was based on counter-conditioning techniques, also called active desensitisation (see Hurley & Holmes, 1998). With a training effort of 5-15 min per day and animal for 3-5 consecutive days, followed by 1-2 days off, Delphi and Sharky were comfortably carrying the tag for periods of up to one h after 4 and 7 months, respectively.

Both Delphi and Sharky invented techniques to deliberately take off the unit, whereas Flip and Vicky were not seen making any such attempts. Delphi usually engaged in a series of breaches, landing on the side of her body, whereas Sharky detached the tag by making a few swift and forceful partial rolls from one side to the other. Although these behaviours only occurred on a few occasions during the study, they had to be counteracted by the trainer, and this considerably slowed down the progress of the desensitisation.

Recording Procedures

The tagged animals were filmed using a black and white underwater video camera (Red Eye; Poro AB, Kåge, Sweden), mounted on a manually operated camera-rig attached to the pool wall and connected to a VHS VCR (Samsung A2/NICAM SV-6213X). The behavioural data were collected using focal animal sampling (Altmann, 1974; Mann, 1999). The concurrent acoustic activity in the pool was picked up with a 25.4-mm HS/70 ball hydrophone (Sonar Research and Development, Ltd, Beverley, East Yorkshire, UK), and was recorded on the VCR's sound track. The hydrophone was suspended from the roof of the building to a mid-water depth in the south part of the pool, and was protected inside a rigid plastic tube from dolphin bites. This audioband system had a flat frequency response between 1 and 20 kHz.

Before the tag was attached to the dorsal fin, an artificial pattern of pulses was recorded on the VCR and the MOSART tag simultaneously. It was later used to synchronize the MOSART tag recordings with the VCR recordings when they were copied onto a new VHS tape. In this copying process, a Vertical Image Time Code (VITC) was added to facilitate computer-based behaviour analysis. Before sound analysis, the analogue output of the MD recorder was recorded on a computer, using a sampling frequency of 44.1 kHz.

Behavioural Impact

A series of tag recordings with Delphi and Sharky was carried out in the spring of 2001, in the main 800 m^2 and 4-m deep display pool, to evaluate the potential of the MOSART system in recording pulsed sounds in social interactions. Some of the recordings with Delphi were designed to allow an assessment of the possible behavioural impacts of the tag. These recordings included a pre-tag baseline, a tag period, and a post-tag follow-up. All tag recordings with Delphi also were analysed to evaluate possible changes in the tag impact over the entire study. During all recordings, the dolphins (including the animal wearing the tag) were free to leave the observation pool since the gate to the adjacent holding pools was open.

The pulsed sounds, recorded with the audioband system, as well as the MOSART tag, were divided into three categories: (1) echolocation click trains, (2) slow and irregular pulse trains, and (3) pulse bursts. A total of 12 concurrent visual behaviours, the respiration intervals, and the dolphins' preferred positions in the pool were also recorded (see Appendix).

Analyses

Acoustic analyses were made using two software programs: *SeaPro* v. 1.1 (Centro Interdisciplinare di Bioacustica e Ricerche Ambientali, Università degli Studi, Pavia, Italy) and *Adobe Audition®*, v. 1.0 (Adobe Systems Incorporated, 345 Park, Avenue, San Jose, CA 95110-2704, USA). Selected behaviours were analysed using *VideoPro* v. 4.0 (Noldus Information Technology, Wageningen, The Netherlands). The ECD simulations were carried out using *MATLAB®* v. 5.3 (The MathWorks, Inc., Natick, MA 01760-2098, USA). The results were tested statistically with one-way ANOVA and Least Square Mean contrast, using *JMP Statistical* software v. 4.0.2 (SAS Institute Inc., 100 SAS Campus Drive, Cary, NC 27513-8617, USA).

Results

MOSART Tag vs Broadband Recordings

During the recordings in the spring of 2001, Sharky carried the tag 10 times over 16 days with a total of 3.2 h of recordings, and Delphi wore the tag 26 times over 71 days with a total of 13 h of recordings. Delphi had the longest tag attachment of 63 minutes, while Sharky reached 34 min. In total, the MOSART tag recorded 207 echolocation click trains, 344 slow and irregular pulse trains, and 65 pulse bursts. Of these, Sharky received 99, 95, and 29, and Delphi received 108, 249, and 36, respectively. Most of these sounds contained energy within both the 70-kHz and 120-kHz filter bands (Figures 3 and 4). The relative amplitude difference between the two filter frequency bands often changed (see Figure 4). A more in-depth analysis of the social aspects of these recordings will be published elsewhere.

Most pulse bursts were recorded during aggressive interactions and had a complex, "noisy" appearance, and also a more or less pronounced negative DC-offset (Figure 3). Low repetition rate echolocation click trains and slow and irregular pulse trains rarely had this DC-offset (Figure 4). To find the cause of the DC-offset, trains of positive, single or double (inter-pulse-interval 500 μsec) square pulses were fed into the MD-recorder to simulate the ECD output. Amplitude overload had no effect on the DC-level, whereas increasing the pulse repetition rate and/or pulse duration produced an increasingly negative DC-offset, similar to that found in the MOSART recordings. In spite of this DC-offset, however, the total pulse peak amplitude could be measured.

To evaluate the tag's representation of pulsed sounds, an aggressive pulse-burst and an echolocation click train, recorded with a 150-kHz bandwidth using a fixed hydrophone placed in a gate between two pools (for recording set-up details, see Blomqvist & Amundin, 2004), were run through a *MATLAB*® simulation of the tag's two bandpass filtered ECD channels. As can be seen in Figure 5A, the original aggressive pulse burst contains very long and complex pulses. Figure 5B gives a waterfall presentation of the spectra of each of the pulses in this burst, showing the main peak above 100 kHz and considerable energy below 20 kHz. In Figure 6A-B, the echolocation clicks are much "cleaner," have a single peak above 100 kHz, and lack the pronounced audioband component. Figures 5C-D and 6C-D show the tag's simulated ECD representations of these two sounds in the two filter bands, and Figures 5E and 6E show their click repetition rate pattern. In addition to dolphin-produced pulses, high-frequency noise was recorded on both channels of the MOSART tag. This noise was created by water flow and air bubbles in connection with surfacing and high-speed swimming, for example.

Behavioural Impact of the Tag

Twelve complete recording sessions, each containing a pre-tag baseline, a tag period, and a post-tag follow-up, were obtained with Delphi. Pre-tag baselines had an average duration of 23.8 min; tag periods, 29.4 min; and post-tag follow-up, 22.8 min. As shown in Table 1, there were significant differences between these periods in 4 of the 12 visual behaviours. The behaviours fast swim, pointing rostrum, and belly up occurred significantly more often during post-tag follow-up than during tag periods. The number of surfacings was significantly higher during post-tag follow-up periods than during both pre-tag baselines and tag periods. For one of the locations in the pool (location south), all three recording periods were significantly different from each other, with the highest use of this part of the pool during the tag periods.

In addition, Delphi also showed a significant trend over the entire recording period of 71 days in five of the behaviours measured in 26 tag recordings (Table 1). Three behaviours increased: logging, slow swim, and inter-breath-interval. A decrease was found in spy hopping and tilt. There was also a trend in her movements in the pool, with an increase in her staying in the southern and northern parts of the pool and leaving the pool (i.e., gone) more often. As a consequence, she spent significantly less time in the middle part of the pool.

Discussion

System Evaluation

The short duration and simple envelope of the pulses in the recorded echolocation click trains and slow and irregular pulse trains indicated that they were similar to the normal bottlenose dolphin broadband echolocation clicks (see Au, 1993). The ECD is very suitable for these kinds of simple pulses. Although the MD introduced a considerable negative DC-offset when recording the complex pulses in the aggressive pulse bursts, the tag recordings allowed a number of important aspects of these sounds to be ascertained: the relative peak amplitude within each filter band, the duration and repetition rate of the bursts, and often the pulse repetition rate within each burst.

The recorded water flow and air bubble noise neither interfered with nor affected the quality of the pulsed sounds recorded on the tag. Instead, the noise created in connection with surfacing could be used as an additional synchronisation cue between the recording from the tag and the one from the pool.

Evaluation of the Behavioural Impact of the Tag

The significant increase found in post-tag follow-up in relation to tag periods for fast swim, pointing rostrum, belly up, and surfacing suggested that Delphi felt relieved when the tag was removed—that is, that she was somewhat hampered by the tag. Still, this impact has to be considered small since the remaining 8 of the 12 selected visual behaviours (see Table 1) did not show any differences between the recording periods.

The significant increase over the whole study period in logging and slow swim may have been a result of the training method used (i.e., the animal was moving slowly and carefully to avoid the tag from falling off). It would also be a way to

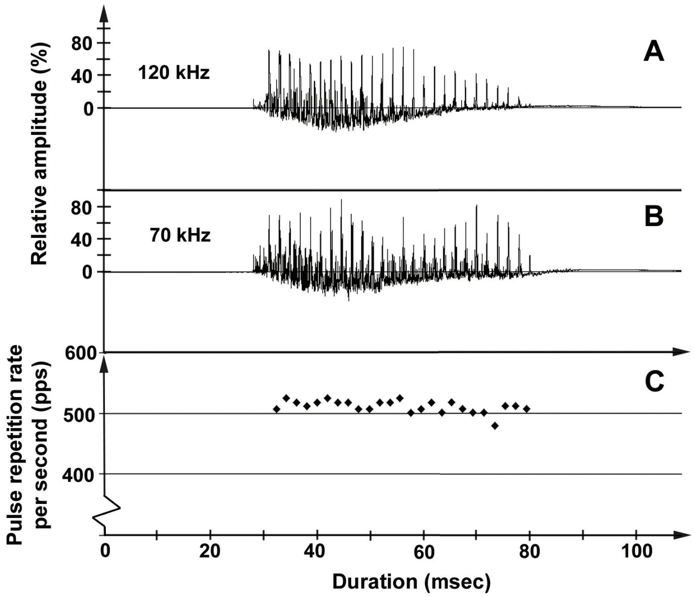

Figure 3. A pulse burst recorded by the MOSART tag in an aggressive interaction between two subadult males and an adult female carrying the tag: A – time domain plot of the 120-kHz Envelope Click Detector filter channel, B – time domain plot of the 70-kHz filter channel, and C – the pulse repetition rate (pulses/sec); the DC-offset was introduced by the MD-recorder in response to the long duration of the pulses and their high repetition rate; the total amplitude, including the DC-offset, remained equal to the input amplitude.

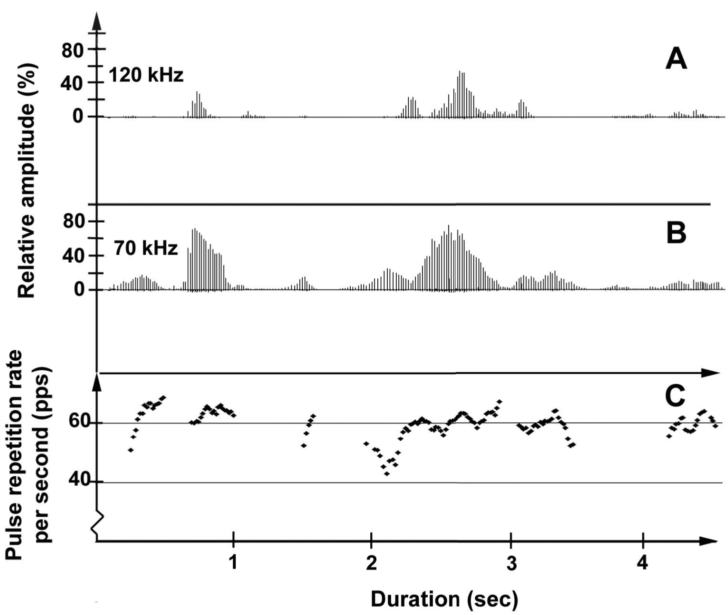

Figure 4. An echolocation click train, recorded by the MOSART tag: A – time domain plot of the 120-kHz Envelope Click Detector filter channel, B – time domain plot of the 70-kHz filter channel, and C – the pulse repetition rate (pulses/sec); each vertical bar in A and B indicates the positive envelope of individual pulses. Note the varying relative amplitude differences between the two filter bands.

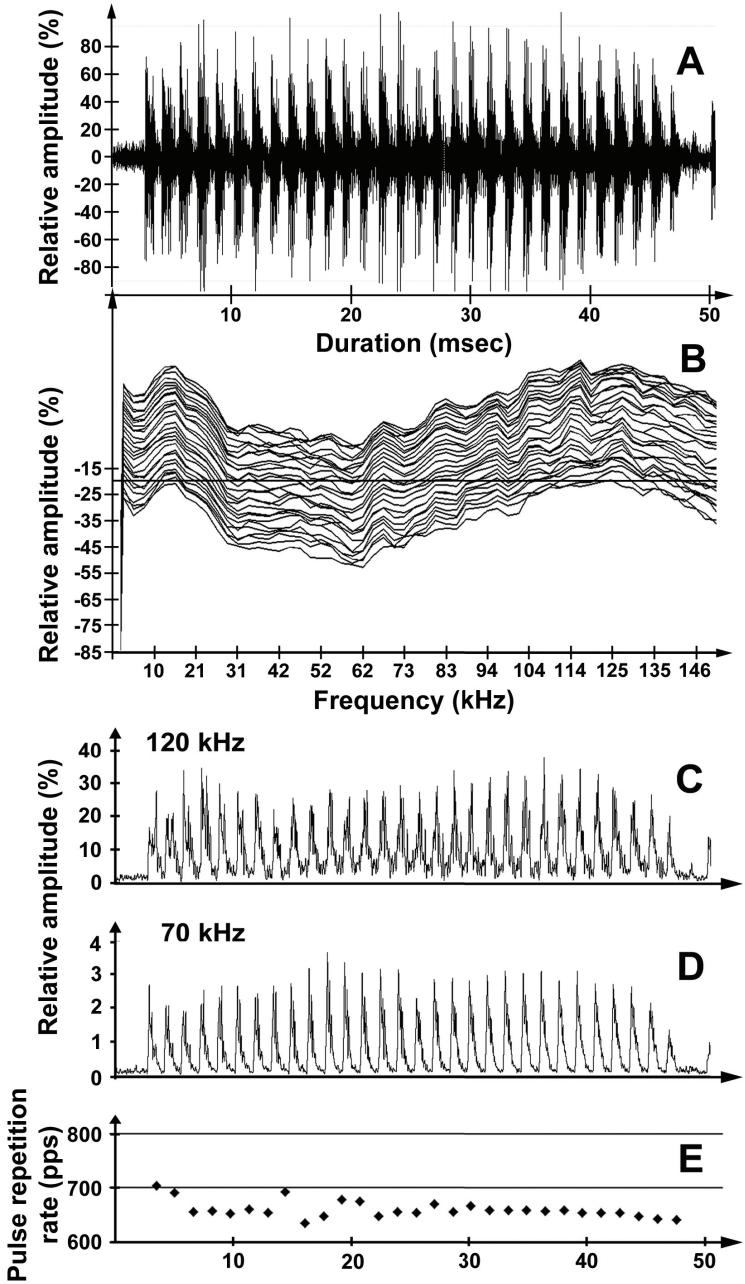

Figure 5. A pulse burst recorded in an aggressive interaction between two dolphins across a netted gate on which a fixed hydrophone was mounted (cf. Blomqvist & Amundin, 2004): A – the time domain plot of the original pulse burst (the sampling frequency was 333 kHz), B – a waterfall plot of the power spectra of the pulses, C – the pulse burst run through a *MATLAB*® simulation of the tag's 120 kHz band pass filtered ECD channel, D – like C, but run through the 70 kHz filter channel, and E – the pulse repetition rate (pulses/sec); note the long duration and complex waveform of individual pulses in A (cf. Figure 6A) and the pronounced energy peak below 20 kHz in B (cf. Figure 6B). The absence of a DC-offset in C and D, compared to the tag recordings (cf. Figure 3A-B), is due to the fact that the simulation did not include this error that was introduced by the MD-recorder. Also note the different amplitude scales in C and D.

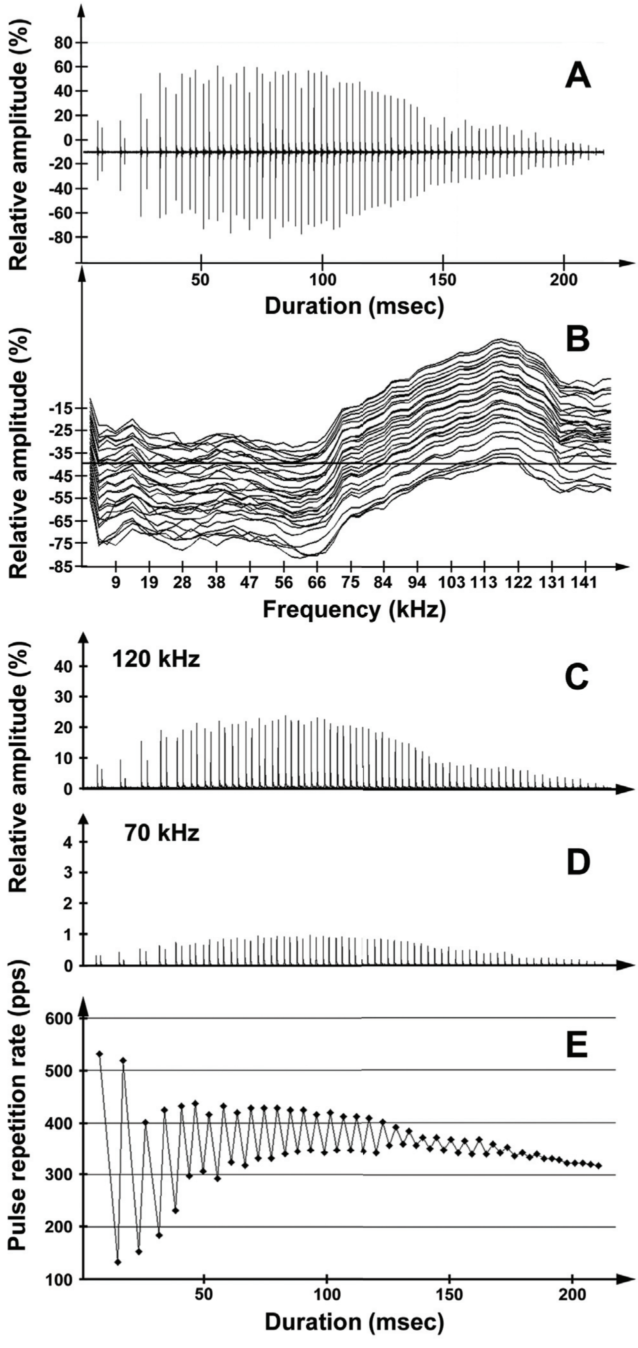

Figure 6. An echolocation click train recorded with a fixed hydrophone mounted on a netted gate (cf. Blomqvist & Amundin, 2004): A – the time domain plot of the original click train (the sampling frequency was 300 kHz), B – a waterfall plot of the power spectra of the clicks, C – the echolocation click train run through a *MATLAB*® simulation of the tag's 120 kHz band pass filtered ECD channel, D – like C, but run through the 70 kHz filter channel, and E – the pulse repetition rate (pulses/sec); note the short and "clean" clicks in A (cf. Figure 5A), the low energy levels below 70 kHz in B (cf. Figure 5B), the clear ECD representation of the individual pulses in C and D, and the double-pulse pattern in E. Also note the different amplitude scales in C and D.

Table 1. Summary of results from several one-way ANOVA tests comparing the occurrence of 12 behaviors by three recording blocks (pre-tag baseline, tag period, and post-tag follow-up). See Appendix for definitions of behaviours in Column 1. Column 2 shows the presence/absence of statistical differences between means for 12 recording sessions; number in parentheses give the significant relationships between different recording blocks. Column 3 reports the statistical results over the whole study period of 71 days.

	Statistical results for 12 recording sessions	Statistical results over entire tag period of 71 days
Behaviours	*(n) = 3x12 = 36*	*(n) = 26*
Fast swim	F=4.96 p=0.0131 (3>2)	ns
Normal swim	ns	ns
Slow swim	ns	F=4.95 p=0.0357 (+)
Logging	ns	F=11.47 p=0.0024 (+)
Spy hopping	ns	F=4.85 p=0.0376 (-)
Surfacing	F=6.22 p=0.0051 (3>1.2)	F=4.64 p=0.0415 (-)
Swim alone	ns	ns
Swim with pod mate(s)	ns	ns
Followed by pod mate(s)	ns	ns
Pointing rostrum at pod mate	F=5.30 p=0.0101 (3>2)	ns
Belly up	F=5.23 p=0.0107 (3>2)	ns
Tilt	ns	F=5.44 p=0.0284 (-) R^2=0.1848
Position in the pool	*(n) = 3x12 = 36*	*(n) = 26*
Location south	F=10.02 p=0.0004 (2>1; 1>3; 2>3)	F=9.35 p=0.0054 (+)
Location north	ns	F=7.01 p=0.0141 (+)
Location middle	ns	F=20.24 p=0.0001 (-)
Gone	ns	F=6.06 p=0.0214 (+)
Breathings	*(n) = 921*	*(n) = 1145*
Inter-breath-interval	ns	F=5.0 p<0.0001 (+)
Audioband recordings	*(n) = 3x8 = 24*	*(n) = 20*
Pulse bursts	ns	ns
Slow and irregular pulse trains	ns	ns
Echolocation click trains	ns	ns
MOSART tag recordings	-	*(n) = 22*
Pulse bursts	n/a	ns
Slow and irregular pulse trains	n/a	ns
Echolocation click trains	n/a	ns

minimize the effect of the extra drag produced by the tag. This reduced activity level, in combination with a reduction in spy hopping, may explain the significant increase over the whole study of the respiration interval. It was not possible to determine if the dolphin was really breathing during spy hops. Therefore, a decreased frequency of spy hopping automatically gave an increased inter-breath-interval. Spy hopping is believed to be a behaviour used to keep an eye on the activities on land, so the decreasing frequency of spy hopping over the whole study may be due to a reduced expectation in the animal of the trainer coming to take off the tag.

Tags bolted to the dorsal fin of wild dolphins are inevitably done so with no prior desensitisation. On the other hand, the exposure to the tag is constant and unavoidable, which probably speeds up the desensitisation and habituation, and these animals apparently return to normal swim and dive behaviour shortly after the tagging (Geertsen et al., accepted 2004). This, however, does not automatically imply that all aspects of their behaviour are similarly unaffected. Usually tagged dolphins cannot be monitored visually for any longer period of time, so the only information on any possible behavioural impact is that which can be deducted from the tag's sensors. Often, this is limited to dive depth and duration and geographical location data (see, e.g., Heide-Jørgensen et al., 1998; Read & Westgate, 1997; Teilmann, 2000; Wells et al., 1999), which tell little about the impact of the tag on the animal's social interactions. Recently, Johnson & Tyack (2003) developed a tag, which recorded pitch, roll, and heading of the tagged animal, in addition to dive depth, water temperature, and sound. These parametres in concert may give insight into more subtle behaviours, possibly also including social behaviours. Still, we recommend that data on social behaviour collected with tags attached to wild animals should be interpreted with caution until this aspect has been thoroughly studied on animals under controlled conditions (i.e., with dolphins in human care).

Conclusions

The MOSART tag proved successful in recording broadband and directional pulsed sounds that were aimed at the tagged dolphins in social interactions. The peak amplitude and duration of pulses resembling sonar clicks were correctly logged. The tag recorder had more difficulties in handling the complex pulses in the aggressive pulse bursts, where the duration of the individual pulses could not be determined. Still, in many of them, the pulse amplitude and repetition rate could be measured. The desensitisation program, although extended over a long period of time, was successful in making the selected animals comfortably and voluntarily carry the tag, although some minor behavioural impact of the tag could be found throughout the study.

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Appendix. Definitions of behaviours of bottlenose dolphins at Kolmårdens Djurpark

Behaviours	Description
Fast swim	More than one fluke beat per sec
Normal swim	One fluke beat per sec
Slow swim	Less than one fluke beat per sec
Logging	Floating at the water surface with little or no movements
Spy hopping	Lifting head high above the water surface, often while standing in a vertical position, or a surfacing of longer duration with the whole head above the water surface
Surfacing	The blowhole above the water surface, with the possibility to breathe (actual breathing could not be seen through the underwater camera)
Swim alone	Swimming more than one body length from any pod mate
Swim with pod mate(s)	Swimming closer than one body length to, and often synchronised with, a pod mate
Followed by pod mate(s)	One/several animals following directly behind the focal animal, and/or aiming the rostrum(s) at the focal animal, following its movements
Pointing rostrum at pod mate	Swiftly pointing the rostrum towards a pod mate
Belly up	Tilting 180°, swimming completely upside down
Tilt	Tilting to one side, more than ~30° but less than 180°
Position in the recording pool	
Location south	Staying in the southern ⅓ of the pool
Location north	Staying in the northern ⅓ of the pool
Location middle	Staying in the middle ⅓ of the pool
Gone	Swimming into the adjacent holding pool
Breathings	
Inter-breath-interval	The duration between two consecutive surfacings, (i.e., possible breaths); calculated from surfacing
Sounds	
Pulse burst	Short (<1 sec) pulse burst, with a high pulse repetition rate (>100 pps)
Slow and irregular pulse train	Short train of pulses, often <10 pulses, with variable consecutive interpulse-intervals
Echolocation click train	Click train ≥1 sec long with a steady or a gradually changing click repetition rate