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Can dolphins heal by ultrasound?

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Abstract

In recent years, dolphin-assisted therapy has become very popular and an increasing number of facilities offer therapy programs with dolphins worldwide. To this date, there are no studies concerning the behavior of dolphins during these therapies. As a result of speculations that the echolocation of dolphins may play an important role for the success of the therapy and the high publicity of this in the media, people pay much more for dolphin-assisted than for other animal-assisted therapy programs. Based on publications in medicine, we will show that ultrasound emitted by dolphins could have an effect on biological tissue under some circumstances; such as sufficient intensity, repeated application over several days or weeks and a certain application duration per session. We recorded 83 sessions at the "Dolphins Plus", a fenced area with ocean water in the Florida Keys. Our observations demonstrate that only one out of five observed dolphins behave significantly differently towards patients compared to other humans and that the duration of the observed close contacts did not meet the requirements for common ultrasound therapies.

Keywords: Dolphin; Animal; Assisted; Therapy; Ultrasound

1. Introduction

Dolphin-assisted therapy has been employed for about 20 years to help mentally and physically handicapped or terminally ill people. In contrast to the knowledge about swimming programs with healthy humans (Samuels and Spradlin, 1995; Frohoff and Packard, 1993; NMFS, 1990), there are virtually no publications concerning the behavior of dolphins in swimming programs with handicapped children or adult patients. Since 1982 there has been a small number of publications about dolphins-assisted therapy by several psychologists: The first publication was a case study on an autistic child (Smith, 1981, 1988). Another experiment showed significant differences in the ability of learning (Nathanson, 1989, 1993) and an improvement of motor patterns (Nathanson and de Faria, 1993) in mentally disabled children. An improvement of the social situation in families with disabled children could also be observed (Voorhees, 1995). Analysis of EEG showed that interaction with dolphins has a relaxing influence on humans (Cole, 1996; Birch, 1997). Effectiveness of short-term (Nathanson et al., 1997) and long-term (Nathanson, 1998) dolphin-assisted therapy for children with severe disabilities was presented. Furthermore, effects on psychoneurological (Lukina, 1999) and psychosomatical (Iikura et al., 2001) symptoms of diseases could be observed. But there also exists severe criticism that some of the publications used flawed data resulting in flawed conclusions (Marino and Lilienfeld, 1998). Finally, some effects and outlooks in general were discussed (McKinney et al., 2001). Curtis points out that all publications were focused on humans but not on dolphins and possible disadvantage for these animals (Curtis, 2000). Additionally, there is still an open discussion about the ethical and safety concerns of using wild animals (Iannuzzi and Rowan, 1991). However, to this date no studies exist that investigate the behavior of dolphins during that kind of therapy.

One reason for the success of the dolphin-assisted therapy could be that humans are very attracted by these animals. We do not think that this is a sufficient explanation, as a high percentage of patients are very young or, for instance, autistic, and it is very unlikely that these patients could have developed this attachment before the commencement of therapy. Moreover, we

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observed that many patients hesitated to interact with the dolphins in the first sessions because they were scared by these huge, unknown animals. However, if there is any difference to other animal-assisted therapies, other than the water environment itself, we expect it to be linked to the behavior of dolphins.

Generally there are many reasons for the success of animal-assisted therapies, most of which are based on the effects of socializing, such as increasing trust or responsibility of patients and motivation by uncommon sensory stimulations (Blue, 1986; Fine, 2000; Friedman and Thomas, 1985; Levinson, 1984; Veevers, 1985; Wilson, 1987). Some of these mechanisms are certainly also valid for dolphins. But trainers, therapists, and patients have reported that dolphins interact differently with patients than they do with healthy individuals when they were not under the trainers' control. If dolphins indeed interact in a different way with patients than with healthy humans, this self-motivated behavior could be the difference to other animal-assisted programs and a reason for the success of dolphin-assisted therapy.

A very speculative hypothesis predicts that ultrasound from the echolocation clicks of dolphins may have a healing effect (Cole, 1996; Birch, 1997). Some psychological and psychosomatic illnesses are caused by dysregulation of hormones, an example of which is the biochemical model for autism (Chamberlain and Herman, 1990). Birch and Cole postulate that the ultrasound of dolphins has a mechanical and/or electro-mechanical effect on the endocrine system of humans and stimulates it positively. The resulting change in hormone concentration should be recognizable as an effect on the EEG (Cole, 1996; Birch, 1997). Birch and Cole showed that subjects' brain waves change significantly in frequency and amplitude after swimming with dolphins compared to the measurements before swimming. There were no changes in the control group that swam without dolphins. Birch and Cole found that artificially generated ultrasound with the same physical parameters as ultrasound generated by dolphin has no effect on the subjects' EEG, but ultrasound generated by dolphins during subjects' interaction with them did. Birch and Cole suggest that the EEG effect is caused by ultrasound of dolphins.

To better understand this effect we have to clarify if and under which conditions the ultrasound of dolphins can affect biological tissue. Limited observation of dolphins attacking fish prey coupled with the high peak-to-peak source level has initiated the hypothesis that dolphins may stun their prey by focusing high-intensity echolocation clicks on their prey at short ranges (Norris and Mohl, 1983). However, there has not been any experimental substantiation of the prey stunning hypothesis. The primary effect of ultrasound is mechanical. The effect of ultrasound on biological tissue is well investigated by medicine. The interest is due to the question of safety of ultrasound diagnostic methods and also in therapeutic treatments. The effect depends on duration, pressure and frequency. All past research was focused on the range of frequencies between 500 kHz and 10 MHz; the frequencies used in medicine (Barnett, 1996). Therefore it is difficult to compare results of this experiment with the ultrasound emission of dolphins, who used frequencies of about 120 kHz. However, to estimate the safe use of ultrasound, a mechanical index (MI) was defined (AIOM/NEMA, 1998). The formula (Formula 1 in the appendix) for the MI is based on a trend which was found in the entire frequency range and could probably also be useful for lower frequencies like dolphins echolocation. To remind the user of a potential risk of damaging tissue, all devices that use ultrasound have to display the mechanical index from $MI = 0.4$ if the threshold of $MI > 1$ can be exceeded (AIOM/NEMA, 1998). The mechanical index becomes more important if contrast agents or gas bubbles are present in the tissue (Barnett, 1996). CO_2 micro-bubbles can occur in animals or humans during athletic activity (Laak, 1992). In the case of the dolphin-assisted therapy, it is possible that patients who are not used to swimming feel uncomfortable in the water and are therefore very active. Hypothetically, this activity could increase micro-bubbles in the tissue. However, in order to compare artificially generated and dolphin-generated ultrasound, we have to recalculate some parameters (Formula 2 in the appendix). To be comparable with human medicine, dolphins have to have their heads oriented towards the patients, because the ultrasound beam is focused only in one direction with an opening angle of 10° to the left and to the right (Au, 1993). Also, they have to be in less than 1 m distance because the measurements of dolphins were made within this distance. Experiments with dolphins showed that based on the production principle of ultrasound in the head of the dolphins, the sound pressure at a distance of 2 m lost about 5 dB and at a distance of 5 m about 10 dB compared to a distance of 1 m (Au, 1993). If we put frequency and maximum pressure of dolphins' ultrasound in Formula 2, we find that the MI in 1 m distance would be about 0.9, in 2 m about 0.6 and in 5 m about 0.3. The value of 0.9 is very close to the threshold of 1, where doctors have to pay attention to the application time, especially if contrast agents or micro-bubbles are present. However, the mechanical index is only an orientation and it is not certain that ultrasound which exceeds this threshold can damage or affect biological tissue.

Dolphins are able to manipulate the ultrasound impulses they generate (Verfuß, 1996; Au, 1993; Moore and Pawloski, 1990) and can produce resonance in the swim bladder of fish (Foot, 1980). Experiments on rats could show that resonance or vibration has an influence on different neuro-physiological hormones (Weinstein et al., 1988). Birch and Cole's hypothesis that the sound of dolphins may have an effect on the endocrine system of humans is based on this experiment. Furthermore, if a sound wave with approximately 1 W/cm^2 (less than the dolphins' power; see Formula 3 in the appendix) reaches a cell membrane of 0.6 μm, it produces a pressure of 100 Pa on this membrane (Barnetts, 1996). The shear force at border surfaces and on big molecules produced a multiplicity of biochemical reactions (Duarte et al., 1996; Ryaby et al., 1989; Yang et al., 1996), which could cause an unspecific impact on patients. Another impact possibility of ultrasound on patients in the dolphin-assisted therapy is the so-called piezoelectric effect. This effect is an electric impulse caused by a mechanical stimulus as produced, for example, by ultrasound on bone structures (Duarte, 1983; Klug and Knoch, 1986). Consequently, there is the possibility that the brain is irritated by piezoelectric impulses in the skull, which could result in a changing of the EEG. People with experience in interacting with dolphins report a phenomenon where dolphins produce a very loud noise directed at the person, causing in them a feeling of ''seeing stars''. This is usually an agonistic behavior that should prompt the termination of the interaction. Based on these considerations, it would be possible to arrive at the conclusion that it is likely possible that ultrasound generated by dolphins can have an influence on the human physiology under certain circumstances.

All known use of therapeutic ultrasound in medical treatments requires repeated application with certain intensity and duration. The repeated application is given by the dolphin-assisted therapy because the therapy takes place over the course of several weeks. The intensity of dolphins' ultrasound could be sufficient as described above. The reported duration for the medical application of ultrasound ranges from 30 min (Ryaby et al., 1991), 20 min (Ryaby et al., 1989), 15 min (Duarte, 1983; Yang et al., 1996), 3 min (Klug and Knoch, 1986) to at least 2 min (Reuter et al., 1987) per session. This means that patients have to be exposed to dolphins' ultrasound directed at them for at least 2 min per session.

It was technically impossible to record ultrasound directly on patients and healthy humans because of the large equipment and the resulting disturbance to the dolphins. Therefore we have to focus on visually observable behavior and formulate the following hypothesis:

> One or more dolphins exhibit a behavior that results in patients' exposure to ultrasound in doses comparable to those in medical treatments.

In other words, dolphins have their heads pointed towards the patients, staying in this position for some minutes per session and repeating this behavior over several sessions.

2. Material and methods

2.1. Observations and participants

The observations took place between April and December 1998 at the ''Dolphins Plus'', Florida Keys, a fenced area with ocean water. The therapy there was conducted by therapists of the ''Island Dolphin Care, Inc.'' and was divided into three parts: (1) therapy in the classroom, (2) therapy with trained dolphins and (3) therapy with untrained dolphins. We included in our study only handicapped children of less than 12 years of age; all these children are further referred to as *patients*.

The patients had several mental and physical handicaps. There were no special requirements necessary to take part in this therapy, except that patients had to have head control. The other swimmers were divided into two groups: adults and children under 12 years. This differentiation was used to analyse whether dolphins prefer short or tall people.

The situations we observed included swimming programs with adults and children, therapy sessions with patients, and breaks in which the dolphins were undisturbed. There were two different groups of dolphins that were used in swim and therapy programs at the Dolphins Plus. One group was trained and it is very unlikely that they had the opportunity of acting in a self-motivated manner toward patients as they were always under the strict supervision of the trainers. The other group was untrained and interacts spontaneously with the swimmers with no control from the trainers. These dolphins were not used to being touched; all interactions with humans were initiated by the dolphins themselves. We decided to only observe the behavior of the untrained dolphins. There was a group of four adult females between 13 and 16 years, who were caught in the Gulf of Mexico and one 4-year old sub-adult male, born at the Dolphins Plus itself. These dolphins could also interact with adults or with children in the public swim sessions. In contrast to these swim sessions, the patients in the therapy sessions were assisted by a therapist. We assume that these dolphins had the choice to decide if and how long they want to interact with different swimmers. These conditions were equal to those in Birch's experiment. In our observations we concentrated on contact and distance behavior of *Tursiops truncatus*.

The dolphins were identified by natural marks (Würsig and Würsig, 1977, 1979; Würsig, 1978). The recording period was 30 min which was the same duration as the swimming sessions and therapy programs. Altogether, 83 sessions were recorded: 30 undisturbed sessions with no humans in the water, 30 in swimming programs with tourists, and 23 in therapy programs. Every session took 30 min and was continuously recorded.

2.2. Materials and apparatus

The pool was observed with two cameras with a resolution of 752×582 pixels. One camera with a wide-angle lens captured the entire pool area; the second camera recorded only a highly frequented spot. This spot was used to identify the dolphins. Two VCRs were used to record the video streams synchronized by the rapid time code on SVHS tapes. In contrast to many studies in the past (e.g., Samuels and Gifford, 1997), this arrangement makes it possible to analyse the behavior of each individual dolphin continuously during nearly the entire observation period. After identifying an individual in the small camera spot, a special computer program on the video screen (covering the entire pool) was used to determine the position of every dolphin and human over time. To do so, the analog video stream was digitized and presented on a computer screen. Every individual was followed by the computer cursor, and the position of the cursor was recorded once every second. Furthermore, it was possible to add notes about each individual (dolphin or human) at any particular time, describing, for instance, the color of swimming gear. One part of the project was to correlate the observed behavior to the acoustic communication (Brensing et al., 2001). Therefore the computer cursor was always pointed to the melon of dolphins. This high precision of the position data also allowed us to correlate the position from every swimmer or dolphin to every other at any given time. Based on known positions in a three-dimensional coordinate system it is possible to calculate different parameters like distance, speed, frequency of contact, and duration of contact. All these parameters were used to describe the behavior of dolphins to different kinds of humans (Brensing and Linke, submitted, 2002). Concerning our hypothesis, we were focusing only on the parameter contact duration in different situations. These situations were: (1) adults (swimmers of an age over 12), (2) children (swimmers of an age under 12) and (3) patients (children with unspecific mental or physical handicap under 12 years of age). This distinction was necessary to prevent misinterpretation, especially if dolphins should have a preference to small or short humans.

The distances between two points in a two-dimensional coordinate system can be calculated. The contact-duration is the time in which two individuals swim in a distance of less than two meters.

2.3. Statistics

The descriptive and inferential statistics were calculated with SPSS version 8. A one-way ANOVA was used to determine whether the differences in dolphins' behavior towards different kinds of humans were statistically significant. Before each analysis, a test of variance homogeneity was computed and the data had to be square root transformed. Significant results were further analysed using Turkey post-hoc comparison.

3. Results

Contact-duration was analysed to describe the individual behavior of dolphins to different categories (kinds) of human. None of the dolphins, with the exception of Sarah, distinguished between the different groups of humans, and no trend could be found.

The behavior of Sarah is in two respects of remarkable sense. First, she was the only dolphin who distinguished between different groups of human in a statistically significant manner. Secondly, she especially preferred patients, whereby she did not distinguish between adults and children. In some cases, this contact lasted longer than 1 min. Sarah was the only dolphin who established contacts with humans that lasted longer than a few seconds and the duration of contacts with more than 90 seconds per session was more than double that of the other dolphins (Fig. 1). In fact, the raw data show that Sarah's contact-duration to patients was equal to Samantha's contact-duration to the other dolphins.

Sarah's long contacts invite a closer look. For nearly 50% of the contact-duration, Sarah's head was directed to the patients (Fig. 2). Usually the patients did not move much, so that Sarah had to remain in her position or to swim around the patients. The data shows that Sarah swam side by side with the patients for about 22% of the time. She used this position to turn her belly towards the patients in about 4% of the time, and several times this movement was connected with a body contact with the patients. Twenty-five percent of the

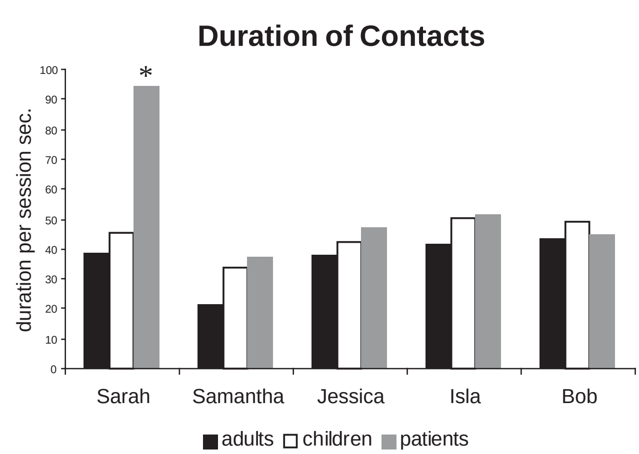

Fig. 1. Total duration of contacts between dolphins and humans per session in seconds. Significant differences on the $p = 0.05$ level are shown as *.

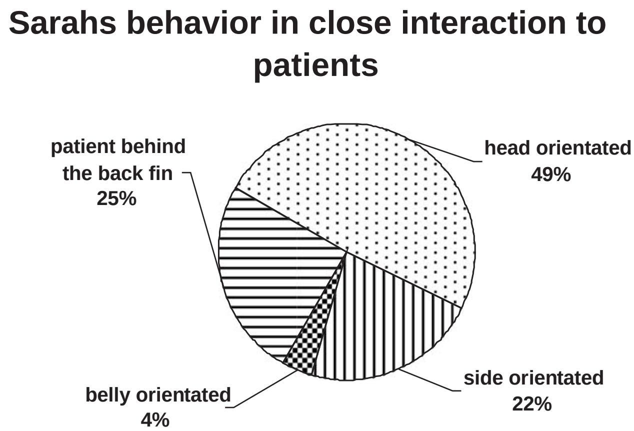

Fig. 2. Behavior of Sarah in close interaction with patients. This is only the behavior of Sarah if the distance between her and the patients was less than 2 m. Head, side and belly orientated means that these different parts of Sarah's body were directed towards the patients. 'Patient behind the back fin' means that the therapist as well as the patient were swimming behind Sarah.

time, Sarah was swimming in front of the patients or the patients were close to her but behind her back fin, but in both cases she was swimming very slowly so that the therapist with the patient could follow her.

4. Discussion

The observation of dolphins in the wild is complicated and time-consuming (Norris and Dohl, 1980; Mate et al., 1995; Ridoux et al., 1997; Wells, 1991). However, it was the goal of this work to examine natural and therefore self-motivated behavior of dolphins. That is why this work was carried out in an open water enclosure with untrained dolphins.

The contact-duration, the time spent in proximity of less than 2 m distance, is of high relevance. The contact-duration is an expression of a stable condition, namely the time spent together in a small area.

As described above, it is essential that the dolphin's head is pointed towards the patients. If a dolphin approaches a human, its head is usually directed forward and pointed towards the human but once the human passed, dolphins' heads were still directed forward but no longer towards the human. We observed that if the dolphin's head was directed to humans over more than a few seconds, the dolphins usually stopped beside and remained close to the human (Brensing and Linke, submitted, 2002). This behavior was typical for Sarah in interaction with patients. In all other cases, the head was only directed to the humans for the time needed to approach and is comparable to the average speed of just passing by the swimmers. To verify these contacts we defined a distance range of 2 m around the humans. With the exception of Sarah, the other dolphins tended not to increase the duration of contact to the special kind of human (Fig. 1).

As described above, ultrasound of dolphins could have an impact on biological tissue. But can Sarah's behavior indeed include therapeutic ultrasound emissions? All known use of therapeutic ultrasound in medicine requires repeated application and a certain intensity. This could have possibly occurred during the dolphin-assisted therapy, as the therapy extends usually over several days or even weeks, and the ultrasound intensity could be high enough (as described in the introduction). Another prerequisite is a duration of the application of some minutes per therapy session (Ryaby et al., 1989; Ryaby et al., 1991; Duarte, 1983; Yang et al., 1996; Klug and Knoch, 1986; Reuter et al., 1987), which could not possibly have been accomplished under the present circumstances. Sarah had about 90 seconds close contact to patients during the 30 min of therapy, but only in about 50% of that time (Fig. 2) she was in the necessary position for an ultrasound application. The remaining application time of 45 s was divided among five or six patients, resulting in less than 10 s exposure time per patient.

Our hypothesis: one or more dolphins exhibit a behavior that results in patients' exposure to ultrasound in doses comparable to those in medical treatments, has to be rejected because, even if Sarah produced ultrasound continuously with a maximum power of 230 dB, the application time of 10 s per patient is not long enough compared to therapeutic ultrasound in human medicine. Additionally, we observed that the heads of the patients were mostly out of the water, so that it is quite unrealistic to think that a hypothetical piezoelectric effect on the skull could have had an influence on the success of the therapy. Nevertheless, while it cannot be ruled out that dolphins use an unknown mechanism, the effects of ultrasound on biological tissue have been very well investigated over the last centuries, and it seems highly unlikely that there is such kind of an unknown mechanism. Also, we have to take into consideration that dolphins ultrasound may in fact cross the whole pool making the dolphins' proximity to the patients irrelevant. But we could not observe any patient-related behavior except that of Sarah's (Brensing and Linke, submitted, 2002). In other words, we do not agree with the hypothesis of Cole (1996) and Birch (1997) and we do not see serious reasons for further research in this direction.

What alternative reasons might be offered for the success of the dolphin-assisted therapy? If, besides the water environment, there is a positive impact of dolphins on the success of the therapy, then it could be based on the dolphins' gentle behavior towards humans and may be a kind of complex interaction. The exploration of this interaction between dolphins and humans should be the aim of further research. We suggest experiments where the neurophysiological response of humans such as EEG, EKG and EMG are continuously recorded and compared to several kinds of interactions with dolphins.

Dolphin-assisted therapy is a growth business all over the world, and expansion from pens to oceanariums is likely to occur. An interaction between dolphins and humans has a serious risk of infections and parasitism (Geraci and Ridgway, 1991) for both interacting parties. To minimize this risk, oceanariums have to increase the concentration of chlorine. However, even if dolphins are shown to have a healing effect on humans, it does not necessarily mean that it would be ethical to keep them in unhealthy conditions. As described in 1991 by Iannuzzi and Rowan, even today there is still no proof that dolphin-assisted therapy has more benefit than other animal-assisted therapies. Further research is required, to compare different kinds of animal-assisted therapy programs, and defining under which conditions dolphin-assisted therapy should take place.

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Appendix

$$MI = \frac{p}{\sqrt{f}} = \frac{0.316\ \text{MPa}}{\sqrt{0.12\ \text{MHz}}},$$

$$MI = 0.91.$$

Formula 1: Calculation of the mechanical index of ultrasound in human medicine. To estimate the mechanical index for dolphins, we used the maximum observed sound pressure of dolphins (Formula 2; Au, 1993) and the observed frequencies of the dolphins at the 'Dolphins Plus' with a maximum power at about 120 kHz (Brensing et al., 2001).

$$\text{loudness in [dB]} = 230\ \text{dB} = 20 \log \frac{p_1}{p_2} = 20 \log \frac{p_1}{1\ \mu\text{Pa}},$$

$$p_1 = 316\ \text{kPa}.$$

Formula 2: Conversion of the maximum observed loudness of dolphins, with 230 dB at the best frequency of 120 kHz (Au, 1993), to kPa; measured in a distance of 1 m compared to the reference of 1 μPa.

$$I = \frac{p^2}{2\delta v} = \frac{(316\ \text{kPa})^2}{2 \times 1000\ \text{kg/m}^3 \times 1500\ \text{m/s}} = 33.3\ \text{kW/m}^2,$$

$$I = 3.3\ \text{W/cm}^2.$$

Formula 3: Calculation of the maximum power (p) of dolphins' ultrasound. The density (δ) of water is set to 1000 kg/m^2 and the velocity is set (v) to 1500 m/s.

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