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CONCURRENT RECORDING OF DOLPHIN BEHAVIOURS, FREQUENCY-MODULATED TONES, AND PULSED VOCALISATIONS (INCLUDING ECHOLOCATION CLICKS) UNDERWATER WITH A SWIMMER-PROPELLED SYSTEM

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1. ABSTRACT

A mobile video/acoustic system (MVA), previously developed Dudzinski [1], was modified with new hydrophones and a new hydrophone mount to increase the recorded frequency bandwidth and to decrease low frequency noise due to movement in the physical mount, respectively. The MVA permits real-time synchronous recording of vocal and behavioural activities of individual dolphins. The system is swimmer-propelled and facilitates localisation of dolphin sound sources by associating video data of animal distributions with audio data from two hydrophones spaced relative to the human interaural distance as scaled to speed of sound in water. A recent addition to the original design was a small second housing containing a Sony TCD D8 digital recorder together with a pre-processor circuit which detects the highly directional part of a dolphin's echolocation 'clicks' and makes these audible and recordable. The technique is similar to that employed to successfully detect harbour porpoise (*Phocoena phocoena*) signals Goodson & Sturtivant [2]. This pre-processor comprises a preamplifier with band pass filtering, which selects only signals between 90 kHz and 130 kHz. The filter output is then rectified and the low frequency envelope extracted by a further filter. This technique produces a low frequency pulse accurately representing the original signal amplitude that can be recorded on the R-DAT sound track. As the directionality of the original signal, the inter-pulse intervals and the pulse amplitudes are retained, this band-limited data carries significant information and the loss of the high frequency spectrum is acceptable in this application. This 'click detector' data is recorded onto one track of the recorder while unprocessed low frequency signals from the hydrophone are captured on the second. The R-DAT stores real-time information (date & time) in the sub-code of recorded signals so that video image data, with in-picture timecode, can be correlated accurately with the echolocation behaviour. Data is captured when dolphins swim directly towards the MVA and click detector unit. The modified MVA system (including click detector) has been used to document the behaviour and vocalisations of interacting Atlantic spotted dolphins (*Stenella frontalis*) in the Bahamas and bottlenose dolphins (*Tursiops truncatus*) in Japan. Example data sets will provide evidence of this system's utility for examining the social lives and signal exchange among interacting, free-ranging dolphins.

2. INTRODUCTION

In the underwater environment, sound is an ideal medium for information exchange primarily because it can travel to greater distances as compared with light waves that are rapidly absorbed. Sound has long been suspected as the primary sensory channel for cetaceans. With at least 50 years of research on the production, structure and reception of vocal exchanges used by captive and free-ranging dolphins, little is definitively known (though much hypothesised) about potential functions of their vocal behaviour in relation to activity or context. Several factors have hindered the process of our understanding to specifics of sound use by dolphins. Obtaining recordings of sufficient quality and bandwidth were limited because of the available equipment for use in the marine environment. Free-ranging dolphins are often difficult to approach and follow because of their behaviour or the water turbidity. Another important consideration is the identification of the animal vocalising. Dolphins do not have consistent visual cues accompanying the production of auditory signals. The advent of inexpensive, portable high-resolution videography has made behavioural descriptions of dolphins underwater a relatively easy task. Couple this with the existing technology for recording sounds underwater and one can record dolphin vocal productions in relation to behaviour and context with increased ease. Dudzinski [1] discussed a simple device that made possible the ability to correlate vocalisations and behaviours of free-ranging dolphins underwater. This mobile video/acoustic (MVA) system uses binaural input, compensated for the water to air sound speed ratio, to allow a person to estimate direction to an underwater sound source from videotaped interactions between dolphins. This MVA system is useful for sounds in the human-audible hearing range, especially whistles, below 20 kHz. Low frequency click trains were recorded with this unit, Dudzinski [3], but because of equipment limitations, it was not possible to conclusively determine if these clicks were the low frequency band of delphinid echolocation clicks. Studies on captive dolphins have shown that dolphins can produce an echolocation signal with spectral energy peaking at about 120 kHz, depending on the species, Au [4]. These pulsed vocalisations possess a -3 dB bandwidth greater than 50 kHz and it is usually possible to capture the low frequency component of these echolocation pulses with recording equipment not designed to capture the actual high frequency signal. The high frequency, high-energy component in the echolocation signal is narrow in beamwidth by nature and thus not always detected with hydrophones unless the dolphin's head is directed at the hydrophone. Numerous studies have been conducted on the dolphin's production and potential uses of echolocation in the captive arena [4]. It is theorised that dolphins use echolocation 'clicks' primarily for foraging and especially during prey interception and capture, but there is little evidence to suggest it is a useful navigation tool as the narrow-beam and pulse/echo ensonification is directed ahead of the animal and is range limited by the 'click rate' and therefore cannot indicate the surrounding topography of the ocean floor to the dolphin. Lower frequency components have less directivity and may play a part in communications. The use of 'burst-pulse' sounds in a social context has been observed in several other species, Dawson [5]. However, precisely because of the narrow-beamwidth of the high frequency components it is particularly difficult to record definitive echolocation data from free-swimming groups of dolphins, as their individual orientation towards the hydrophone cannot be ascertained.

To determine if the band-limited recordings (<20 kHz) of click trains recorded from Atlantic spotted dolphins (*Stenella frontalis*) by Dudzinski [3] were indeed portions of their echolocation pulses, we designed and built an echolocation click detector (ECD). This ECD unit comprised a Sony R-DAT recorder and high frequency hydrophone connected through a pre-processor circuit. While collecting data with the MVA system, dolphins often approached the swimmer and the system. This behaviour would facilitate the ability to record echolocation signals from individual dolphins in a non-captive setting. Thus, the ECD unit was mounted to the dorsal surface of the modified MVA system.

The modified mobile video/acoustic system including the new echolocation click detector was used to document the behaviour and vocalisations of interacting Atlantic spotted dolphins in the Bahamas and bottlenose dolphins (*Tursiops truncatus*) in Japan. The data provide evidence of this system's utility for recording an expanded range including both frequency-modulated and pulsed vocalisations produced by dolphins. With this increase in available information, we are better equipped to examine the social lives and signal exchange among interacting, free-ranging dolphins.

3. METHODS

3.1 Design of mobile video/acoustic system

The mobile video/acoustic (MVA) system consists of a stereo Hi8 video camera (with audio bandwidth of 20 kHz) linked via cables threaded through the housing backplate to two omni-directional hydrophones (model HTI-MIN-96, with a bandwidth of 400 Hz - 20 kHz and a sensitivity of -3 dB re 1mPa). Styrofoam baffling around the hydrophones decreases sensitivity to high frequency sounds from the sides and back of the housing unit [1]. The hydrophones are mounted on 15 mm diameter PVC tubing with a separation of 70 cm - a length approximately five times the human interaural distance to account for the difference of sound speed in water and air [1]. An internal cable links the electronic remote of the camera to the external housing switches: the switches magnetically trigger the camera's internal remote. This system is portable, weighs less than nine kilograms in air, and is neutrally buoyant [1].

3.2 Design of echolocation click detector unit

A small second housing containing a Sony TCD D8 digital recorder and a pre-processor circuit with an externally mounted Sonatech hydrophone (3.0 kHz - 150 kHz with a sensitivity of -156 dB re 1 μPa to -160 dB re 1 μPa, respectively) was recently added to the MVA system (Figure 1). This unit detects the highly directional portion of a dolphin's echolocation clicks and makes them audible and recordable. The technique is similar to that employed to successfully detect harbour porpoise signals [2]. The pre-processor comprises a preamplifier with band pass filtering, which selects only signals between 90 kHz and 130 kHz. The filter output is then rectified and the low frequency envelope extracted by a further filter. This technique produces a low frequency pulse accurately representing the original signal amplitude that can be recorded on the R-DAT sound track. As the directionality of the original signal, the inter-pulse intervals and the pulse amplitudes are retained; this band-limited data carries significant information. The loss of the high frequency spectrum is acceptable in this application. This 'click detector' data is recorded onto one track of the recorder while unprocessed low frequency signals from the hydrophone are captured on the second. The R-DAT stores real-time information (date & time) in the sub-code of recorded signals so that video image data, with in-picture timecode, can be correlated accurately with the echolocation behaviour. Data is captured when dolphins swim directly towards the MVA and click detector unit.

The echolocation click detector (ECD) is secured to the MVA system via Velcro strips and a webbed strap (Figure 1). The click detector housing causes negligible drag to the swimmer handling the unit (including the ECD and MVA). The ECD housing measures 35.5 cm by 12.0 cm by 6.5 cm and is equipped with two external mechanical switches to operate the R-DAT recorder. The high frequency hydrophone is also baffled by Styrofoam and mounted to the left PVC tubing of the MVA system (Figure 1).

3.3 Application of MVA and ECD for recording dolphins

The MVA system was used to record dolphin vocalisations and behaviour during swims from May to September, 1993-1995, and during June to December 1997. The ECD was employed to capture dolphin echolocation clicks from June 1997 to the present. Use of the MVA system before 1997 provided data for Dudzinski's doctorate (Dudzinski 1996).

Atlantic spotted dolphins: The study group of Atlantic spotted dolphins is found in Bahamian waters, and generally travels in small groups of one to ten individuals Dudzinski [6]. Members of this group seem to be resident to the Little Sand Banks north of Grand Bahama Island. Ninety-five recognisable individual spotted dolphins have been identified: 46 females, 43 males, six unidentified gender. These spotted dolphins have tolerated human swimmers and divers regularly for the past 25 years Jones [7], Herzing [8], Dudzinski [3].

Mikura-jima bottlenose dolphins: Around Mikura Island, Japan, bottlenose dolphins have been sighted for several years, but only systematically observed since the early 1990's (T. Iwatani, I.C.E.R.C. Japan, pers. comm., 1995; Moyer [9]). At least 125 individual dolphins have been identified within 300 km of Mikura's coast, with an 86% re-identification rate between 1994 and 1995. A 1:1 sex ratio of identified dolphins has been reported (R. Soeda, I.C.E.R.C. Japan, pers. comm., 1996). Early analyses suggest that adult females with calves are the most frequent group types observed around Mikura-jima. Average group size increases near mid-day and decreases in the afternoon.

These bottlenose dolphins are observed nearer to shore, in colder temperatures, and in an area with different bottom topography as compared to the study group of Atlantic spotted dolphins. Preliminary observations of contact behaviour among individuals and vocalisations of both species, however, were similar in exchange and context (pers. observ., 1995). Caution should be noted, because it remains to be determined if the Mikura-jima dolphins use contact behaviour or vocalisations during the same types of behavioural activities, as do spotted dolphins. It remains to be determined if general activity (including vocal productions) is also significantly affected by other external factors. Such as: preferred prey species, climate, seasonal changes (including light levels - latitude), seabed topography, water depth, coastal vs. offshore distribution, temperature, and more.

4. RESULTS

4.1 Example of MVA use with dolphins

The MVA system was used from 1993 to 1995, and in 1997 to record, Atlantic spotted dolphin behaviour and vocalisations. Data from 1993 - 1995 are detailed in Dudzinski [3]. During preliminary analyses of data collected during 1997, 73 minutes of recorded swim time were captured on videotape. At least 200 whistles were detected, with approximately 38.0% attributed to a specific dolphin. These results concur with previous findings for the utility of the MVA system for recording frequency-modulated tones from dolphins in relation to behaviour and context.

The new, more secure PVC mount for the hydrophones did reduce the amount of fluctuation to each hydrophone and its Styrofoam backing while the unit was propelled through the water by a swimmer. The mounts also are angled for variability in hydrophone placement and direction. The new design is detachable from the housing and facilitates easier shipping and transportation of the MVA system to study sites.

4.2 Example of ECD use with dolphins

Figure 2. - shows an oscilloscope trace; channels one is a digitally synthesised (raised cosine) echolocation 'click' and channel two shows the output of the ECD when operating at unity gain. The time shift between the input click and the output envelope is cause by the propagation delay of the filter used to condition the input signal. Using faster more expensive operational amplifiers could reduce this time delay, although the delay is not considered a problem, as it is constant so the 'click' repetition information and timing will still be correct. The output envelope frequency is typical around 12kHz (depending on animal species), therefore allows the data to be captured on commercially available recording equipment. Information contained in the click envelope includes; click amplitude, click duration, and inter-click periods.

Figure 3. - Spectrogram showing a harbour porpoise searching for prey at 300m range (Display frequency range 0-20kHz). The highly directional high frequency component of the echolocation pulse is only detected when the animal points its head towards the hydrophone. The spectrum of the envelope-detected signals shown here are in the audible range and can be recorded using conventional audio equipment. Although the original frequency and phase information of the pulse is lost, the amplitude and inter-click timing information remains. This image also demonstrates some surface multipath echoes, pulse pairing, providing evidence that this animal was swimming close to the surface Goodson [11].

Note: An addendum will accompany the proceedings at the conference. The addendum will include figures of echolocation pulse envelopes from data collected and analysed from the bottlenose dolphins found around Mikura Island, Japan.

5. DISCUSSION

We have described a unit that captures into the human-audible range the signal envelope of the high frequency signal of a dolphin's echolocation click. Previous work on high frequency pulsed sounds from individual dolphins was conducted on captive animals [4]. Using omnidirectional hydrophones, several researchers have collected and analysed echolocation pulses from within groups of interacting dolphins [5]. Because of the narrow directional characteristics of echolocation signals, recordings from identified individual, free-ranging dolphins in context to behaviour had not been possible previously. Dudzinski [3] detailed the approach behaviour of individual Atlantic spotted dolphins swimming at the mobile video/acoustic (MVA) system. The head-scanning and low frequency bands of pulses suggested that dolphins were using echolocation to investigate the recording unit and swimmer. Data gathered in this study support this hypothesis. Both Atlantic spotted and bottlenose dolphins use echolocation when investigating swimmers or novel objects in their environment.

The use of this mobile recording system provides information on dolphin behaviour and concurrent vocal productions. It provides a video and audio record of interactions and signal exchange among socialising dolphins. This record can be viewed by several independent examiners to establish accuracy and consistency on the interpretations of potential meanings within dolphin signals and behaviours.

As indicated by Dudzinski [1], the MVA and new echolocation click detector (ECD) do have limitations. Bubble noise and signal intensity are factors that have potential to saturate the audio recordings and may cause clipping of some sounds. A filter was added between the hydrophones and the camera to decrease noise below 1.0 kHz: this works to avoid most saturation due to movement through the water, bubble noise and high intensity sounds from dolphins within 1.0 meter of the unit. Likewise, since echolocation clicks are collected primarily when dolphins exhibit inquisitiveness towards the camera or swimmers, these data may not be completely representative of the range of use of high frequency pulsed sounds by dolphins. Still, the MVA and ECD present an inexpensive, easy-to-operate, and accurate recording methodology for simultaneously capturing the behaviour and vocal activity of interacting free-ranging dolphins. Add to this the ability to identify the individual producing the sounds, for 37.7% of all recordings [1], and these units continue to facilitate the examination of delphinid social structure.

One final note worthy of mention is that the development of the MVA, and in particular the ECD, represents an all-to-rare collaboration between two distinct scientific disciplines: biological sciences and electrical engineering. It is common for researchers of one discipline (whichever the subject) to become absorbed in their field to the exclusion of almost every other application. This "tunnel vision" has hindered a more encompassing, forward scientific progress that is possible through a division of labour and a collaborative effort among researchers from various fields. It is our hope that our collaboration is not an isolated case but represents the advent of more open and shared flow of information among scientists from differing disciplines.

6. ACKNOWLEDGMENTS

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8. FIGURES

Figure 1. Schematic of the Mobile Video/Acoustic System and echolocation click detector. (1 mm = 10 cm)

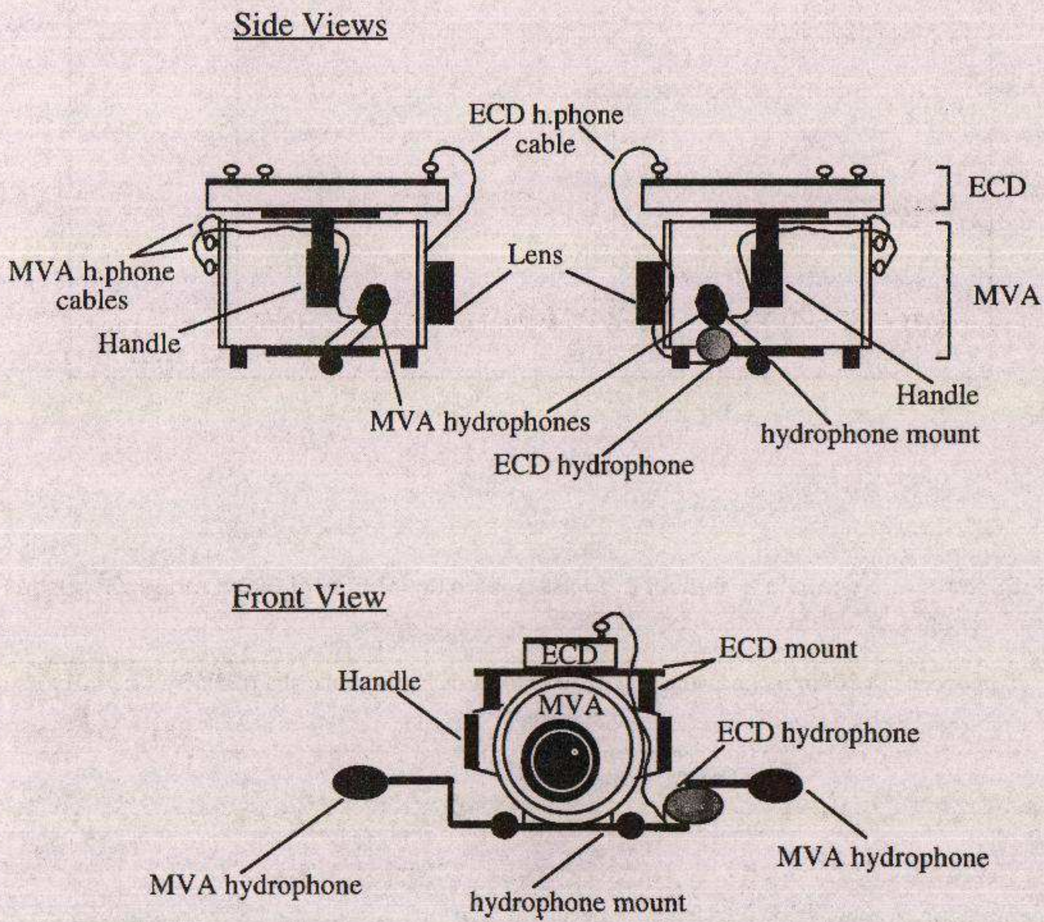

Figure 2. Digitally synthesised porpoise echolocation 'click' and click envelope

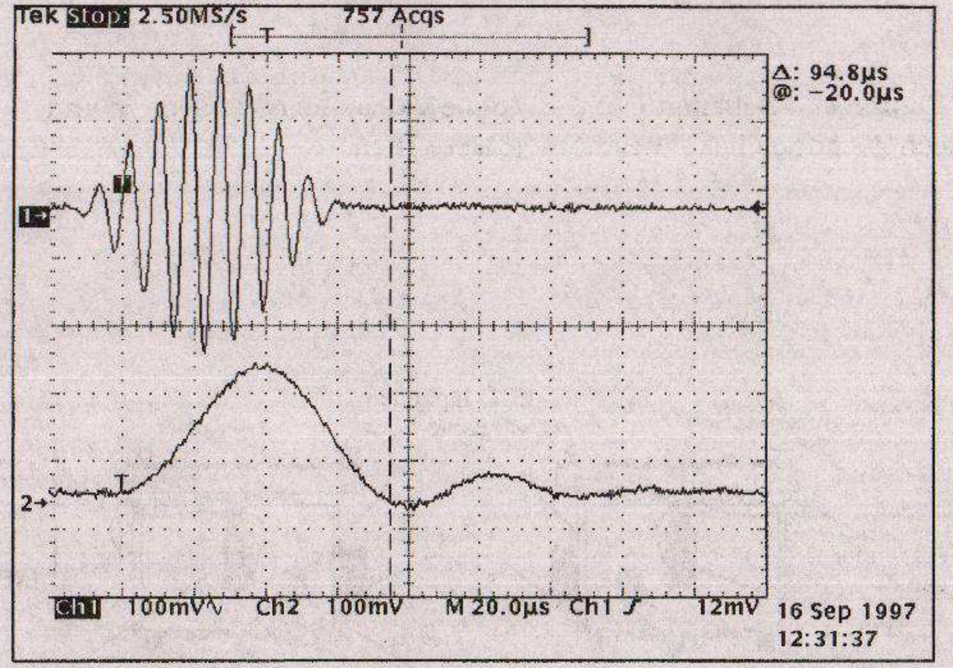

Figure 3 - Spectrogram showing a harbour porpoise searching for prey at 300m range, Goodson [11]