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Behavioral Responses of Odontocetes to Playback of Anthropogenic and Natural Sounds

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LONG-TERM GOALS

The long-term goal of this research project is to safely study responses of beaked whales to naval sounds in order to understand the causal chain of events leading from sound exposure to risks of stranding and to measure the exposure required to elicit responses that are safe but indicate potential for risk. The project is designed to provide critical information required to develop measures to protect beaked and other whales from risks related to exposure to sonar and other sounds.

OBJECTIVES

A critical objective for understanding possible links between sonar exposure and injury or stranding involves developing techniques to safely study how beaked whales respond to sound. The objective of this project is to establish, test and refine new protocols for studying how beaked and other whales respond to sound using established sound playback experiment paradigms; to define responses of beaked whales and other species of odontocete whales to mid-frequency active (MFA) sonar, to a control noise stimulus with similar timing and bandwidth, and to natural sounds such as those from killer whales; and to measure exposure parameters for sounds that evoke a behavioral response.

APPROACH

The approach for this study involves controlled exposures to tagged whales where the scientific team controls the sound source (Tyack et al. 2003). This research effort seeks to quantify the probability and severity of behavioral change as a consequence of sonar exposure and to discover what factors affect the probability of behavioral effects (e.g. received level at the animal, distance of the source, sound propagation conditions, waveform of the sound signal, behavioral state of the animal). Our experimental approach gives us the ability to study the causal relationship between sonar exposure and behavioral responses, to compare differences between species and stimuli, and to test for other factors that may affect behavioral responses.

Field efforts were conducted at the Atlantic Undersea Test and Evaluation Center (AUTEC) on Andros Island, Bahamas, adjacent to the deep canyon of the Tongue of the Ocean (TOTO). AUTEC has a 600 square mile, permanent range of 82 bottom mounted hydrophones which can be used for detecting and locating cetaceans on the range using marine mammal monitoring equipment developed by NUWC-

NPT (DiMarzio et al. 2008). This capability for real time monitoring was a critical part of our experimental approach, as we used the range to find whales, and to determine in real time when they started and stopped producing echolocation clicks during deep foraging dives, responses that were used to control the playbacks (Boyd et al., 2007). The design of these playback experiments called for tagging the subject with a calibrated sound and orientation recording tag (Digital Acoustic Recording Tag – DTAG: Johnson and Tyack 2003), measuring pre-exposure behavioral data, conducting a playback, and then measuring post-exposure behavioral data. For beaked whales, playbacks were started when the whales started producing echolocation clicks during a deep foraging dive, and were stopped when they ceased echolocating. Playbacks to other species had timing similar to those for beaked whales. Working at AUTEC requires close collaboration with NUWC and its marine mammal monitoring (M3R) team. Tagging research has been conducted on this site to establish baseline data and we collaborated with the Bahamas Marine Mammal Research Organisation (BMMRO) for long term studies of these populations. This project required extensive collaboration with biologists from the Sea Mammal Research Unit (SMRU) at the University of St. Andrews, biological oceanographers from Duke University, and bioacousticians at Cornell University.

WORK COMPLETED

The primary work for this project during this year involved analysis of data from the BRS 07 and 08 experiments, writing up the results for primary journal articles and also for review articles. The analyses focused on effects of playbacks of sonar and other sound on beaked and other whales, and on calls of pilot whales and clicks of beaked whales. Our analyses of recordings from tagged pilot whales showed problems with previous analyses (Taruski 1979, Weilgart and Whitehead 1990), requiring a new categorization of calls. Recordings of echolocation clicks of beaked whales that were made as part of this project have also been analyzed to define the probability that the detection cue of an echolocation click could be heard. With support from the DECAF project, this new analysis of these data have formed the basis for an important new method using passive acoustic monitoring to define the abundance and density of cetaceans (Marques et al. 2008).

RESULTS

Taken together with the results of Aguilar et al. (2006), this small sample of preliminary results suggests that beaked whales silence and show avoidance responses to anthropogenic sounds in a surprisingly narrow range from 136-140 dB re 1 μPa (Table 1). A similar but more intense response was seen in response to the killer whale playback, which was elicited by an exposure just barely above the ambient noise at 102 dB re 1 μPa. After the killer whale playback, the beaked whale had a prolonged post-dive avoidance response. Nevertheless there remains an ambiguity in the interpretation of the killer whale playback; since the killer whale playback was the second in a series on the same animal, it is possible that the prolonged response was a consequence of the second exposure rather than the killer whale waveform. This suggests that carrying out additional playbacks of sonar and of killer whale should be a priority for future work to resolve this uncertainty. While the playback results are drawn from just two individual beaked whales exposed to playback, this pattern of behavior has been measured against dives on control animals that were not exposed to a playback of any sound. The baseline tagged whales greatly strengthen the power of our statistical analyses.

Table 1. Summary of received sound pressure levels at which beaked whales respond to anthropogenic sounds. The MFA stimulus is mid-frequency active naval sonar, PRN is a pseudorandom noise stimulus with the same overall timing and bandwidth as the MFA stimulus, and Orca is recordings of the calls of killer whales, a known beaked whale predator.

Species	**Stimulus**	**Received Level**	**Source**
Ziphius cavirostris	Ship propulsion	**136-140** dB re 1 µPa rms broadband	Aguilar et al. (2006) Marine Mammal Science, 22(3): 690–699
Mesoplodon densirostris 2	PRN		BRS08
Mesoplodon densirostris 1	MFA		BRS07
Mesoplodon densirostris 1	Orca	**~102** dB re 1 µPa rms broadband	BRS07

Data from playbacks to non-beaked whales in 2007 have been analyzed for vocal behavior recorded on the tag. Four short-finned pilot whales were recorded with DTAGs in August 2007 as part of the Behavioral Response Study (BRS) in AUTEC. In order to assess possible vocal responses of pilot whales to playbacks, it was first necessary to characterize the pilot whale vocal repertoire, which was the goal of this analysis. Calls were visually classified into categories, and no attempt was made to distinguish between pulsed and tonal calls. We analyzed approximately 30 hours of acoustic data from 4 tagged whales. Tag durations were as follows: tag 229a: 12 hours and 43 minutes; tag 229b: 3 hours and 56 minutes; tag 259a: 12 hours and 7 minutes; tag 260a: 1 hour and 36 minutes. Tags sampled audio at 96 kHz. Using Adobe Audition, all calls were excised to produce 3,202 files, some containing multiple calls, for a total of 4,090 calls. Spectrograms of all files were produced with the same time and frequency scaling, and these were printed and then mixed so that information regarding sequential ordering of calls was unavailable. Spectrograms were then independently categorized into call types by three auditors.

Of the total of 4090 calls, 1,734 (42%) were placed into 174 call types, which was defined as any call that occurred two or more times. The remainder consisted of short calls (27%), distinctive but unclassifiable calls (7%), long pulsed calls (3%), and calls that were unclassifiable due to poor signal/noise (21%). Of the 174 call types, 51 contained a minimum of 10 calls (mean = 24), and comprised 70% of the categorized calls. These calls that were detected at least 10 times are referred to as predominant call types (PCT's). PCT's accounted for 38% of all calls with sufficient signal/noise for categorization. Predominant call types tended to occur in sequences of the same call. Of 1,168 transitions between PCT's, significantly more (760 or 65%) occurred within 30 seconds of another PCT of the same type than over greater time periods (407 or 35%; paired t test, $p<0.001$). In most cases, these tightly timed sequences appeared to be produced by a single animal, based on consistency in amplitude and lack of overlap. However, in several cases we observed apparent exchanges, consisting of adjacent or overlapping calls of the same type. In some of these cases calls had quite different amplitudes, suggesting that they were produced by different whales. Further evidence for call types being produced by multiple whales comes from the result that 10 of 51 PCT's (20%) were recorded on two tags.

Our data clearly illustrate that pilot whales produce shared, stereotyped calls, some of which consist of overlapping tonal and pulsed components, and that these calls comprise a large portion of their vocal repertoire. The data also suggest the possibility that pilot whales may produce individually distinctive call types in addition to shared call types. Overall, these data indicate that rough counts of calls may mix very different kinds of signals, and emphasize the importance of categorizing calls before attempting to draw conclusions about call usage and possible effects of sonar on vocal behavior. In contrast to beaked whales, many delphinid species are highly social. They live in relatively large groups, making frequent use of sound to communicate in both affiliative and agonistic contexts, and use group or individual-specific calls to maintain social cohesion. During the next phase of this work, we will analyze variation in overall calling rates and rates of PCT's as a function of playback condition.

Unlike beaked whales, which appear to silence and flee from predators, delphinids may rely in some contexts on social defenses against predators or conspecific competitors (Tyack 2000). Initial examination of the BRS DTAG sound recordings revealed several instances in which false killer whales (*Pseudorca crassidens*) produced whistles similar to the MFA signal just after its reception. We therefore conducted a quantitative analysis to test whether false killer whales and the other delphinid species exposed to simulated MFA signals (pilot whales *Globicephala macrorhynchus* and melon-headed whales *Peponocephala electra*) responded to MFA by increasing whistle production rate and by mimicking the MFA sound. An index of similarity between each whistle contour and the MFA signal contour was calculated using a dynamic time warping (DTW) metric (Buck and Tyack 1993).

To test for a correlation between whistle and MFA similarity and the time since the last MFA reception, we fitted a straight line to the DTW score data and applied a rotation test (DeRuiter and Solow 2008), using the line's slope as the test statistic. We tested the hypothesis that DTW score increases (i.e., whistles become less similar to the MFA signal) with increasing time since last MFA reception by comparing the observed slope of the DTW data with those obtained in 100,000 rotations of the dataset. We also applied a point-process time series model (Truccolo et al. 2005) to quantify whistle production rate and relate it to time since the last MFA reception, time since the first MFA reception, and number of whistles occurring in the preceding interval. One group of false killer whales (pc08_270a) and one group of pilot whales (gm08_273a) produced very few whistles during the MFA exposure (4-5 whistles total per group). No clustering or autocorrelation of whistle times was detected for those groups, although the power of the tests was limited by the very small sample size. For all other groups, whistle times were clustered and auto-correlated. The point-process model took such clustering into account by allowing for dependence on whistle production rates in the preceding interval. This clustering parameter was significant ($p<0.05$) in all cases except when sample size was very small (under 10 whistles). For the false killer whale group (pc08_272a), the rotation test indicated a correlation between DTW score and time since last MFA reception: whistle-MFA similarity was highest immediately following each MFA reception. Point process analysis results for the false killer whale (pc08_272a) group confirmed the rotation test findings, as both overall and MFA-like whistle rates were inversely related to time since last MFA reception. The results of these analyses support the hypothesis that one false killer whale group responded to MFA by mimicking the MFA signal: the group whistled more immediately following each MFA reception, and whistle-MFA similarity decreased with time since the last reception. We did not observe mimicry or vocal response to the MFA signal by any of the other four delphinid groups we studied; in fact, the melon-headed whales had lower whistle rates immediately after individual MFA receptions.

Other data used for preliminary description of possible responses in the 2007 and 2008 playbacks come from dive records on the tag and observations of the visual observers on the vessels near the whales. Although reactions to sonar sounds and control sounds were observed in some of the playbacks to delphinids, there was little consistency in the responses observed. By contrast, the beaked whales showed premature silencing and surfacing to all 3 playbacks, along with prolonged avoidance to the killer whale playback. The delphinids tested showed much more variable responses in dive behavior and vocal and avoidance behavior. While some delphinids did swim away from the sound source during playback, there was no prolonged avoidance behavior of the sort observed with the beaked whale exposed to killer whale calls. During some playbacks to delphinids, the visual observers described the whales as increasing their rate of travel during the playback, but during other playbacks, the whales slowed down and increased group cohesion. While these responses of delphinids to playback were varied, they all were clearly different from the responses of beaked whales to playback of the same sound stimuli, and many are consistent with social defense against a threat.

These data are consistent with the conclusion that, similar to harbor porpoises (Southall et al. 2008), beaked whales are particularly sensitive in terms of behavioral responses to acoustic exposure. If delphinids rely less upon flight and more upon social defense against a threat, this may put them at less risk of stranding. In the US, regulators have a separate exposure criterion for harbor porpoise than other cetaceans. Regulators predict that any exposure above 120 dB SPL will disturb behavior in porpoises, while a variety of higher criteria are used for other species (Southall et al. 2008). Our results support a similar criterion of about 140 dB SPL for beaked whale exposure to mid-frequency sounds. Our results do support a lower acoustic threshold of disturbance for beaked whales than is currently applied in the US. However, more data from beaked whales are required to finalize a dose:response function, and analyses of similar experiments with different species are required to support the interpretation that other species may be less sensitive or less at risk than beaked whales. The research described here has pioneered the techniques that will be required to complete the understanding of how beaked and other whales respond to sonar and other sounds, and to define the function relating acoustic dosage and behavioral response.

IMPACT/APPLICATIONS

This study aims to reduce risks to whales from naval sonar and to foster the development of mitigation measures by defining the mechanisms by which beaked whales and other species are affected by sonars. The results will have immediate applications for regulators and for the Navy.

TRANSITIONS

The methods developed by the Behavioral Response Study have been used in three additional studies based on the same methodology: the 3S project, a joint Norwegian-Dutch-St Andrews – WHOI project studying responses of cetaceans to sonar in Norwegian waters, the Med09 project studying responses of toothed whales in the Mediterranean to sonar and killer whales, and the BRS Socal project. The passive acoustic monitoring results from tagging beaked whales on the AUTEC range have provided critical input data for the DECAF project (http://www.creem.st-and.ac.uk/decaf/), leading to the first paper using passive acoustic monitoring to estimate absolute density and abundance of cetaceans (Marques et al. 2008).

RELATED PROJECTS

ONR: Tagging and Playback Studies to Toothed Whales N00014-09-1-0528
ONR: Cetaceans and Naval Sonar: Behavioral Response as a Function of Sonar Frequency N00014-08-1-0661
Naval Postgraduate School: Dtagging and analysis of studies on effects of naval sounds on marine mammals in waters off southern California
SERDP: Acoustic Response and Detection of Marine Mammals on Navy Ranges Using a Digital Acoustic Recording Tag.
Naval Oceanographic Office: Behavioral Response Study (BRS-07) Analysis and Supplemental Funding for BRS08
Marine Mammal Monitoring on Navy Ranges (M3R; David Moretti PI, NUWC-NPT)

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