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The common murre (*Uria aalge*), an auk seabird, reacts to underwater sound

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ABSTRACT:

Marine mammals have fine-tuned hearing abilities, which makes them vulnerable to human-induced sounds from shipping, sonars, pile drivers, and air guns. Many species of marine birds, such as penguins, auks, and cormorants, find their food underwater where light is often limited, suggesting sound detection may play a vital role. Yet, for most marine birds, it is unknown whether they are using, and can thereby be affected by, underwater sound. The authors conducted a series of playback experiments to test whether Alcid seabirds responded to and were disrupted by, underwater sound. Underwater broadband sound bursts and mid-frequency naval 53 C sonar signals were presented to two common murres (*Uria aalge*) in a quiet pool. The received sound pressure levels varied from 110 to 137 dB re 1 μ Pa. Both murres showed consistent reactions to sounds of all intensities, as compared to no reactions during control trials. For one of the birds, there was a clearly graded response, so that more responses were found at higher received levels. The authors' findings indicate that common murres may be affected by, and therefore potentially also vulnerable to, underwater noise. The effect of man-made noise on murres, and possibly other marine birds, requires more thorough consideration. © 2020 Acoustical Society of America. <https://doi.org/10.1121/10.0001400>

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I. INTRODUCTION

Animals use sounds in their environment for navigation, communication, and to detect predators or prey. One obvious example is birds performing elaborate acoustic displays as part of their reproductive behavior. In some birds, obvious hearing adaptations are found to improve nocturnal hunting abilities (e.g., barn owls, *Tyto alba*; Payne, 1971) or obstacle avoidance (e.g., oilbirds, *Steatornis caripensis*; Griffin, 1958).

Underwater sound is extremely important for many animals as it travels further and more reliably than other sensory cues (such as light). All aquatic vertebrates studied to date have ears, and several of the secondarily adapted aquatic vertebrates, such as marine mammals, turtles and crocodiles have special anatomical and physiological adaptations to improve their underwater hearing abilities (Thewissen and Nummela, 2008). Thus, hearing is a crucial sensory modality for many aquatic animals.

Aquatic birds, such as penguins, auks, ducks, and cormorants, are secondarily adapted to the aquatic environment. The

importance of in-air acoustic cues for aquatic birds, with their often-boisterous calls, is well-documented (Aubin and Jouventin, 2002; Lengagne *et al.*, 2004; Searby *et al.*, 2004). Aerial hearing data have been obtained from several species of aquatic birds (Crowell *et al.*, 2015; Crowell *et al.*, 2016; Hansen *et al.*, 2017; Maxwell *et al.*, 2017; Mooney *et al.*, 2019). Acoustic signals serve important purposes for individual and conspecific identification, as well as providing vital health information of chicks (Aubin and Jouventin, 2002; Searby *et al.*, 2004; Lengagne *et al.*, 2004). Airborne anthropogenic sound can have deleterious effects on sea birds. For example, the noise from nearby human activities resulted in American oystercatchers (*Haematopus palliatus*) and Brandt's cormorants (*Phalacrocorax penicillatus*) spending less time on their nests and therefore risking a decrease in survival rate of their chicks (Borneman *et al.*, 2016; Buxton *et al.*, 2017).

In contrast to in-air hearing, underwater hearing has only been measured in two species of aquatic birds, the lesser scaup (*Aythya affinis*) and the great cormorant (*Phalacrocorax carbo*). Both species are sensitive to underwater sound, with thresholds not substantially different from that of odontocetes and pinnipeds at low frequencies (Crowell *et al.*, 2016; Hansen *et al.*, 2017; Therrien, 2014).

Whether or not marine birds make use of underwater acoustic cues while foraging or communicating is largely unknown. Frost *et al.* (1975) found avoidance responses in jackass penguins (*Spheniscus demersus*) when killer whale

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(*Orcinus orca*) calls were played back to them. Recently, Pichegru *et al.* (2017) suggested jackass penguins may be displaced by seismic exploration activities (Cooper, 1982). It is conceivable that underwater anthropogenic noise may adversely affect diving sea birds in a myriad of ways. Sounds can mask important acoustic cues, or cause displacement from foraging or breeding areas, therefore decreasing the fitness of the animal. The majority of studies investigating the effects of anthropogenic underwater noise on aquatic animals have focused on marine mammals and fish, whereas birds have been largely neglected (Popper and Hawkins, 2016). This is in spite of aquatic birds being of special concern, as many populations are declining at an alarming rate (Croxall *et al.*, 2012).

Common murres (*Uria aalge*), also known in British English as common guillemots, are marine birds of the Auk family, known for their extreme aquatic adaptations and for foraging on fish. We investigated the behavioral responses, any change of behavior or lack thereof, of two diving common murres by playing underwater sounds in the form of a broadband sound burst and a naval 53C mid-frequency active sonar at various intensity levels in a quiet pool at sound pressure levels ranging from 110 to 137 dB re 1 μ Pa. The animals showed clear reactions to both types of underwater sound, indicating that common murres may be affected by anthropogenic noise.

II. MATERIALS AND METHODS

The experiments were conducted over six days between November 13 and December 10, 2018, in a 7 m \times 4 m \times 1.7 m (length \times width \times depth) pool located in an outdoor aviary at the University of Southern Denmark's Marine Biological Research Center in Kerteminde, Denmark. The test subjects were one male and one female common murre, both 4 yr old and born in captivity in the United Kingdom. They were on loan from Copenhagen Zoo to be trained for psychophysical studies in Kerteminde.

Both birds were in the pool simultaneously during the playbacks. Each bird could be individually identified by a differently colored leg band, Green (male) or Blue (female), as well as different degree of black/white feathering around the head. At the start of each trial, a feeder (a 56 cm long PVC tube wrapped in fishing net) containing eight pieces of 5 g sprat (*Sprattus sprattus*) was placed vertically into the water and suspended 10 cm from the bottom of the pool.

Two underwater cameras (Diver Pro, LH Camera, Fredericia, Denmark) were placed at 90-deg angles from each other and at a distance of 140 cm from the feeder (Fig. 1). Both cameras were connected via Elgato video capture USB devices to two laptop computers recording both the video and the emitted signals.

The signals were played from the headphone jack of one of the laptops using Adobe Audition (Adobe, Inc.) through an underwater loudspeaker (UW-30, Electro-Voice, Buchanan, Michigan, USA; 20 cm) held in place by a vertical PVC tube, at a depth of 132 cm. The playback signals

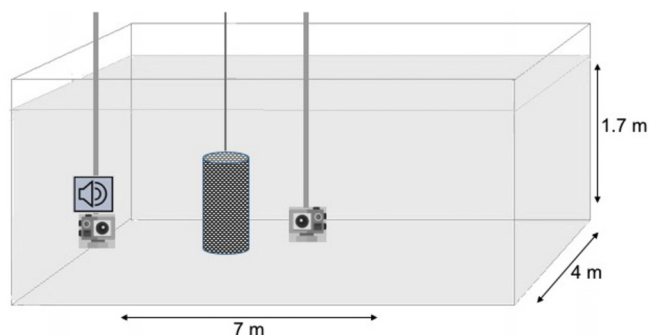


FIG. 1. (Color online) Playback setup, indicating the location of the feeder, the two underwater cameras, and the underwater speaker.

were a broadband sound burst, with a duration of 0.5 s, and a mid-frequency active naval sonar signal (MFA) of 1.5 s duration (Fig. 2). The sound burst was generated as a 0.5 s broadband sound pulse in Adobe Audition, with 100 ms ramp-up and ramp-down at signal start and end. Due to the varying frequency response of the loudspeaker, the played back stimulus was not flat but had prominent peaks at 1 and 2 kHz (Fig. 2). This signal was identical to the one used during a previous playback study on Gentoo penguins, which reacted strongly to this type of signal (Sørensen *et al.*, 2020). The MFA recording was a recording of a U.S. Navy model 53C sonar, obtained from the U.S. Navy. The 1.5 s long signal consisted of three parts, each 500 ms long: First, a pure tone at 4.1 kHz, then a linear sweep from 3.5 to 3.6 kHz, and finally a pure tone at 3.7 kHz. MFA sonars are used to find submarines and other large objects at very long ranges. They are emitted at extremely high source levels and may cause behavioral disruptions and affect hearing abilities in some species of marine mammals. Therefore, several studies have aimed at understanding how marine mammals are affected by MFA emissions (e.g., Kastelein *et al.*, 2017). Several of these studies have used the identical sound stimulus as the one used in our playback study of murres.

The broadband sound burst was emitted at four different received sound levels: 110, 120, 130, and 137 dB re 1 μ Pa rms, and the MFA sonar signal was emitted at three different sound levels: 110, 120, and 130 dB re 1 μ Pa rms, all levels measured at the site of the feeder. Both signals were read by Adobe Audition from a WAV file with a sample rate of 48 kHz at 16 bits. Control “no sound” trials were also conducted. The order between trial type and signal level was randomized.

Measurements of the played back sound levels and the ambient noise level were made regularly throughout data collection. A SoundTrap model ST300HF (Ocean Instruments, Inc; sampling rate 48 kHz, 16 bits) acoustic data logger was used to calibrate the different stimulus levels. The data logger was calibrated using relative and reciprocity calibration (see Au and Hastings, 2009) with two Reson TC4034 and one Reson TC4014 hydrophones in a calibration tank from 20 to 150 kHz and in air by relative calibration in a sound-proof chamber against a GRASS $\frac{1}{2}$ in. microphone from 0.2 to

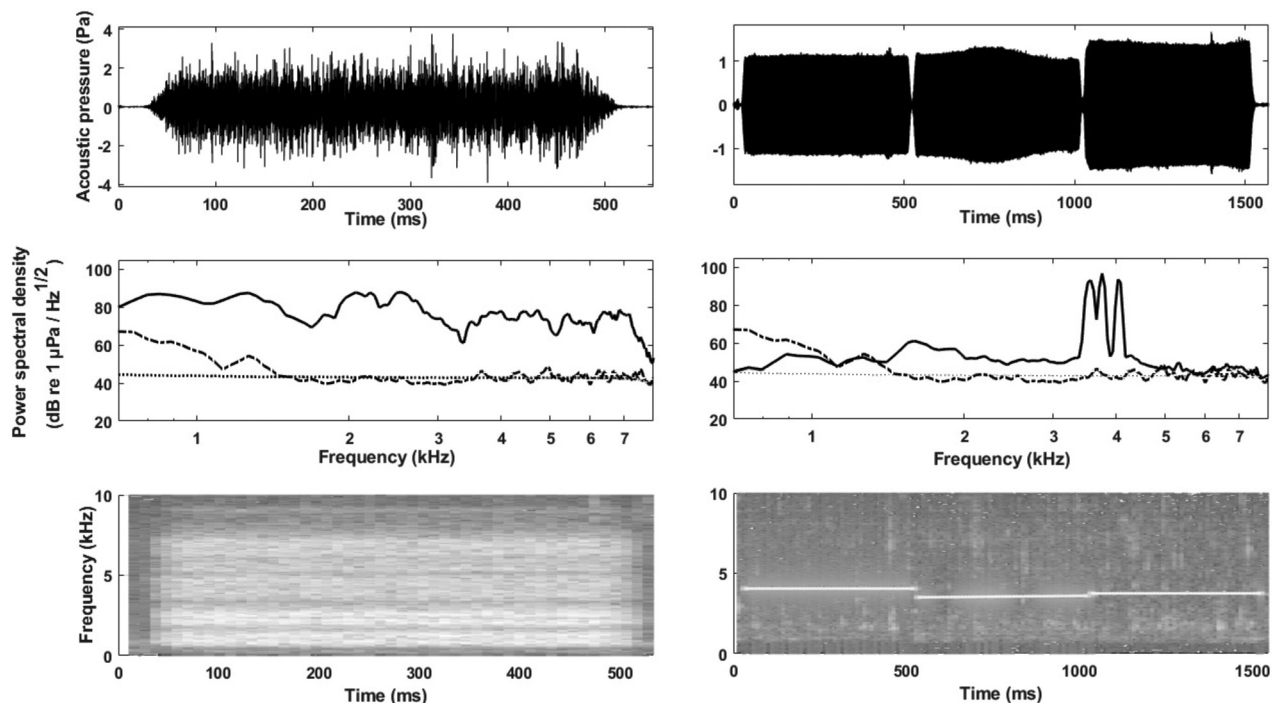


FIG. 2. Playback signals. Top: oscillogram (sample rate 48 kHz, 16 bits); middle: power spectrum (FFT size 1024, Hanning window); bottom: spectrogram (48 kHz, FFT size 1024, Hanning window, 50% overlap). Left: broadband sound burst and right: naval mid-frequency MFA sonar signal and ambient noise measurements (stippled). Self-noise of the recording system is indicated with a dotted line.

5 kHz. The variation in its sensitivity was less than ± 3 dB. To estimate the variations in the sound field experienced by the birds around the feeder, the signals were recorded at different distances, directions and depths from the loudspeaker in 10 cm increments and in a 10–30 cm range from the feeder. Ambient noise recordings were made by positioning the SoundTrap in front of the feeder and at the same level and angle of the underwater speaker. The playback signal and ambient noise recordings were analysed using Matlab ver. 2018 and Welch spectral averaging (Hanning window, FFT size 256, 50% overlap). The ambient noise levels were always lower than all the stimuli’s received levels (Fig. 2). The level of the stimulus was always within ± 3 dB from the nominal level measured at the feeder straight in front of the loudspeaker.

The experimenter was located in a control room outside of the aviary, out of sight of the birds, controlling the emission of sounds and video recordings. After starting the video recordings, the feeder, contained with fish, was lowered down into the pool to a depth of 132 cm by loosening a rope in the control room that was connected to the feeder. Both birds would immediately gather around the feeder and try to pull out the fish (Fig. 3). The experimenter started the randomly chosen sound file when the feeder was fully lowered, and both birds were either at the feeder or within 10 cm of the feeder, and within the camera’s visual field. There was one session per day with 5–8 trials per session. There was a minimum of 3 min between each trial. Each session included a control trial with the same procedure as the stimuli presentations, but no sound was played. The birds were presented

five times with each of the different source levels for the two different stimuli for a total of 35 trials.

Behavioral responses from the trial videos were subjectively graded by the two experimenters and three additional experienced observers. The behavioral responses were graded into response scores from 1 to 3 (RS1–3; Table I). During analysis, the observers were not aware of the exposed source level for each trial, allowing for non-biased grading of the responses. The observers did not significantly disagree with each other (Kruskal-Wallis, d.f. = 3, $p > 0.05$). Therefore, their average response score for each trial was used in the analysis. For the control trials, the first instance where both



FIG. 3. Underwater photo showing both common murrelets at the feeder at the start of a trial.

TABLE I. Response score definitions.

Response score (RS)	Definition
1	No reaction (calmly swimming around feeder and eating while staying near the feeder)
2	Reaction (abrupt stop in feeding for 1–4 s, staying within 0.5 m from feeder)
3	Strong reaction (startle, stop feeding, and fleeing further than 0.5 m from feeder)

birds were in the right position for playback were used as the instant of “playback” and the bird responses were then ranked using the same response score (Table I) as in the sound trials.

The relationship between the response and response score was tested with a multinomial logistic regression (MLR) using R-studio (<https://rstudio.com/>). In this statistical model, the RS2 and 3 (“reaction” and “strong reaction”) scores were combined and tested against RS1 (“no reaction”). ANOVAs were used to compare responses between trials with and without signals. A significance level of $p = 0.05$ was used.

III. RESULTS

A. Control trials

For all six control trials, when no sound was played back, there was no response (RS1) from any of the birds.

B. Broadband sound burst

For the broadband sound burst stimulus, the female exhibited an almost equal amount of different reactions for all received levels, except at 130 dB, where only reaction scores of 2 (“Reaction”) were observed [Fig. 4(a)]. The male exhibited a graded response to increased sound level, with 100% RS1 (“No Reaction”) at 110 dB and reactions (RS2 and RS3) in 50% of the trials at 137 dB re 1 μ Pa [Fig. 4(b)]. There was a statistical tendency ($p < 0.1$), albeit not

significant, between response and sound level, when combining the data from both individuals.

C. MFA Sonar

For the MFA sonar stimulus, both the male and the female showed graded responses, with all strong reactions (RS3) occurring at the highest tested received level (130 dB re 1 μ Pa; Fig. 5). There was no statistically significant relationship between reaction score and sound level for any of the birds, albeit a statistical tendency was found for the male ($p < 0.1$).

D. Pooling data

We pooled the response data for each intensity level and for both types of signals into a summed score (giving the weight 0 to RS1, 1 to RS2, and 2 to RS3), and plotting the summed score as a function of signal level category (where 0 = no playback, 1 = 110 dB, 2 = 120 dB, and 3 = 130 dB re 1 μ Pa; the 137 dB data were left out in this analysis as it was only performed for the broadband burst). A linear regression explained 60% of the variance in this data and was significantly different than 0 (ANOVA, $p < 0.05$).

IV. DISCUSSION

The murrelets reacted to both the underwater broadband sound burst and the MFA sonar signal. For the female, the highest playback intensity elicited the strongest reactions, whereas the reactions of the second animal, a male, were more variable. Overall, the female reacted more strongly to the broadband sound burst than the male, and the male reacted more strongly to the MFA than the female. The fact that both birds showed clear reactions to both the broadband sound burst and the sonar signal, as well as the lack of response to the control trials, clearly indicates that murrelets react to underwater sounds. At least in some cases, this response seems intensity dependent, even at moderate intensities.

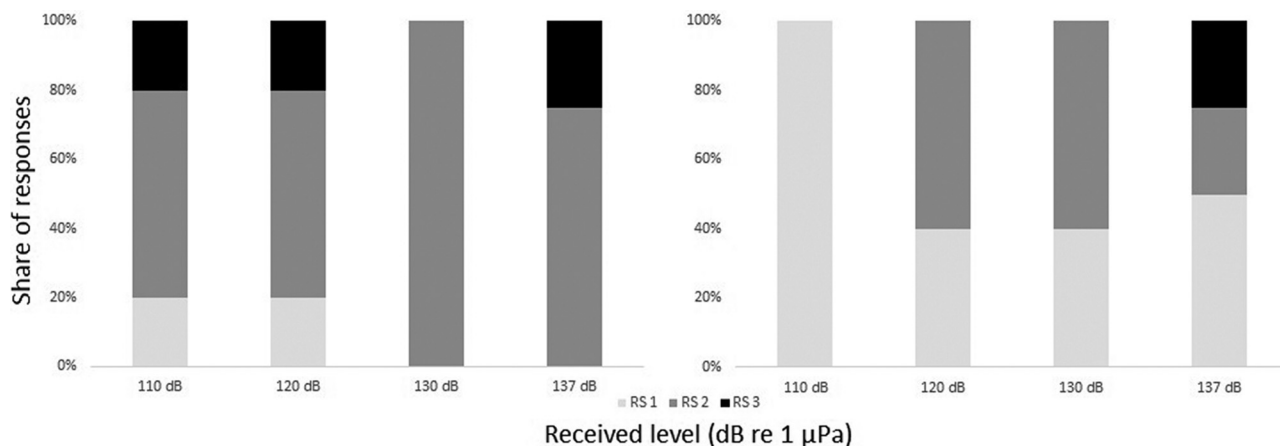


FIG. 4. Common murre response scores when exposed to broadband sound burst stimulus. Left (a): female (“blue”), right (b): male (“green”). RS1: no reaction; RS2: reaction; RS3: strong reaction.

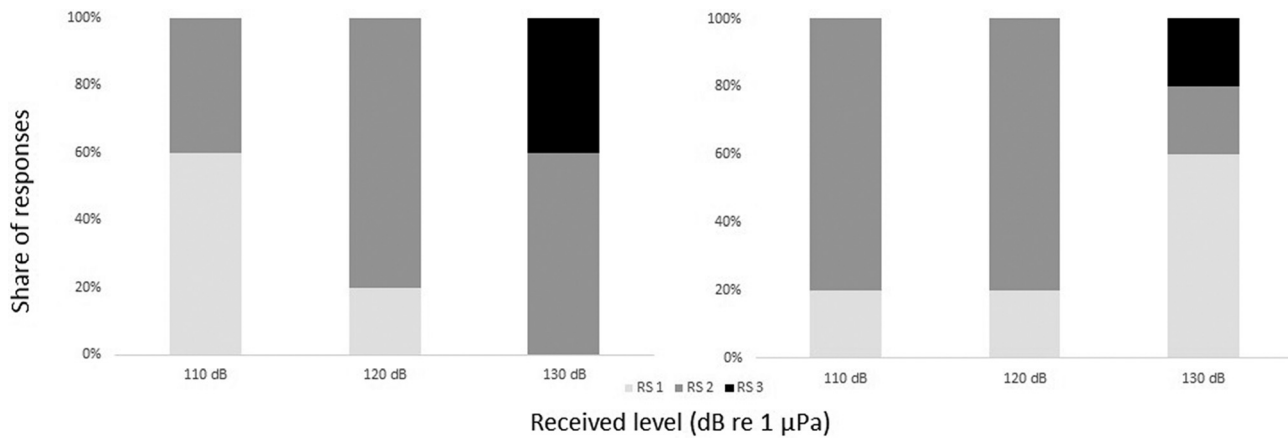


FIG. 5. Common murre response scores when exposed to the naval mid-frequency sonar (MFA) signal. Left: female (“blue”), right: male (“green”). RS1: no reaction; RS2: reaction; RS3: strong reaction.

The reason for the two birds to react differently on the playback may either be due to individual or sex differences in hearing or their reaction to sound, or individual differences in the birds’ behavior (i.e., one animal may be more “sensitive” or risk adverse). Also, the animal’s previous experience with sound exposure may have affected their response. However, the birds were born and reared in captivity and lived together since birth (born only two days apart), therefore their exposure history was probably very similar. The individual difference may instead be explained by the behavioral context of the bird. What is it doing when the sound is emitted and how focused is the bird on doing that behavior? The female reacted more strongly to the broad band sound burst, a very short, broadband sound, which may result in a “flight or fight” behavioral response. The male, however, showed a stronger interest in the feeder and was very focused on obtaining the food. At any rate, differences in behavioral states between the two individuals and between trials could have greatly affected their response to the played back sound.

For strong (RS3) reactions, both birds always moved away and in the opposite direction of the sound source. This is the reaction one would expect if the birds are able to tell the direction to the sound source underwater. Birds are adept at aerial sound-source localization (Coles *et al.*, 1980; Richards and Wiley, 1980). Yet, an ear adapted for only hearing well in air is not efficient in discerning the direction to a sound source underwater, as directional cues (time lag and intensity differences between the two ears) diminishes underwater due to the high speed of sound. Having directional hearing is usually regarded as a prerequisite for making efficient use of sound cues and could therefore indicate underwater adaptations in the hearing system of murre. However, the observed behavior does not necessarily indicate that murre are able to discern the direction of underwater sound. The birds were moving fast while being exposed to sound and may therefore have followed the intensity gradient of the sound towards lower sound levels. Also, the birds may have learned for various reasons that sounds were emitted from the loudspeaker and therefore instantaneously turned away from it as soon as the stimulus was played.

Irrespective of murre using underwater sounds as cues while diving, the results presented here should cause some concern for conservation issues based on how marine animals react to underwater sounds. The lowest levels that elicited behavioral responses in the birds, 110 dB re 1 μPa, were surprisingly low. These sound levels are similar to the ones known to affect harbour porpoise behavior for sounds of comparable frequencies (Kastelein *et al.*, 2019). MFA sonars have source levels way beyond 200 dB re 1 μPa, and therefore our findings indicate that murre could react to sound from such devices at distances of many kilometres, assuming spherical spreading. This may have important consequences for how the use of this type of sonars is mitigated in areas known to be used for foraging in murre and other Alcids. Furthermore, the broadband sound burst that was used here contained a broadband range of frequencies, not very dissimilar to the spectral signature of a nearby boat propeller. Even though propeller noise is quite a different type of signal than the played back one, the fact that the birds reacted to the broadband sound burst may indicate that diving murre may also react to boat noise. Just as marine mammals and fish are of great concern of being affected by anthropogenic noise, these findings indicate that marine birds may share the same risk and should be further investigated.

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