

TEXTE

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Final Report

Hearing in Penguins

by:

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Abstract: Hearing in Penguins

The main aim of the project "Hearing in Penguins" was to measure audiograms in penguins both in the air and under water. Within the four years of the project, we were able to train Humboldt penguins to ultimately measure in-air audiograms. The results of this psychoacoustic approach indicate that penguins hear best between 1 and 4 kHz in air. We also developed a non-invasive method based on the use of external electrodes to measure in-air auditory evoked potentials in penguins. Moreover, the creation of an animal audiogram databank that we launched online during the course of the project has facilitated the comparison between audiograms measured in penguins and those measured in other aquatic animals. Because of a variety of unexpected difficulties, we were, however, unable to measure underwater audiograms in penguins. Hearing adaptations in penguins were also investigated by visualizing their inner and middle ear with CT-scans, which suggested that the hearing capacity of penguins is likely preserved during diving. In line with this finding, we found through playback experiments that penguins could avoid noise pulses underwater with a surprisingly low reaction threshold and could be conditioned to underwater sounds. A great effort was also made to communicate about the project and underwater noise pollution, using a variety of approaches by presentations to the general public, in media and online. Overall, the project "Hearing in Penguins" was successful, as the vast majority of the original objectives were reached. Most importantly, our project laid the foundation for future studies on the hearing capacity of diving birds and has large applications to understand how seabirds are affected by underwater noise.

Kurzbeschreibung: Hearing in Penguins

Das Hauptziel des Projekts "Hearing in Penguins" war es, Audiogramme bei Pinguinen sowohl in der Luft als auch unter Wasser zu messen. Innerhalb der vier Jahre des Projekts konnten wir Humboldt-Pinguine für die Messung von Audiogrammen trainieren. Die Ergebnisse dieses psychoakustischen Ansatzes zeigen, dass Pinguine in der Luft zwischen 1 und 4 kHz am besten hören. Wir haben außerdem eine nicht-invasive Methode entwickelt, die auf der Verwendung von externen Elektroden basiert, um die akustisch evozierten Potenziale in der Luft bei Pinguinen zu messen. Darüber hinaus hat die Entwicklung einer Tieraudiogramm-Datenbank, die wir im Laufe des Projekts online gestellt haben, den Vergleich zwischen den bei Pinguinen und anderen Wassertieren gemessenen Audiogrammen erleichtert. Aufgrund einer Reihe unerwarteter Schwierigkeiten war es uns jedoch nicht möglich, Unterwasser-Audiogramme bei Pinguinen zu messen. Die Anpassungen des Gehörs bei Pinguinen wurden außerdem untersucht, indem ihr Innen- und Mittelohr mit CT-Scans sichtbar gemacht wurde, was darauf hindeutet, dass das Hörvermögen von Pinguinen beim Tauchen wahrscheinlich erhalten bleibt. Entsprechend fanden wir während Unterwasser-Playback-Experimente heraus, dass Pinguine mit einer erstaunlich niedrigen Reaktionsschwelle Geräuschimpulsen unter Wasser ausweichen können und auf Unterwassergeräusche konditioniert werden können. Es wurden auch erhebliche Maßnahmen ergriffen, um über das Projekt und die Lärmbelästigung unter Wasser zu kommunizieren. Mit einer Vielzahl von Ansätzen wurde die Öffentlichkeit, in den Medien und online, z.B. durch Präsentationen erreicht. Insgesamt war das Projekt "Hearing in Penguins" sehr erfolgreich, da die überwiegende Mehrheit der ursprünglichen Ziele erreicht wurde. Am bedeutendsten ist jedoch, dass unser Projekt den Grundstein für zukünftige Studien über das Hörvermögen von tauchenden Vögeln gelegt hat und so zu einem größeren Verständnis beiträgt, inwiefern Meeresvögel von Unterwasserlärm betroffen sind.

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List of abbreviations

AAD	Animal Audiogram Database
AEP	Auditory Evoked Potential
DMM	Deutsches Meeresmuseum (<i>German Oceanographic Museum</i>)
DOG	Deutsche Ornithologische Gesellschaft (<i>German Ornithological Society</i>)
HIP	Hearing in Penguins
IPC	International Penguin Conference
MfN	Museum für Naturkunde (<i>Museum of Natural History, Berlin</i>)
MSC	Marine Science Center (Rostock)
PI	Principal Investigator
POMA	Proceedings of Meetings on Acoustics
RSOS	Royal Society Open Science
SDU	University of Southern Denmark
UBA	Umweltbundesamt (<i>German Environment Agency</i>)
WP	Work Package

Summary

Although penguins (order: Spheniciformes) probably show specific hearing adaptations as a result of their amphibious lifestyle, almost nothing was known about their hearing capacity both in-air and under water before the project "Hearing in Penguins" was launched in January 2018. Hearing data on penguins are needed, as these birds are increasingly exposed to sounds of anthropogenic origin in their natural environment. However, whether higher sound exposure levels represent a threat for penguins is currently unknown. Knowledge on the hearing capacity of penguins is therefore necessary for stakeholders to formulate guidelines regarding the regulation of human sound production in the birds' environment. The motivation of "Hearing in Penguins" was to learn what penguins acoustically perceive and how they react when being exposed to different sources of noise. One early study on the hearing of African penguins (*Spheniscus demersus*) had shown that they hear best between 0.2 and 4.0 kHz in air. This study used an invasive approach which could no longer be used today because of ethical concerns. Moreover, whether the results of this study applied to other penguin species remained unknown. Finally, no investigation at all had been conducted on the hearing capacity of penguins under water, despite the ability of these diving birds to reach the greatest depths among all existing bird species.

In this context, the Deutsches Meeresmuseum (DMM, Stralsund), the Marine Science Center (MSC, Rostock), the University of Southern Denmark (SDU, Odense) and the Museum für Naturkunde (MfN, Berlin) formed a consortium and worked together within the project "Hearing in Penguins" between January 2018 and September 2022. The main aim of the project "Hearing in Penguins" was twofold: (1) investigating the hearing capacity of penguins in the air and under water, and (2) science communication about the ongoing underwater sound pollution.

During the project "Hearing in penguins", the investigation of the hearing capacity of penguins was mostly based on psychoacoustic methods conducted on three penguin species held in captivity at the DMM (Humboldt penguins; *Spheniscus humboldti*), MSC (Humboldt penguins) and Odense Zoo/SDU (king penguins; *Aptenodytes patagonicus*, and Northern rockhopper penguins; *Eudyptes moseleyi*). Penguins involved in the project were either juveniles recently hatched in captivity at the DMM or at the Odense Zoo (Humboldt and king penguins) or adults (rockhopper penguins). The psychoacoustic methods used consisted in training penguins to indicate if they heard a tone characterized by a certain frequency and intensity. This approach was expected to ultimately produce audiograms (i.e., the frequency and intensity threshold above which penguins can hear), both for in-air and underwater sounds. No training had been previously performed on penguins for bioacoustics investigations. It was therefore challenging to anticipate how long the training process would take to measure audiograms in these birds. Because data collection took longer than expected, the scientific part of the project, which was originally planned to end in April 2021, was extended until September 2022.

In all institutions, the training of penguins started with basic commands for them to get familiar with their training environment and to stay still at the place where sound signals were to be played during future measurements. For the in-air training conducted at the DMM and the Odense Zoo, penguins were also progressively trained to respond to commands while being more and more isolated from the trainer and enclosed in a sound-proof chamber. Penguins were then trained to associate a simple sound signal (e.g., 2 kHz tone) with a behavioral response by touching a target when a tone was played in the chamber. After almost two years of intensive training, it was possible to start the actual in-air audiogram measurement on the four Humboldt penguins trained at the DMM. These measurements lasted two years before all the raw data necessary to generate audiograms were collected. These audiograms show that Humboldt

penguins hear best between 1 and 4 kHz in-air. This result is comparable to the other audiograms recently measured in great cormorants (*Phalacrocorax carbo*) through psychoacoustic methods. The similarity in frequency range of hearing in deep-diving penguins and more shallow-diving cormorants suggest that the hearing capacity of sea birds is similar, irrespective of the diving depth they can reach. An article about the training process of the Humboldt penguins at the DMM was published 2022 in Applied Animal Behaviour Science, and another article about the results is in preparation.

Within the four years of the project “Hearing in Penguins”, we were not able to measure in-air audiograms through psychoacoustics in king penguins as their training progress was too slow. Eventually, it was decided to stop training them and to instead train Northern rockhopper penguins for this task, as they appeared more responsive to training activities. The first data on two rockhopper penguins suggested that they could hear in the air all tested frequencies (1, 2 and 4 kHz) for intensities higher than 50 dB re 20 μ Pa, but their hearing capacity decreased for lower intensities.

In addition to their slowness to be trained in the air, king penguins were reluctant to dive into their water tank for training activities, so that they could not be trained underwater as originally planned in the project. In contrast to king penguins, we managed to train Humboldt penguins under water to some extent at the MSC. However, because of a variety of unexpected difficulties, we were not able either to measure underwater audiograms in this species. Among these difficulties, we had to redesign the entire training infrastructure at the MSC to train penguins underwater in the middle of the project. These structural adjustments were necessary to prevent Humboldt penguins from staying all together in water during training sessions instead of being individually trained. Moreover, in all institutions, penguins could hardly be trained when moulting in summer because of their high energetic demand and because of a lack of plumage waterproofing. All these difficulties resulted in long delays in training activities and progress. On top of these difficulties, the most important challenge that we faced was to keep training penguins during the work restrictions imposed by the coronavirus lockdown during a large part of 2020 and 2021. These restrictions either reduced training activities (DMM, SDU) or entirely prevented them (MSC). Finally, an ornithosis outbreak that occurred at the MSC in the middle of the third year of the project resulted in the complete termination of all training activities at this institution.

Besides using psychoacoustic methods, audiograms can also be measured through neurophysiological measurements of Auditory Evoked Potentials (AEP). This method is based on the use of electrodes placed under the skin and measuring the activity of the brainstem of birds exposed to different tones with certain frequency and intensity characteristics. This method had already been successfully used in different bird species including waterbirds (e.g., ducks, loons, gannets, cormorants, auks). AEP measurements are more straightforward than psychoacoustic methods, as the monitored animals do not need to be trained. However, AEP measurements require the sedation of the monitored animals, which may limit their practicability and their general ethical acceptance. To circumvent these limitations, an innovative method allowing AEP measurements without sedating birds was developed at the SDU and the DMM during the course of our project. On the one side, custom electrode leads were developed at the SDU to measure AEP by directly sticking them on the skin of the head of penguins, while on the other sides, Humboldt penguins were trained at the DMM to wear electrodes in contact with their skull skin. For the first time, viable AEPs could be measured with this method on awake penguins in response to broadband click stimuli. AEP responses were observed at stimulus levels between 50 and 100 dB, resulting in an estimated auditory threshold of 48 dB re 20 μ Pa to the click

stimulus. This rapid and reliable method to measure AEP therefore provides a promising approach for future studies examining the hearing capacity of penguins.

In order to set a reference for the audiograms measured in penguins, an audiogram database ([Animal Audiogram Database](https://www.animalaudiograms.org/); <https://www.animalaudiograms.org/>) was created and launched online in 2020. This database gathers audiograms that have been measured in aquatic vertebrates (mostly cetaceans and pinnipeds) so far and are available in the scientific literature. The database is freely accessible and is designed to be used as a repository for studies measuring and publishing audiograms in any animal species. To optimize the database for its users, a workshop gathering audiogram experts from all over the World was organized in early 2021 to discuss potential improvements to add to the database. An article describing the Animal Audiogram Database was published in the *Journal of the Acoustical Society of America* in early 2022.

The aim of the project “Hearing of penguins” was not only to examine the hearing capacity of penguins through the measurement of audiograms but also to use other methods to assess their hearing adaptations. For instance, the bony structure of the ear of nine penguin species (covering all penguin genera except one) was analyzed with CT-scans and compared with that of diving waterbirds from three different orders (Suliformes, Charadriiformes, Anseriformes) at the MfN. Penguin specimens were selected from the bird collections of the MfN and the DMM. In addition, specimens from three different penguin species (African penguin; gentoo penguin, *Pygoscelis papua*; emperor penguin, *Aptenodytes forsteri*) were stained to visualize their soft tissues. These scans were used to reconstruct the internal auditory organs of penguins using specialized software. [Videos of the 3D models](https://doi.naturkundemuseum.berlin/data/10.7479/c5qd-xd79) (<https://doi.naturkundemuseum.berlin/data/10.7479/c5qd-xd79>) showing the auditory organs were created from the scans and were published online as freely available data publications. The results of these anatomical investigations showed a smaller ratio of the eardrum to the columella footplate in penguins compared to other waterbirds. This result suggests that the relatively small size of the eardrum of penguins may represent a protection mechanism, possibly as an adaptation of underwater hearing. Moreover, the residual volume of the ear, as measured from CT scans, was found to be proportional to the surface area of the round window, thereby suggesting that the hearing capacity of penguins is likely preserved during diving.

In line with this finding, gentoo penguins were found to avoid noise sources underwater during a playback experiment conducted at the Odense Zoo. Moreover, the fact that gentoo penguins avoided noise sources underwater with a surprisingly low reaction threshold suggests that acoustic cues may be of great importance for these diving birds. Accordingly, by acoustically conditioning gentoo penguins to a sound followed by the presentation of a fish close to the loudspeaker through a ‘fish flush’ system, it was also found at the Odense Zoo that penguins could associate underwater sounds with food, which may help them to locate food under water in their natural habitat. The results of the anatomical investigation of the ear of penguins were published in the journal *Proceedings of Meetings on Acoustics* and the results of the underwater playback experiment in gentoo penguins were published in the journal *Royal Society Open Science*, both in 2020. The results of the conditioning experiment were published in *Biology Open* in 2022.

In parallel to the scientific approaches used in the project “Hearing in Penguins”, a great effort was made to communicate about the project itself and about underwater noise pollution more generally. Towards this end, a great variety of approaches was used by both the MfN and the DMM, which made the project and the topic “underwater noise” highly visible to both the scientific community and the general public.

The project was presented during different scientific conferences (e.g., “International Penguin Conference”, “The Effect of Aquatic Noise”, “International Conference on Acoustics”, “African Bioacoustic Conference”) and an entire symposium was even devoted to the project during the annual meeting of the German Ornithological Society in 2020. It was also presented less formally during a penguin workshop organized by the professional association of animal keepers at the Opel Zoo in Kronberg, during an elephant seal meeting at the Chizé Center for Biological Studies (CNRS, France), and during the Summer School on Acoustic Communication organized by the SDU. Overall, the project “Hearing in Penguins” was well received by the scientific community and generally considered as novel, timely and well-integrated with current scientific questions.

To communicate about the project, we also participated in major events for the general public such as the “Long Night of Museums” at the MfN and the DMM, during which the results of the 3D models and the corresponding penguin vocalizations were presented. Moreover, commented training sessions were conducted at the DMM during the “Family Summer” and “World Penguin Day” 2019. A podium discussion gathering experts on underwater noise (e.g., politicians, NGO representatives, scientists) was also organized online at the end of the project to raise awareness on this mostly-overlooked but growing environmental disturbance. Finally, a closing meeting was organized at the originally-planned end of the project (April 2021) to summarize the progress made and the results obtained during the project. On this occasion, we also broadened the scope of our project by inviting researchers working in related fields (e.g., in-air measurements of AEP audiograms in Alcids, avoidance of seismic survey activities by penguins) to present their research. All these communication events were coupled with the annual topic “Kein Lärm Meer – No Noisy Sea” at the DMM.

To make the project more visible online, we created an Instagram account where news about the project were regularly posted. An information platform about underwater noise (Lautes Meer – Meereslaute) was also developed and launched online on the occasion of the “International Noise Awareness Day” (2020). The platform includes informative background on underwater noise, a link to a video on underwater noise pollution that we created and published online in 2020, information about the project “Hearing in Penguins” including a blog with 20 articles, and interactive content (an audio quiz on underwater sounds, an underwater sound mixer for people to grasp how animals perceive their acoustical environment under water, especially when being exposed to noise of anthropogenic origin). To promote the new web platform, we hosted two online lectures on the occasion of the “World Penguin Day” (2020) and the “Day Against Noise” (2020) and organized an online campaign on MfN’s social media channels. A making-of video focusing on the CT scans made at the MfN and providing a brief overview of the project at the DMM was completed and launched online in 2019. An explanatory video on underwater noise pollution was also created and published in 2020, and a Sonic Chair was developed for users to experience underwater soundscapes in an unprecedented way while getting informed about underwater sounds.

Finally, throughout the project, we actively interacted with major media (e.g., Focus, Die Zeit, die Welt, NDR, BR), which communicated approximately 450 times about the project between January 2018 and April 2021 (when our communication strategy ended).

Overall, the project “Hearing in Penguins” was successful, as the vast majority of the originally planned objectives were reached. However, because of our lack of pre-knowledge about the duration of the training of penguins for scientific purposes and most importantly because of the unexpected difficulties mentioned above, not all our original goals could be achieved (e.g., underwater audiograms), and the scientific part of the project had to be extended. Thanks to the results already published by the project “Hearing in Penguins” as well as the communication work we made about the project and underwater noise pollution, we hope that the project

“Hearing in Penguins” will be a source of inspiration for other research teams working on diving birds in general and in penguins in particular.

Zusammenfassung

Obwohl Pinguine (Ordnung: Spheniciformes) aufgrund ihrer amphibischen Lebensweise wahrscheinlich spezifische Anpassungen des Gehörs aufweisen, war vor dem Start des Projekts "Hearing in Penguins" im Januar 2018 fast nichts über ihr Hörvermögen sowohl in der Luft als auch unter Wasser bekannt. Hörphysiologische Daten von Pinguinen werden benötigt, da diese Vögel in ihrer natürlichen Umgebung zunehmend Geräuschen anthropogenen Ursprungs ausgesetzt sind. Ob die höheren Schallbelastungen eine Bedrohung für Pinguine darstellen, ist derzeit jedoch nicht bekannt. Erkenntnisse über das Hörvermögen von Pinguinen sind daher von wesentlicher Bedeutung, um Richtlinien für die Regulierung der menschlichen Geräuschproduktion im Habitat der Vögel aufzustellen. Die Motivation von "Hearing in Penguins" war es, zu untersuchen, was Pinguine akustisch wahrnehmen und worauf sie reagieren, wenn sie verschiedenen Lärmquellen ausgesetzt sind. Eine frühe Studie über das Gehör von Afrikanischen Pinguinen (*Spheniscus demersus*) hatte gezeigt, dass sie am besten zwischen 0,2 und 6,0 kHz in der Luft hören. Diese Studie verwendete einen invasiven Ansatz, der heute aus ethischen Gründen nicht mehr angewendet werden kann. Außerdem blieb abzuklären, ob die Ergebnisse dieser Studie auf andere Pinguinarten übertragbar waren. Bis zu diesem Projekt wurde bisher keine Untersuchung über das Hörvermögen von Pinguinen unter Wasser durchgeführt, obwohl diese tauchenden Vögel die größten Tiefen unter allen existierenden Vogelarten erreichen können.

In diesem Zusammenhang bildeten das Deutsche Meeresmuseum (DMM, Stralsund), das Marine Science Center (MSC, Rostock), die Süddänische Universität (SDU, Odense) und das Museum für Naturkunde (MfN, Berlin) ein Konsortium und arbeiteten von Januar 2018 bis Juni 2022 gemeinsam im Rahmen des Projekts „Hearing in Penguins“. Die Hauptziele des Projekts „Hearing in Penguins“ waren: (1) zum einen die Untersuchung des Hörvermögens von Pinguinen in der Luft und unter Wasser und (2) zum anderen die Wissenschaftskommunikation über die derzeitige Schallverschmutzung unter Wasser.

Während des Projekts „Hearing in Penguins“ basierte die Untersuchung des Hörvermögens von Pinguinen hauptsächlich auf psychoakustischen Methoden, die an drei verschiedenen Pinguinarten durchgeführt wurden, die im DMM (Humboldtpinguine; *Spheniscus humboldti*), im MSC (Humboldtpinguine) und im Odense Zoo/SDU (Königspinguine; *Aptenodytes patagonicus*, und Tristanpinguine; *Eudyptes moseleyi*) in Menschenhand gehalten wurden. Pinguine, die an dem Projekt beteiligt waren, waren entweder Jungtiere, die kürzlich im DMM oder im Odense Zoo in Gefangenschaft geschlüpft waren (Humboldt- und Königspinguine) oder Erwachsenen (Eselspinguine). Die verwendeten psychoakustischen Methoden bestanden darin, die Pinguine darauf zu trainieren, anzugeben, ob sie einen durch eine bestimmte Frequenz und Intensität charakterisierten Ton hörten. Dieser Ansatz sollte letztendlich Audiogramme (d. h. die Frequenz- und Intensitätsschwelle, ab der Pinguine hören können) sowohl für Luftschall als auch für Unterwasserschall erzeugen. Da zuvor keine Pinguine für bioakustische Untersuchungen trainiert worden waren, war es schwer vorherzusehen, wie lange der Trainingsprozess zur Messung von Audiogrammen bei diesen Vögeln dauern würde. Da die Datenerfassung länger dauerte als erwartet, wurde der wissenschaftliche Teil des Projekts, der ursprünglich bis April 2021 geplant war, bis September 2022 verlängert.

In allen Einrichtungen begann das Training der Pinguine mit grundlegenden Befehlen, damit sie sich mit ihrer Trainingsumgebung vertraut machen und an der Stelle stillstehen, an der bei zukünftigen Messungen Schallsignale abgespielt werden sollten. Bei dem im DMM und im Zoo Odense durchgeführten Lufttraining wurden die Pinguine außerdem schrittweise darauf trainiert, auf Kommandos zu reagieren, während sie in einer schalldichten Kammer immer mehr

vom Trainer isoliert wurden. Die Pinguine wurden dann darauf trainiert, ein einfaches Tonsignal (z. B. einen 2-kHz-Ton) mit einer Verhaltensreaktion zu assoziieren, indem sie ein Ziel berührten, wenn ein Ton in der Kammer abgespielt wurde. Nach fast zwei Jahren intensiven Trainings konnte mit der eigentlichen Audiogramm-Messung an den vier am DMM trainierten Humboldt-Pinguinen begonnen werden. Diese Messungen dauerten zwei Jahre, bis alle notwendigen Rohdaten zur Erstellung der Audiogramme gesammelt waren. Die Messungen zeigen, dass Humboldtpinguine am besten zwischen 1 und 4 kHz hören können. Diese Ergebnisse sind vergleichbar mit einem anderen Audiogramm, das kürzlich bei großen Kormoranen (*Phalacrocorax carbo*) mit psychoakustischen Methoden gemessen wurde. Die Ähnlichkeit der Frequenzabhängigkeit der Sensitivität des Gehörs bei tief tauchenden Pinguinen und flacher tauchenden Kormoranen lässt vermuten, dass das Hörvermögen von Seevögeln ähnlich ist, unabhängig davon, welche Tauchtiefe sie erreichen können. Ein Artikel über den Trainingsprozess der Humboldt-Pinguine bei der DMM wurde bei Applied Animal Behaviour Science 2022 veröffentlicht, und ein weiterer Artikel über die Ergebnisse der Messungen ist in Vorbereitung.

In den vier Jahren des Projekts „Hearing in Penguins“ waren wir nicht in der Lage, Audiogramme durch psychoakustische Messungen bei Königspinguinen zu messen, da ihre Trainingsfortschritte in der Luft zu langsam waren. Schließlich wurde beschlossen, sie nicht mehr zu trainieren und stattdessen Felsenpinguine für die Aufgabe zu trainieren, da sie auf die Trainingsaktivitäten besser zu reagieren schienen. Die ersten Daten von zwei Felsenpinguinen deuten darauf hin, dass sie in der Luft alle getesteten Frequenzen (1, 2 und 4 kHz) bei Lautstärken von mehr als 50 dB re 20 μ Pa hören können, ihr Hörvermögen nimmt jedoch bei niedrigeren Lautstärken ab.

Abgesehen davon, dass die Königspinguine nur langsam in der Luft trainiert werden können, wollten die Königspinguine für die Trainingsaktivitäten nicht von selbst in ihr Wasserbecken tauchen, so dass sie nicht, wie ursprünglich im Projekt geplant, unter Wasser trainiert werden konnten. Im Gegensatz zu den Königspinguinen gelang es uns, die Humboldt-Pinguine im MSC unter Wasser zu einem gewissen Grad zu trainieren. Aufgrund einer Reihe von unerwarteten Schwierigkeiten, konnten wir jedoch auch bei dieser Art keine Unterwasser-Audiogramme messen. Zu diesen Schwierigkeiten gehörte, dass wir mitten im Projekt die gesamte Trainingsinfrastruktur im MSC umbauen mussten, um die Pinguine unter Wasser zu trainieren. Diese baulichen Anpassungen waren notwendig, um zu verhindern, dass die Humboldt-Pinguine während der Trainingseinheiten gemeinschaftlich im Wasser verblieben, anstatt individuell trainiert zu werden. Außerdem konnten die Pinguine während der Mauser im Sommer wegen ihres hohen Energiebedarfs und wegen der dann fehlenden Gefiederabdichtung im Wasser in allen Einrichtungen kaum trainiert werden. All diese Schwierigkeiten führten zu langen Verzögerungen bei den Trainingsaktivitäten und Fortschritten. Zusätzlich zu diesen Schwierigkeiten bestand die größte Herausforderung darin, die Pinguine während der Arbeitseinschränkungen, die durch die Coronavirus-Pandemie während eines großen Teils der Jahre 2020 und 2021 eintraten, weiter zu trainieren. Diese Einschränkungen reduzierten entweder die Trainingsaktivitäten (DMM, SDU) oder verhinderten sie ganz (MSC). Ein Ornithose-Ausbruch, der im MSC in der Mitte des dritten Projektjahres auftrat, führte zur vollständigen Beendigung aller Trainingsaktivitäten in dieser Einrichtung.

Audiogramme können nicht nur durch psychoakustische Methoden gemessen werden, sondern auch durch neurophysiologische Methoden wie die Messung der Akustisch Evozierten Potentiale (AEP). Diese Methode basiert auf der Verwendung von Elektroden, die unter der Haut angebracht werden und die Aktivität des Hirnstamms von Tieren messen, denen verschiedenen Töne mit bestimmten Frequenz- und Intensitätsmerkmalen vorgespielt werden. Diese Methode

wurde bereits erfolgreich bei verschiedenen Vogelarten, einschließlich Wasservögeln (z. B. Enten, Seetaucher, Basstölpel, Kormorane, Alkenvögel), eingesetzt. AEP-Messungen sind einfacher umzusetzen als psychoakustische Methoden, da die überwachten Tiere nicht trainiert werden müssen. Allerdings erfordern AEP-Messungen die Sedierung der überwachten Tiere, was ihre Praktikabilität und ihre allgemeine ethische Akzeptanz einschränken kann. Um diese Einschränkungen zu umgehen, wurde an der SDU und am DMM im Rahmen unseres Projekts eine innovative Methode entwickelt, die AEP-Messungen ohne Sedierung der Vögel ermöglicht. Einerseits wurden an der SDU spezielle Elektroden entwickelt, um AEPs zu messen, indem sie direkt auf die Kopfhaut der Pinguine geklebt wurden und andererseits wurden Humboldt-Pinguine am DMM darauf trainiert, Kontaktelektroden auf ihrer Schädelhaut zu tolerieren. Zum ersten Mal konnten mit dieser Methode nutzbare AEPs bei wachen Pinguinen als Reaktion auf breitbandige Klickreize gemessen werden. AEP-Reaktionen wurden bei Reizpegeln zwischen 50 und 100 dB beobachtet, was zu einer geschätzten Hörschwelle von 48 dB re 20 μ Pa für den Klickreiz führte. Diese schnelle und zuverlässige Methode zur Messung des AEP bietet daher einen vielversprechenden Ansatz für künftige Studien zur Untersuchung des Hörvermögens von Pinguinen.

Um eine Referenz für die bei Pinguinen gemessenen Audiogramme zu setzen, wurde eine Audiogramm-Datenbank ([Animal Audiogram Database](#)) erstellt und im Jahr 2020 online gestellt. Diese Datenbank sammelt Audiogramme, die bisher bei aquatischen Wirbeltieren (hauptsächlich Wale und Robben) gemessen wurden und in der wissenschaftlichen Literatur verfügbar sind. Die Datenbank ist frei zugänglich und ist als Repositorium für Studien vorgesehen, die Audiogramme bei beliebigen Tierarten messen und veröffentlichen. Zu diesem Zweck wurde Anfang 2021 ein Workshop mit Audiogramm-Experten aus der ganzen Welt organisiert, um mögliche Verbesserungen zu diskutieren, die der Datenbank hinzugefügt werden können. Schließlich wurde ein Artikel über die Tieraudiogramm-Datenbank beim *Journal of the Acoustical Society of America* Anfang 2022 veröffentlicht.

Ziel des Projekts „Hearing in Penguins“ war es, nicht nur das Hörvermögen der Pinguine durch die Messung von Audiogrammen zu untersuchen, sondern auch andere Methoden zur Beurteilung ihrer Höranpassungen einzusetzen. So wurde die knöcherne Struktur des Ohres von neun Pinguinarten (die bis auf eine alle Pinguinattungen abdecken) mit CT-Scans analysiert und mit tauchenden Wasservögeln aus drei verschiedenen Ordnungen (Suliformes, Charadriiformes, Anseriformes) im MfN verglichen. Es wurden Pinguinexemplare aus den Vogelsammlungen des MfN und des DMM ausgewählt. Zusätzlich wurden Exemplare von drei verschiedenen Pinguinarten (Brillenpinguin; Eselspinguin, *Pygoscelis papua*; Kaiserpinguin, *Aptenodytes forsteri*) gefärbt, um ihre Weichteile zu visualisieren. Diese Scans wurden verwendet, um die inneren Gehörorgane der Pinguine mit einer speziellen Software zu rekonstruieren. [Videos der 3D-Modelle](#), die die Hörorgane zeigen, wurden aus den Scans erstellt und online als frei verfügbare Datenpublikationen veröffentlicht. Die Ergebnisse dieser anatomischen Untersuchungen zeigten ein kleineres Verhältnis des Trommelfells zur Columella-Fußplatte bei Pinguinen im Vergleich zu anderen Wasservögeln. Dieses Ergebnis legt nahe, dass die relative geringe Größe des Trommelfells bei Pinguinen einen Schutzmechanismus darstellen könnte, möglicherweise als Anpassung an das Unterwasserhören. Darüber hinaus wurde festgestellt, dass das Restvolumen des Ohres, gemessen anhand von CT-Scans, proportional zur Oberfläche des runden Fensters ist, was darauf hindeutet, dass die Hörfähigkeit von Pinguinen beim Tauchen wahrscheinlich erhalten bleibt.

Möglicherweise ist dies der Grund dafür, dass Eselspinguine bei einem im Zoo von Odense durchgeführten Playback-Experiment Geräuschquellen unter Wasser mieden. Die Tatsache, dass Eselspinguine auf Geräuschquellen unter Wasser mit einer überraschend niedrigen

Reaktionsschwelle reagieren, deutet außerdem darauf hin, dass akustische Hinweise für diese tauchenden Vögel von großer Bedeutung sein könnten. Durch akustische Konditionierung von Eselspinguinen auf einen Ton, gefolgt von der Präsentation eines Fisches in der Nähe des Lautsprechers durch ein "Fish Flush"-System, wurde im Zoo von Odense dementsprechend festgestellt, dass Pinguine Unterwassergeräusche mit Nahrung assoziieren können, was ihnen helfen könnte, in ihrem natürlichen Lebensraum Nahrung unter Wasser zu finden. Die Ergebnisse der anatomischen Untersuchung des Gehörs von Pinguinen wurden 2020 in der Fachzeitschrift *Proceedings of Meetings on Acoustics* veröffentlicht und die Ergebnisse des Unterwasser-Playback-Experiments bei Eselspinguinen wurden 2020 in der Fachzeitschrift *Royal Society Open Science* veröffentlicht. Die Ergebnisse des Konditionierungsexperiments wurden in der Zeitschrift *Biology Open* 2022 veröffentlicht.

Parallel zu den wissenschaftlichen Ansätzen, die im Projekt „Hearing in Penguins“ verwendet wurden, wurde eine Kommunikationsstrategie entwickelt, um über das Projekt selbst und über das Thema Unterwasserlärm im Allgemeinen zu kommunizieren. Zu diesem Zweck wurde sowohl vom MfN als auch vom DMM eine große Vielfalt an Ansätzen genutzt, die das Projekt und das Thema „Unterwasserlärm“ sowohl in der wissenschaftlichen Gemeinschaft als auch in der Öffentlichkeit sehr sichtbar machten.

Das Projekt wurde zunächst auf verschiedenen wissenschaftlichen Konferenzen vorgestellt (z. B. „International Penguin Conference“, „The Effect of Aquatic Noise“, „International Conference on Acoustics“, „African Bioacoustic Conference“) und dem Projekt wurde sogar ein ganzes Symposium während der Jahrestagung der Deutschen Ornithologen-Gesellschaft im Jahr 2020 gewidmet. Informell wurde es auch bei einem Pinguin-Workshop der Berufsgenossenschaft der Tierpfleger im Opel-Zoo Kronberg, bei einem Seeelefanten-Treffen am Chizé Center for Biological Studies (CNRS, Frankreich) und bei der von der SDU organisierten Summer School on Acoustic Communication vorgestellt. Insgesamt wurde das Projekt „Hearing in Penguins“ gut aufgenommen und allgemein als neuartig, zeitgemäß und gut mit aktuellen wissenschaftlichen Fragestellungen verknüpft angesehen.

Um über das Projekt zu kommunizieren, nahmen wir auch an großen Veranstaltungen für die Öffentlichkeit wie der „Langen Nacht der Museen“ im MfN und im DMM teil, bei denen die Ergebnisse der 3D-Modelle und die entsprechenden Pinguin-Vokalisationen vorgestellt wurden. Auch im Rahmen des „Familiensommers“ und des „Weltpinguintages“ 2019 wurden kommentierte Trainingseinheiten im DMM durchgeführt. Eine Podiumsdiskussion mit Experten zum Thema Unterwasserlärm (z. B. Politiker, NGO-Vertreter, Wissenschaftler) wurde am Ende des Projekts auch online organisiert, mit dem Ziel das Bewusstsein für diese meist übersehene, aber wachsende Umweltstörung zu schärfen. Zum ursprünglich geplanten Ende des Projekts (April 2021) wurde außerdem ein Abschlusstreffen organisiert, um die Fortschritte und Ergebnisse des Projekts zusammenzufassen. Wir erweiterten auch den Rahmen unseres Projekts, indem wir Forscher, die in verwandten Bereichen arbeiten (z. B. Luftmessungen von AEP-Audiogrammen bei Alken, Vermeidung von seismischen Untersuchungsaktivitäten durch Pinguine) einluden, ihre Forschung zu präsentieren. Alle diese Veranstaltungen waren mit dem Jahresthema „Kein Lärm Meer“ des DMM gekoppelt.

Um das Projekt online sichtbarer zu machen, erstellten wir einen Instagram-Kanal, auf dem Nachrichten über das Projekt regelmäßig gepostet wurden. Außerdem wurde eine Informationsplattform über Unterwasserlärm (Lautes Meer – Meereslaute) entwickelt und anlässlich des „International Noise Awareness Day“ (2020) online gestellt. Die Plattform enthält informative Hintergrundinformationen über Unterwasserlärm, einen Link zu einem Video über Unterwasserlärmverschmutzung, das für das Projekt erstellt wurde und Informationen über das Projekt „Hearing in Penguins“ einschließlich eines Projekt-Blogs mit 20 Artikeln und interaktive

Inhalte (ein Audio-Quiz über Unterwassergeräusche, einen Unterwasser-Soundmixer, mit dem Menschen begreifen können, wie Tiere ihre akustische Umgebung unter Wasser wahrnehmen, insbesondere wenn sie Lärm anthropogenen Ursprungs ausgesetzt sind). Um die neue Webplattform zu bewerben, haben wir zwei Online-Vorträge anlässlich des „Weltpinguintages“ (2020) und des „Tages gegen Lärm“ (2020) veranstaltet und eine Online-Kampagne auf den Social-Media-Kanälen des MfN organisiert. Ein Making-of-Video, das sich auf die im MfN angefertigten CT-Scans konzentriert und einen kurzen Überblick über das Projekt beim DMM gibt, wurde fertiggestellt und 2019 online gestellt. Ein Erklärvideo über die Lärmbelastung unter Wasser wurde ebenfalls erstellt und 2020 veröffentlicht, und es wurde ein Sonic Chair entwickelt, mit dem die Nutzer Unterwassergeräusche auf eine noch nie dagewesene Weise erleben und sich gleichzeitig über Unterwassergeräusche informieren können.

Schließlich haben wir während des gesamten Projekts aktiv mit wichtigen Medien interagiert (z. B. Focus, Die Zeit, die Welt), die zwischen Januar 2018 und April 2021 (als unsere Kommunikationsstrategie endete) etwa 450 mal über das Projekt kommuniziert haben.

Insgesamt war das Projekt „Hearing in Penguins“ erfolgreich, da die überwiegende Mehrheit der ursprünglich geplanten Ziele erreicht wurde. Aufgrund unseres mangelnden Vorwissens über die Dauer des Trainings von Pinguinen für wissenschaftliche Zwecke und vor allem aufgrund der oben erwähnten unerwarteten Schwierigkeiten konnten jedoch nicht alle unsere ursprünglichen Ziele erreicht werden (z. B. Unterwasseraudiogramme), und der wissenschaftliche Teil des Projekts musste verlängert werden. Dank der bereits veröffentlichten Ergebnisse des Projekts „Hearing in Penguins“ sowie der von uns geleisteten Kommunikationsarbeit über das Projekt und die Unterwasserlärmbelastung hoffen wir, dass das Projekt „Hearing in Penguins“ eine Inspirationsquelle für andere Forschungsteams sein wird, die an tauchenden Vögeln im Allgemeinen und an Pinguinen im Besonderen arbeiten.

1 Background

1.1 Objectives

Although penguins (order: Spheniciformes) probably show specific hearing adaptations as a result of their amphibious way of life, almost nothing was known about their hearing capacity before the project “Hearing in Penguins” was launched in January 2018. This was problematic, as penguins are increasingly exposed to sounds of anthropogenic origin in their natural environment. Whether this higher sound exposure represents a threat for penguins remains currently unknown. There was therefore a strong need to know what penguins acoustically perceive and how they react when being exposed to different sources of noise. Such knowledge on the hearing capacity of penguins is essential for authorities to formulate potential guidelines regarding the regulation of sound production in the environment of penguins.

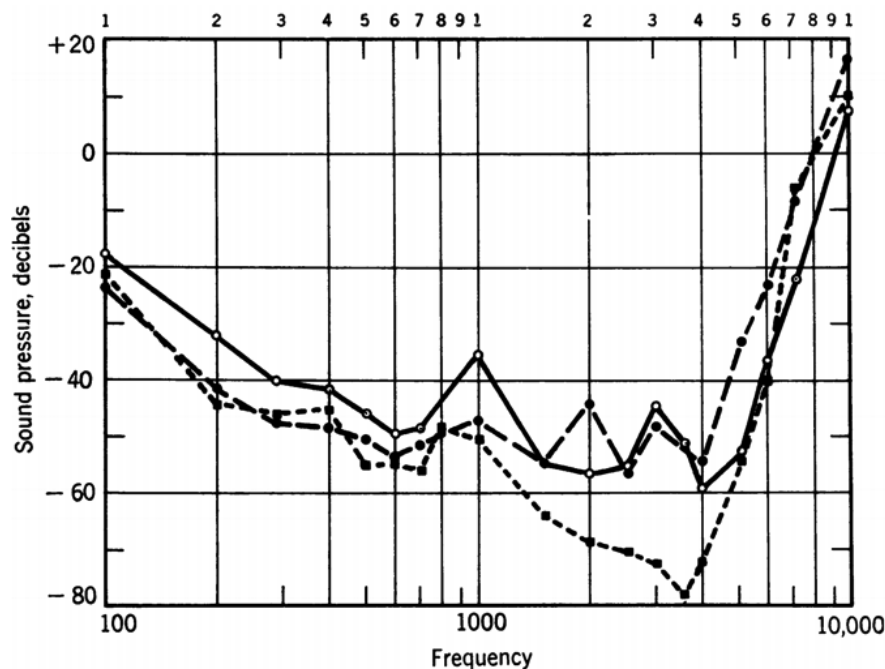
In this context, the main objective of the project “Hearing in Penguins” was to improve our knowledge on the hearing capacity of penguins in order to predict the impact of environmental sounds both in the air and under water. Toward this end, we wanted to:

- ▶ investigate the hearing capacity of penguins by using psychoacoustic methods, and developing non-invasive neurophysiological methods (Auditory Evoked Potentials, AEP),
- ▶ raise public awareness about underwater noise through innovative communication methods.

1.2 State of the art and methods

The hearing capacity of animals is typically represented through audiograms (*i.e.*, the frequency and intensity threshold above which animals can hear; **Figure 1**). Although many waterbirds dive to capture their food (which has probably resulted in adaptations of their hearing capacity), audiograms have hardly been measured in this group of animals. Nevertheless, using an invasive approach, Wever et al. (1969) found that African penguins (*Spheniscus demersus*) heard best in the air between 0.2 and 6.0 kHz, despite strong differences between the individuals studied (**Figure 1**). Whether these results applied to other penguin species remained unknown. Moreover, no investigation at all had been conducted on the hearing capacity of penguins under water despite the ability of these diving birds to reach the greatest depths among all existing bird species.

Figure 1: Recordings of airborne audiograms in three African penguins

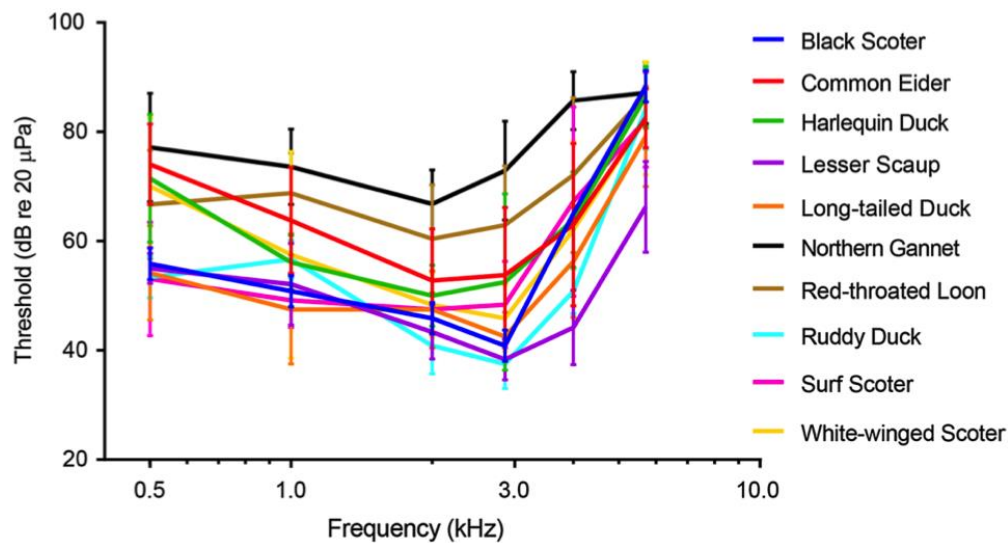


Source: from Wever et al. 1969.

Invasive approaches like those used in the past to measure audiograms could no longer be used today because of ethical concerns. These methods have therefore to be replaced by more refined approaches. For instance, psychoacoustic methods can be used to investigate the hearing capacity of animals and measure audiograms (Okanoya and Dooling 1987). For recording such audiograms, the animals have to be trained to indicate whether an acoustic signal is perceived or not (*e.g.*, by pressing a button). A staircase procedure can be used in which, after a warm-up period, the signals are reduced from a clearly audible level until the animal no longer perceives the signal. The volume is then increased until the animal again indicates that it perceives the signal. This process is repeated once or twice to describe the hearing threshold as the average of the reversal points. Alternatively, the method of constant stimuli, consisting in presenting a fixed set of stimuli (ranging near the threshold) repeatedly in a random order, can be used. In this case, the stimulus value yielding a detection response in 50% of the time is selected as the threshold.

In addition to psychoacoustic methods, the hearing capacity of animals can also be assessed through the measurement of Auditory Evoked Potentials (AEP) based on the use of electrodes placed on or under the skin and measuring the activity of the brainstem of sedated animals exposed to different tones with certain frequency and intensity characteristics (Ruser et al., 2014, 2016). In birds, the method was successfully used first in woodpeckers (Lohr *et al.* 2013) and budgerigars (*Melopsittacus undulatus*; Brittan-Powell et al., 2011; Brittan-Powell and Dooling, 2004; Noirot et al., 2011) before being used in diving waterbirds (Crowell et al., 2015, 2016; Mooney et al. 2019). In particular, the work on diving ducks and loons by Crowell et al. (2015, 2016) clearly demonstrates that the AEP method can be safely applied to waterbirds. The aerial audiograms measured in that study show a clear variability between bird species and the best hearing between 2 and 4 kHz (**Figure 2**).

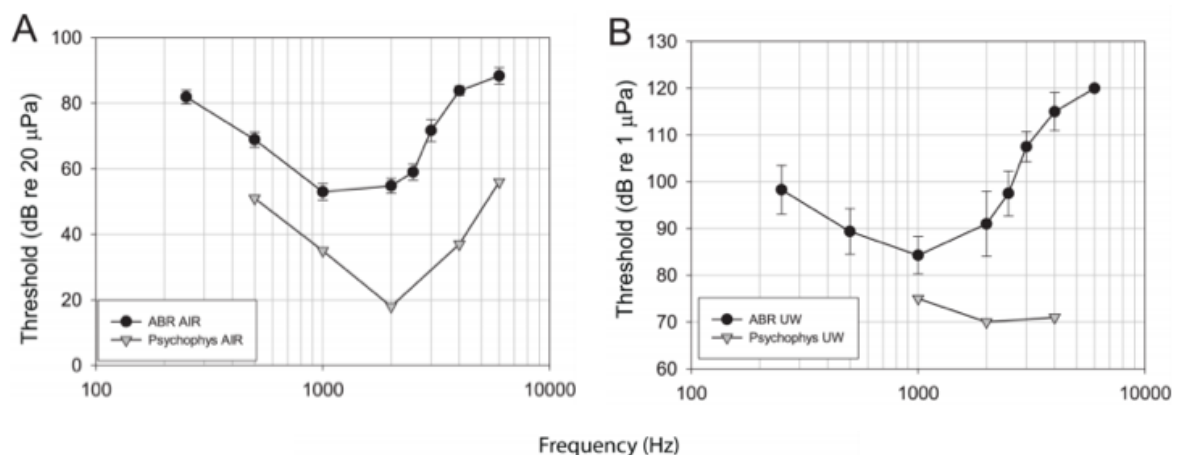
Figure 2: Airborne audiograms of different bird species



All audiograms were measured using the AEP method. Source: from Crowell et al., 2015

Although both psychoacoustic and neuro-acoustic methods can provide reliable results, previous comparisons in marine mammals show that AEP audiograms are always associated with higher hearing thresholds than psychoacoustic methods, and direct comparisons between both methods therefore remain difficult (Wolski et al., 2003; Schlundt et al., 2007; Kastelein et al., 2010; Lucke et al., 2009; Ruser et al., 2016). This was also recently confirmed in birds with the first measurements of psychoacoustic and AEP audiograms in a cormorant (*Phalacrocorax carbo sinensis*) in air and under water (Figure 3; Larsen et al., 2020).

Figure 3: Comparison between AEP thresholds and thresholds determined with behavioural methods in cormorants.

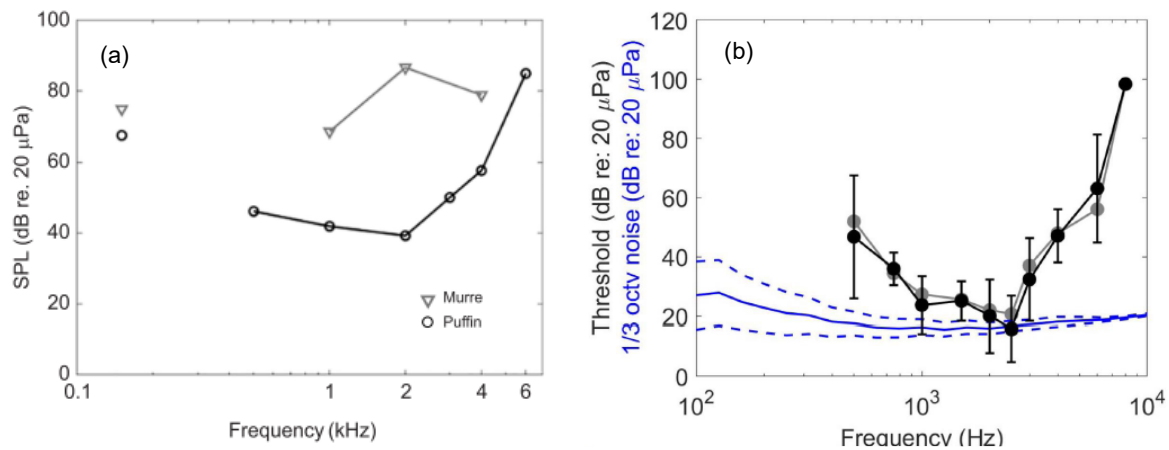


(A) Average AEP threshold curve in air of 12 cormorant fledglings compared to the psychophysical threshold curve of a single adult cormorant in air. (B) Average AEP threshold curve under water of 8 of the 12 cormorant fledglings compared to the psychophysical threshold curve of a single cormorant under water. Source: from Larsen et al., 2020.

Research on seabird hearing was very active during the funding period of the project "Hearing in Penguins". This shows that the project was scientifically timely and well-integrated with current scientific questions. For example, in an Atlantic puffin (*Fratercula arctica*), the lowest measured

thresholds in the air were recently found at 1-2 kHz, with a gradual increase in AEP thresholds at lower frequencies and a steeper increase at higher frequencies (**Figure 4**; Mooney et al., 2019). These results were confirmed by another AEP study published in 2020, which included nine Atlantic puffins (although intensity thresholds were lower; Mooney et al., 2020). For a common guillemot (*Uria aalge*), stimulus responses were found to be higher and the frequency range was narrower (1-4 kHz with no detectable stimulus responses at 3 kHz; **Figure 4**; Mooney et al. 2019, 2020).

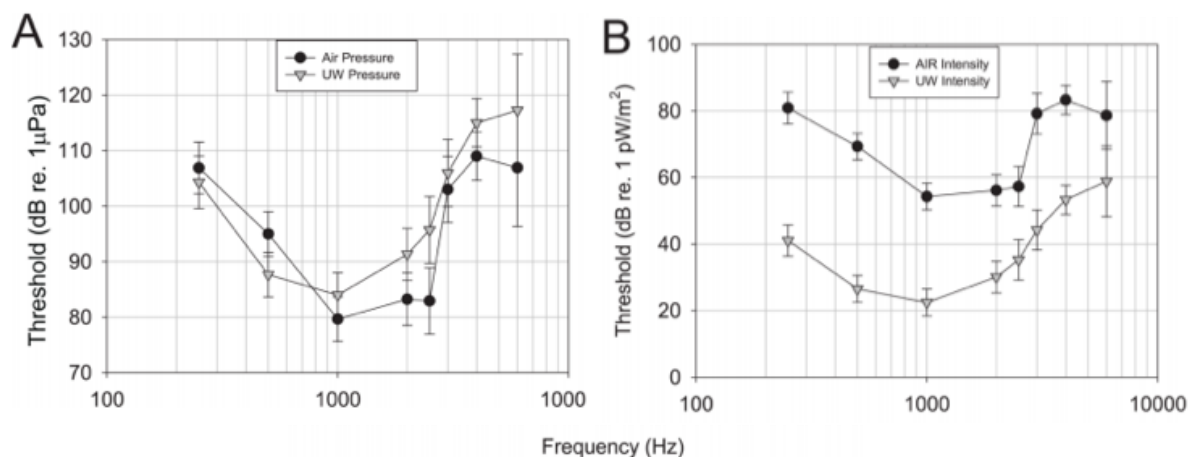
Figure 4: Audiograms of Alcids



(a) Calculated AEP thresholds for a puffin and a guillemot (the isolated dots on the left are click evoked response thresholds; SPL: sound pressure level in rms), (b) Mean and median puffin audiograms. Mean $\pm$ s.d. (black) and median (grey) of all puffins. Ambient noise profile (blue; mean $\pm$ s.d.) of the auditory test chamber. Source: from Mooney et al., 2019 and Mooney et al., 2020.

In cormorant fledglings, the best average sound pressure sensitivity has also recently been found at 1 kHz, both in air and underwater (with head and ears 10 cm below the water surface). However, when thresholds are compared in intensity units, sensitivity is higher underwater than in air (**Figure 5**; Larsen et al., 2020).

Figure 5: Comparison of average AEP thresholds in air and underwater predicted from a repeated-measures ANOVA model



(A) The model predicted mean sound pressure curves in air and underwater (dB relative to 1 μ Pa) that were not significantly different. (B) Measured as average intensity thresholds (dB relative to 1 pW/m²), the model predicted statistically different curves in air and underwater. Source: from Larsen et al., 2020.

In all these recent studies on seabirds, the birds had to be sedated for AEP measurements. One of the goals of the project "Hearing in Penguins" was to circumvent this limitation by using psychoacoustic methods and by developing a technique that allows AEP measurements without sedating the birds.

Recently, free-ranging king, Macaroni (*Eudyptes chrysolophus*) and gentoo penguins have been found to emit short vocalizations (*ca.* 0.05 s) while feeding underwater with a fundamental frequency between 500 and 700 Hz and a maximal frequency between 700 and 1100 Hz (Thiebault *et al.* 2019). If these underwater vocalizations are used to communicate between diving penguins (the actual function of these vocalizations remains to be determined), these results suggest that penguins can hear under water within this frequency range (which would match the underwater hearing capacity of cormorants as presented in **Figure 5**).

2 Psychoacoustic measurements conducted in “Hearing in Penguins”

2.1 Psychoacoustic methods

2.1.1 Generalities

Training for in-air psychoacoustic measurements was conducted in three different penguin species: Humboldt penguins (*Spheniscus humboldti*), king penguins (*Aptenodytes patagonicus*), and Northern rockhopper penguins (*Eudyptes moseleyi*). Training for underwater psychoacoustic measurements was conducted in Humboldt penguins only. In all cases, training was based on operant conditioning using positive reinforcement with fish being used as the primary reinforcer. At the same time, penguins were conditioned to a secondary reinforcer (a whistling sound) that provided the opportunity for the trainer to respond more directly to the animal's behaviour.

2.1.2 In-air psychoacoustics

2.1.2.1 Humboldt penguins

This work was carried out as part of Helen Rößler's doctoral thesis at the University of Greifswald. All Humboldt penguins trained at DMM were from pairs that successfully raised chicks at the DMM in 2017 or 2018. Training activities started in April 2018 with four male penguins hatched in 2017 (in July 2018, two of these males moved to the MSC for underwater training). Four other penguins, hatched in 2018 (two males, two females), were also later trained but the males also moved to the MSC at the end of 2018. From November 2018, the training sessions (**Figure 6**) of the four penguins at the DMM (two males, two females) were conducted once to three times a day (except weekends).

Figure 6: Training of Humboldt penguins at DMM



From left to right: Target training with individual markings and with the penguins being progressively more isolated from the trainer. Finally, the training was conducted in a soundproof box that was completely closed (*i.e.*, the penguins could not see the trainer). Source: own illustration, DMM

The very first step consisted of teaching the penguins their respective names in order to work with them individually. Then, training was expanded in summer 2018 to include several tasks: stationing (placing the head in a constant position on a surface), standing still, and tracking a

target (to guide the penguins to the correct position). Starting in December 2018, the training was successively expanded to include more features, including training to associate a sound signal (stimulus) with a response (touching another target). An article about the training process of the Humboldt penguins at the DMM was written and published in *Applied Animal Behaviour Science* in 2022 (Rößler et al. 2022, Appendix A.7).

In spring 2019, a soundproof box was designed and built. Foam, four speakers, and two video cameras were attached and connected to play sounds in a silent environment and observe penguins' behaviour. The penguins showed no difficulty to enter the box. Once the penguin entered the box and remained with its beak on a support, the door of the box was quietly closed. Then a 2 kHz training tone (1-3 s) was played from a loudspeaker and the penguin had to indicate with its beak if it heard the tone (Figure 6). All four penguins were successful in this training and after almost two years of intensive training, it was possible to start audiogram measurements. Toward this end, a Labview script for an automated, randomized, double-blind method of constants was written. This script was run from a laptop with signalling (National Instruments, DAQ6366USB) attached, and the output was connected to an amplifier that went to a speaker. The trials were activated with a switch. A trial light in the box in front of the penguin was activated, indicating the start of a trial to the animal. A "Go" or "No Go" trial was indicated to the trainer via a green or red LED. The animal's response could then be marked via a toggle switch, and an unclear trial could be invalidated via a separate button. After a month of testing and adjusting the Labview script, the first acoustic tests began according to time plan in late March 2020.

The acoustic test sessions started with a 2 kHz tone played for 600 ms, clearly audible to the penguin. After one week, the sound intensity at 2 kHz was reduced from -6 to -36 dB in 6-dB steps. In subsequent trials, the frequency was changed to 1, 4, and 0.5 kHz. For each frequency, signals in -6-dB sound intensity steps were presented until the probability for the penguin's correct response was close to 50% (Gellermann 1933). With this method of constants, the penguins' hit response rate dropped and the false alarm rate increased quickly when decreasing the stimulus intensity. To circumvent this limitation, an improved script was written in February 2021 and the method of constant stimuli (one frequency with changing intensities in one session) was used for all further test sessions. As recommended by (Green & Swets 1966), we applied the method of constant stimuli with a set middle intensity around the expected threshold and two above and two below threshold intensities all in 6 dB steps. After every session the stimuli and background noise were additionally measured at the penguins' head with a sound level meter connected with a preamplifier and a microphone. Spectral noise levels (around 5 dB rms re 20 μ Pa/Hz in the 2-4 kHz range) were estimated using a specific software. The self-noise of the sound level meter was also 2 - 4 kHz at 5dB rms re 20 μ Pa/Hz, so that the actual acoustic noise level may have even been lower than these measurements.

Data were considered for further analyses when they matched the following criteria: penguin attention score ≥ 2 (among three attention scores; 1: not attentive, 2: moderately attentive, 3: highly attentive), false alarm rate < 30%, hit rate > 50%. Data collection lasted until December 2021 thanks to an extension of the scientific part of the project.

2.1.2.2 King penguins

This work was carried out as part of Kenneth Sørensen's PhD thesis at the SDU. In April 2018, the psychoacoustic training of a female king penguin, hatched in the fall of 2017 at the Odense Zoo (Denmark), started and followed the same steps as described for Humboldt penguins at the DMM. After the first few months of target training (autumn 2018), the penguin was rewarded when it indicated that it heard a sound. At the same time, the penguin was trained to enter a 1.0

x 2.0 x 1.4 m soundproof box where measurements were planned. In 2019, a second female was ready for psychophysical testing in the soundproof box (**Figure 7**). However, due to the slowness of king penguins to be trained, as well as additional difficulties (see 9. below), no audiogram could be measured in king penguins during the funding period of the project. Accordingly, the training of king penguins ended in October 2020. Instead, it was decided to train two Northern rockhopper penguins for psychophysical in-air audiograms.

Figure 7: Training of king penguins at the Zoo Odense

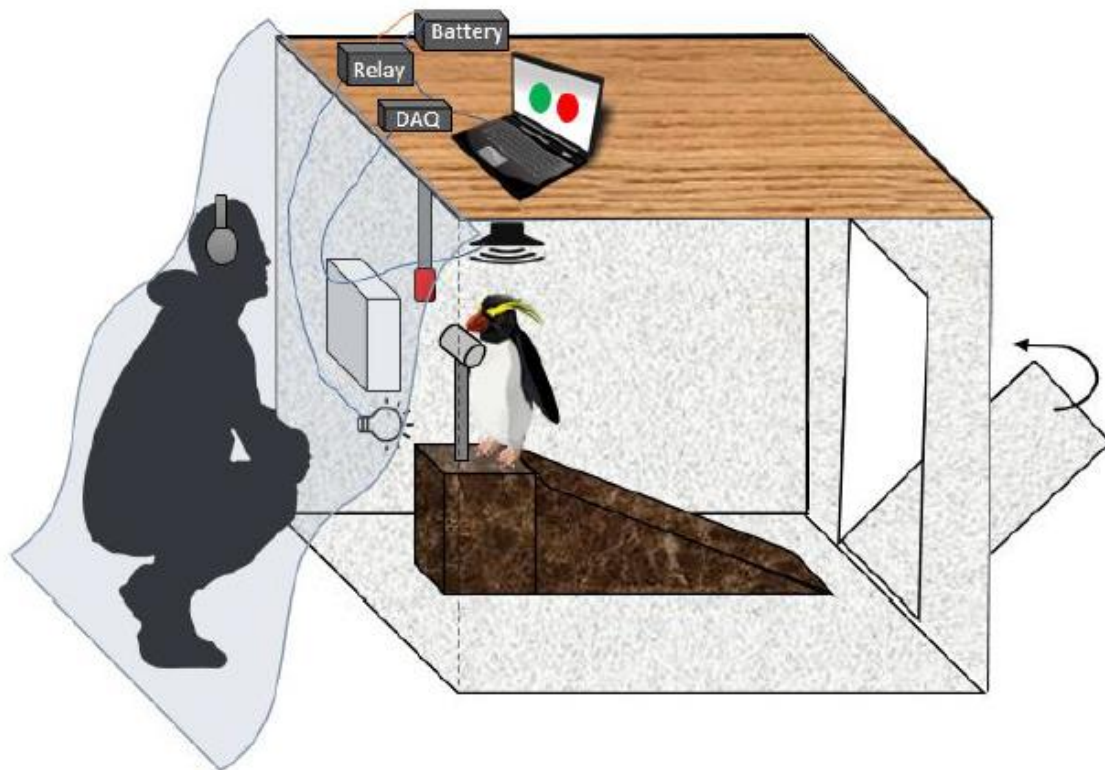


Left: Soundproof box with open back wall for penguin audiometry. Right: Training of a king penguin in the sound chamber at Odense Zoo. Source: own illustration, SDU

2.1.2.3 Northern rockhopper penguins

This work was conducted within the framework of the Master thesis of Malou Friis Vittrup at the SDU (Friis Vittrup 2021). Using the same method as for Humboldt and king penguins, two Northern rockhopper penguins, hatched in 2018, were trained at Odense Zoo from September 2020 to July 2021 (**Figure 8**), as they appeared to be trained more quickly than king penguins. Data collection began in early January 2020 using a constant algorithm method. Three frequencies (1, 2 and 4 kHz) and six stimulus levels were tested during 83 sessions (with a maximum of 26 trials per session). For the frequencies 1 and 4 kHz, the stimulus step size was 6 or 12 dB. For 2 kHz, the step size was 6 or 16 dB.

Figure 8: Training of Northern rockhopper penguins at the Odense Zoo



Experimental setup for the training of Northern rockhopper penguins in an anechoic chamber. During training sessions, the door was closed. Source: own illustration, SDU

2.1.3 Underwater psychoacoustics

It was originally planned to measure underwater audiograms in king penguins at the Odense Zoo/SDU, and in Humboldt penguins at the MSC. However, king penguins were reluctant to dive into their water tank for training. It was therefore decided that the training for underwater psychoacoustic measurements would be conducted exclusively on Humboldt penguins at the MSC. This work was carried out as part of Tabea Lange's PhD thesis at the University of Rostock.

In May 2018, an enclosure was built at the MSC to meet the requirements of Humboldt penguins. All trained penguins were from pairs that successfully raised chicks at the DMM in 2017 or 2018. In July 2018, the first two males were transported from the DMM to the MSC. Two additional male penguins followed in December 2018 (see 2.1.2.1).

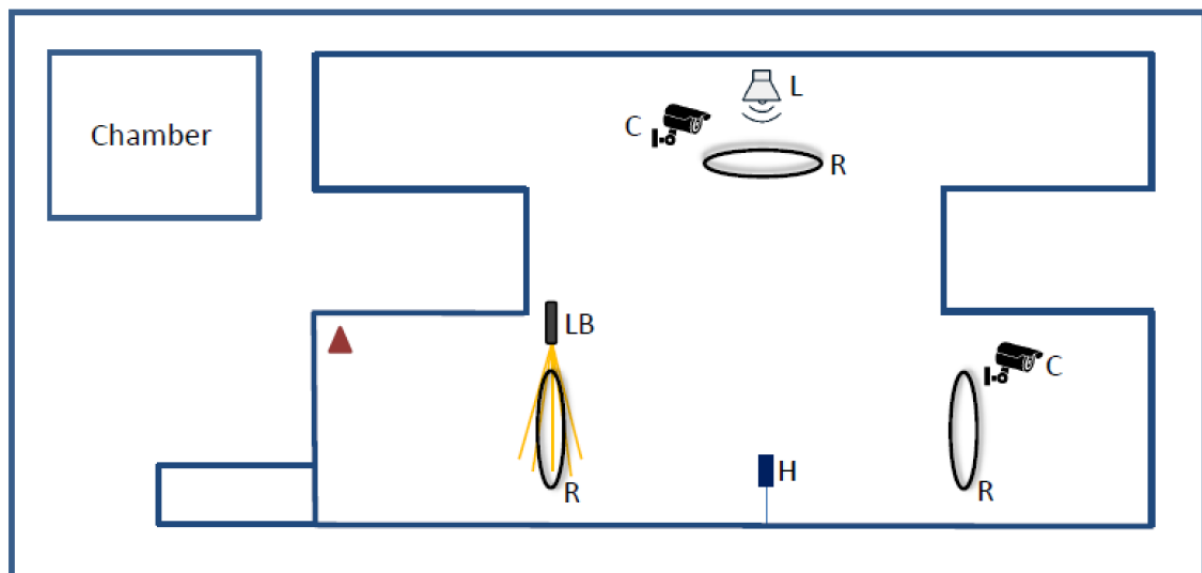
After a three-week acclimation period to the new conditions, the training of penguins started in August 2018 with a schedule of four training sessions per day. Similar to other penguins, the first step was to teach the penguins their respective names in order to work with them individually. Over the next four months (September-December 2018), general commands were introduced for daily handling and for communication needed during training:

- ▶ "Come", in combination with the name, was used to call the animal at the beginning and during a training session.
- ▶ "Target" prompted the animal to touch the beak on a target (*i.e.*, a tool allowing the trainer to station an animal in a specific position, direct it to a new position, or a response to a stimulus).

- ▶ "Wait" was used to ask the animal to wait for an unspecified duration, which was successfully terminated by the reinforcing whistle or a new command. When executed correctly, the animal paused and looked at the trainer. This command could be used, for example, when working on a task during the current session or at the beginning of each trial during an experiment.
- ▶ "Follow" was accompanied by a downward-pointing open palm, which the animal then followed. This could be done on land or in water and allowed the trainer to move the animal to a new location during a training session.

Because of the inability of penguins to remain motionless in one position under water, the experiment was designed as a go/no-go experiment, in which the animal was expected to dive straight through two rings when no stimulus was perceived or to change its swimming direction 90° toward an alternate ring and thus the sound source when a stimulus was perceived. Toward this end, penguins were trained to follow the general command "follow" in water, swimming, and diving through a 0.7 m diameter ring. The latter was the basic step for the experiment in which the animals were asked to dive through rings underwater to guide them to the position where the stimulus was presented (**Figure 9**).

Figure 9: Concept drawing of the experimental setup



The outer blue lines show the dimensions of the enclosure, the inner blue lines those of the water. The red triangle marks the starting position of the animal. The task during a trial was to swim through the first ring with the light barrier, triggering the stimulus. If the stimulus was present, the animal had to make a 90° turn to the left and swim through the ring at the position of the speaker (go response). If the stimulus was not present, the animal had to continue straight ahead (no-go response). R = 0.7 m diameter ring, LB = light barrier, H = hydrophone, C = camera, L = speaker. Source: own illustration, MSC

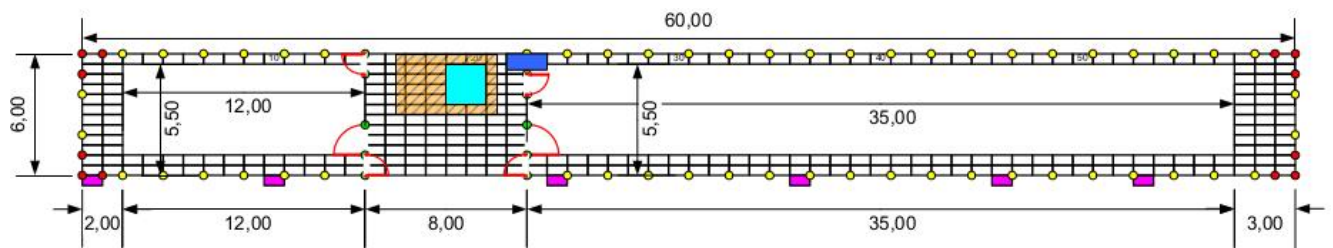
Additional technical equipment necessary for the final training steps, such as adding visual cues, was installed in summer 2019. For example, waterproof LEDs with remote controls were installed underwater to illuminate the correct destination the penguins had to reach. These LEDs were designed to help the penguins learn to change their swimming direction and move toward the transducer when a stimulus was perceived.

Because progress was too slow for two Humboldt penguins being trained for the task, they were excluded from training in early 2019. The other two penguins were further trained to perform

the basic diving task required for the go/no-go procedure of the experiment. They both achieved about half of the required diving task by successfully learning to wait in the water in front of the experimenter before diving to a target when given the "target" command. In addition, both individuals also successfully learnt to return to their start position after the experimenter signaled the completion of the task to receive their reward fish and restart the procedure. Both penguins reliably reached the position of the first ring (which contained the light barrier to trigger the acoustic stimulus in the later data acquisition phase). Due to the moult in summer 2019, training was interrupted for several weeks, as penguins could not stay in and under water during this time due to a lack of waterproofing.

Training resumed in the fall of 2019. For this training, the penguins were separated by keeping the penguin to train in the water and moving the other three animals to the land compartment. However, the three separated penguins showed a strong reluctance to be locked out of the water (presumably because they could not escape back into the water in case of danger). As a result, it was completely impossible to move them out of the water. In addition, the penguins disturbed each other during training sessions. Therefore, a second enclosure with two water access points was designed and construction began in late 2019. This new enclosure was expected to enable one penguin to be trained in one water compartment while the other penguins had access to the second water compartment (**Figure 10**).

Figure 10: Technical drawing of the new penguin enclosure at MSC



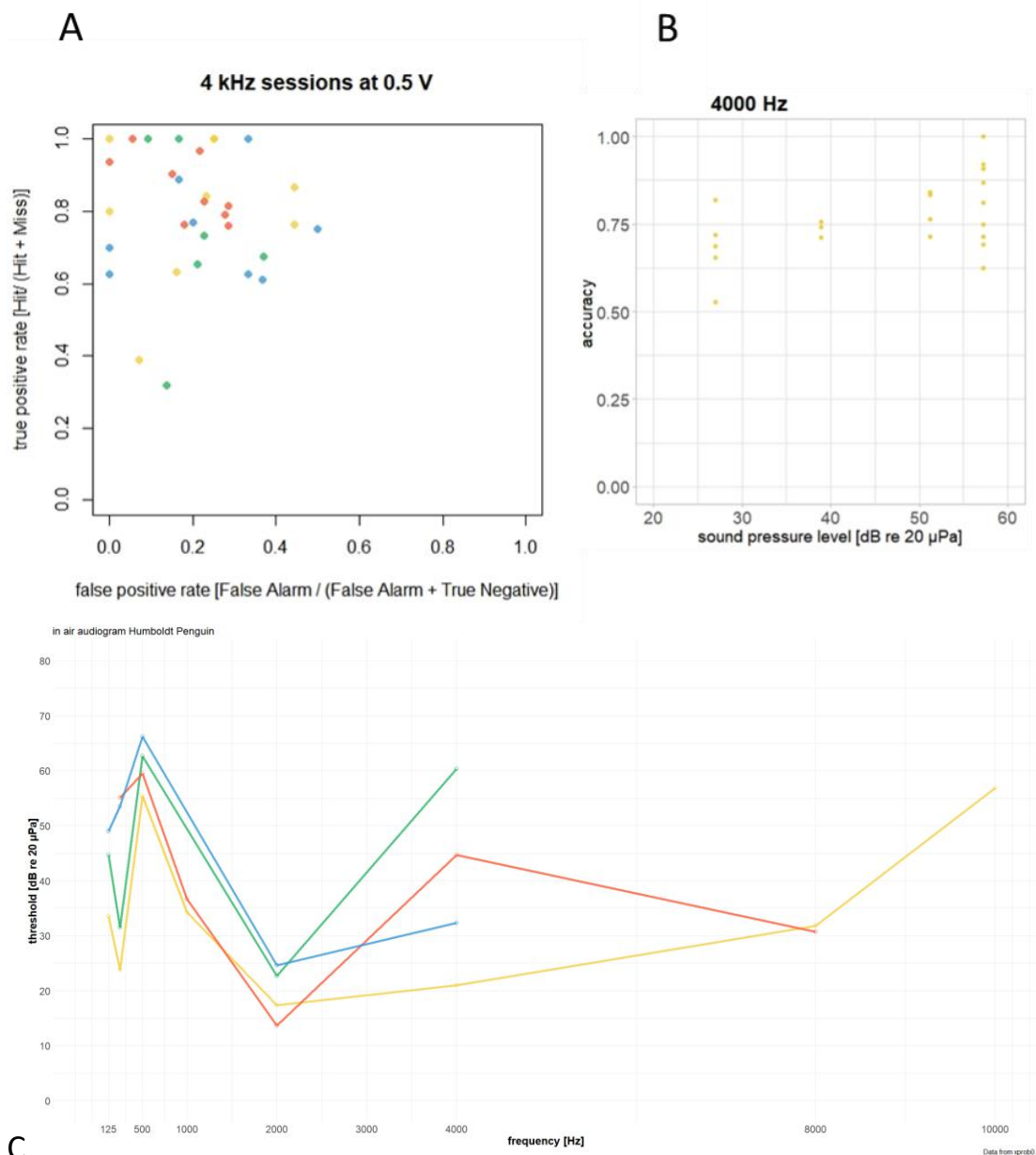
On the left is the gate enclosure, on the right is the experimental enclosure. In between is a land part with a closed shelter (orange) containing a closed quarantine basin (light blue). Rectangles (pink) represent swimmers. Source: own illustration, MSC

Due to serious difficulties that lead to the end of the project at MSC (see 9. below), all training activities at MSC had to be permanently stopped. No underwater audiograms could therefore be measured by psychoacoustic methods during the funding period of the project.

2.2 Psychoacoustic results

Training measurements lasted two years at the DMM before all the raw data necessary to generate audiograms were collected. These audiograms show that Humboldt penguins best hear between 1 and 4 kHz in air (Figure 11C). Hearing sensitivity dropped off towards 500 Hz, but also showed a peculiar increase in sensitivity at lower ranges. This complies with studies such as Wever et al. 1969, but is not substantiated by the ear morphology and therefore needs further work.

Figure 11: Receiver Operating Characteristics (ROC) and Results of the psycho-acoustic methods

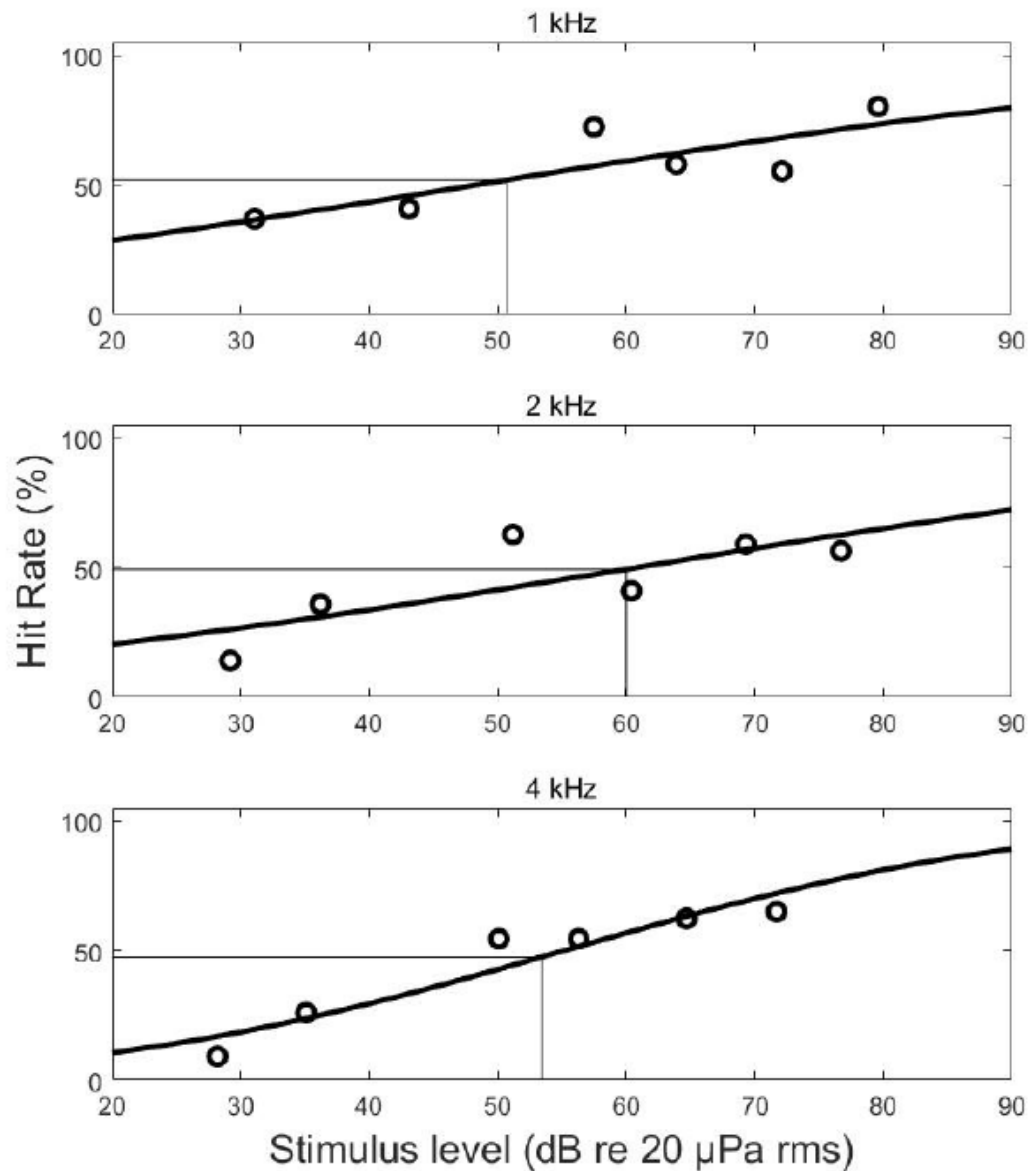


(A) Receiver operating characteristic (ROC) curve for each penguin at an intensity of 0.5 V. Each color represents an individual and each point is a session with the rate of true positives ($= \text{hit} / (\text{hit} + \text{miss})$) plotted against the rate of false positives ($= \text{false alarm} / (\text{false alarm} + \text{true negative})$) at 4 kHz with 57 dB re 20 μPa (sessions were also conducted at 2 kHz with 59 dB re 20 μPa , 1 kHz with 47 dB re 20 μPa , 0.5 kHz with 59 dB re 20 μPa). (B) Accuracy ($= (\text{hit} + \text{true negative}) / ((\text{hit} + \text{miss}) + (\text{true negative} + \text{false alarm}))$) for a penguin at 4 kHz and reducing sound pressure levels (2, 1, and 0.5 kHz were also tested). Each point corresponds to a session with 20 - 80 trials. (C) Preliminary in-air psychoacoustics audiogram for the four Humboldt penguins. The hearing thresholds are derived from signal detection theory, and the coloured lines connect the data points of the individuals with straight lines. Yellow = Frieda (female), Red = Jakob (male), Green = Gustel (female), Blue = Lemmy (male). Not all frequencies could be tested for all individuals. Source: own illustration, DMM

In rockhopper penguins, the average hit rate was calculated for each of the tested frequencies according to the stimulus intensity levels from the weakest signal to the loudest signal. Generally, the louder the signal stimuli the higher the average hit rate. For one of the two trained penguins, it was possible to measure thresholds between the maximum value of hit rate and false alarm: 51.8% at 1 kHz, 49.3% at 2 kHz, and 47.3% at 4 kHz. The resulting thresholds are

50.7, 60.0, and 53.4 dB re 20 μ Pa for 1, 2 and 4 kHz, respectively. The psychometric curve for each of the three frequencies is illustrated for this penguin in **Figure 12**. The other trained penguin was not included in these psychometric analyses due to extremely high false alarm rates, suggesting that this penguin might have needed more training time before the actual acoustic measurements.

Figure 12: Psychometric functions of the in-air hearing of a Northern rockhopper penguin



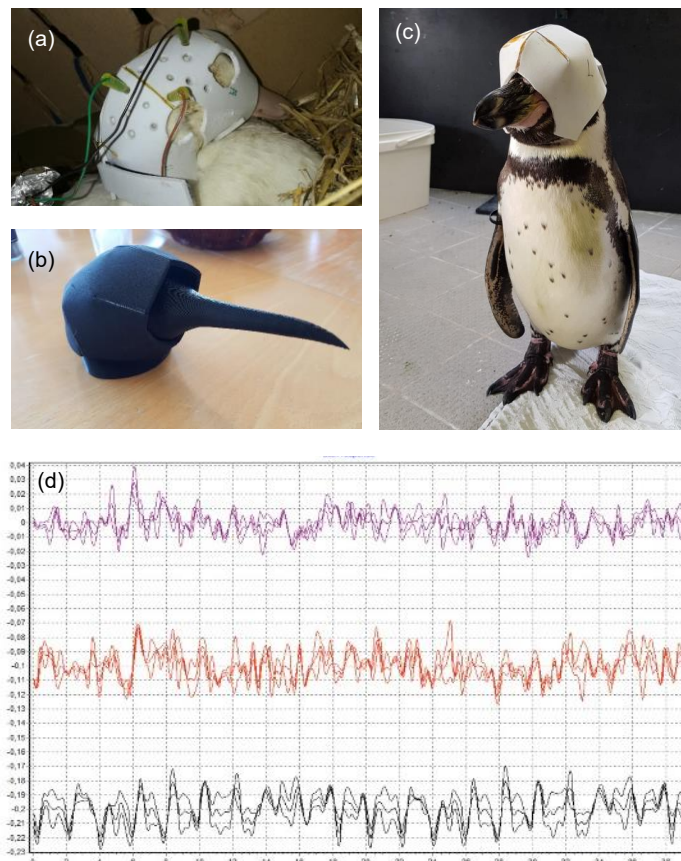
Source: own illustration, SDU

3 AEP measurements conducted in “Hearing in Penguins”

3.1 AEP methods

AEP measurements are more straightforward than psychoacoustic methods, as the monitored animals do not need to be trained. However, AEP measurements require the sedation of the monitored animals, who have to remain still with electrodes implanted under the skin during measurements. This step limits the practicability and the general ethical acceptance of AEP measurements. To circumvent this limitation, an innovative method allowing AEP measurements without sedating birds was developed at the SDU during the course of our project. This novel method relied first on the use of a helmet equipped with electrodes to be worn by awake animals during sound exposure. Indeed, the use of a helmet covering the head of penguins is a standard method to limit stress and keep them calm for several minutes while being handled (Cockrem *et al.* 2008). After its technical development at the SDU, the AEP helmet, equipped with a 16-channel AEP system, was successfully used first on tortoises and then on ducks at the SDU in the fall of 2019 (**Figure 13**). Initial measurements in ducks comparing the established subdermal anesthetic approach with measurements using the AEP helmet looked very promising, as measurements using the helmet were found to be better than measurements using the subdermal electrodes.

Figure 13: Development and use of the AEP-helmet



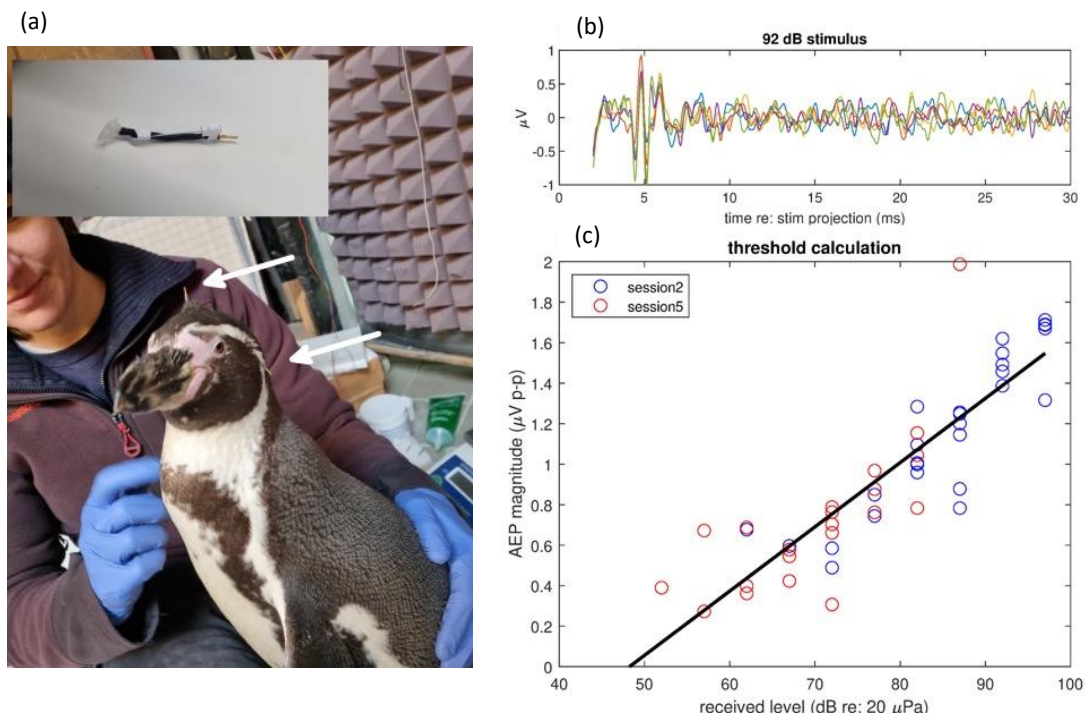
(a) An awake duck wearing the AEP helmet during AEP measurements at the SDU, (b) Actual penguin helmet attached to a 3D-printed head of a king penguin, (c) A Humboldt penguin wearing a training helmet at the DMM, (d) AEP measurements on a duck wearing the AEP helmet at three different exposure levels of 2000 short 2 kHz tone 'pips' (lower black line: Low, Middle orange line: medium, Upper purple line: high). The AEP is visible in the middle and upper lanes at about 3 ms after exposure. Source: own illustration, SDU

At the same time as the AEP helmet was developed and used at the SDU, king penguins at the Odense Zoo and Humboldt penguins at the DMM were trained to wear a dummy helmet for as long as three minutes (in addition to their usual psychoacoustic training; **Figure 13**) to prepare them for the actual AEP measurements. However, king penguins made insufficient training progress so that we concentrated our efforts on Humboldt penguins for further measurements. Even in this species, measurements became challenging, as penguins became agitated when the dummy helmet was equipped with cables, and the helmet design was not robust enough to maintain secure electrodes in contact with the penguins' skin. It was therefore decided to replace the helmet equipped with a novel method based on the use of simple 1.5-2 cm custom electrode leads directly stuck with glue on the skin of the head of penguins. The tips of these electrodes were exposed above the feathers, and thus could be connected and disconnected *via* wires to the main experimental hardware, while maintaining continuous electrode contact to the surface of the skin despite head movements by the animal (**Figure 14**). The electrodes were glued using non-toxic, quick-drying VetBond glue, and could be easily removed at the end of an experimental session. With this method, the first attempt to measure AEP on Humboldt penguins was made at the DMM in March 2022 during which two experimental sessions were successful and provided viable AEP data in response to broadband click stimuli (the only stimulus type that was tested).

3.2 AEP results

AEP responses were observed at stimulus levels between 50 and 100 dB, resulting in an estimated auditory threshold of 48 dB to the click stimulus (**Figure 14**).

Figure 14: Development and use of the AEP-electrodes



(a) An awake Humboldt penguin wearing the AEP electrodes (shown by arrows) at the DMM, (b) example of AEP waveforms elicited by 92 dB click stimuli and recorded via non-invasive electrodes temporarily glued to the unanesthetized penguin (c) plot of the penguin AEP magnitudes versus stimulus received level as recorded using the glued-on electrodes. Data were combined from trials across two separate experimental sessions. The solid black line denotes the linear regression of all point, which was used to estimate an auditory threshold of 48 dB (where the regression line crosses the zero-magnitude level). Source: own illustration, DMM/SDU

These encouraging results show that it is possible to measure AEP in awake penguins with electrodes directly glued on their head skin. However, because of time constraints, we were not able to test different frequencies over the course of the project (thereby precluding the measurement of a full audiogram). Given the reliability of this method coupled with its rapidity, future studies examining the hearing of capacity of penguins should concentrate their efforts on this novel method.

4 Animal Audiogram Database created in the framework of “Hearing in Penguins”

In order to set a reference for the audiograms measured in penguins, an Animal Audiogram Database (<https://animalaudiograms.museumfuernaturkunde.berlin/>) was created by the MfN within the project “Hearing in Penguins”. Towards this end, an expert workshop was first organized as part of the project meeting at the MSC in May 2019 to identify what information was considered essential by internal experts, establish controlled vocabularies, and discuss ways to standardize the visual representation of audiograms for the audiophysiological database. For each study, the parameters entered in the Animal Audiogram Database (AAD) are the following:

- ▶ species name (in Latin, German and English),
- ▶ phylogenetic data (order, family),
- ▶ reference of the study (with DOI when available),
- ▶ number of experimental animals,
- ▶ number of measurements,
- ▶ individual data (sex, name, ID, life stage, age),
- ▶ living conditions (captivity, wild),
- ▶ season,
- ▶ year when measurements were conducted,
- ▶ name of the institution carrying measurements,
- ▶ coordinates of the location where measurements were conducted,
- ▶ position of the animal during measurements (*e.g.*, below the water surface),
- ▶ environment where measurements were conducted (*e.g.*, in a pool),
- ▶ sedation of the studies animals,
- ▶ position of electrodes,
- ▶ background noise,
- ▶ equipment calibration,
- ▶ threshold determination,
- ▶ tone specification (duration, frequency, intensity, form, unit, reference values),
- ▶ procedure (staircase, method of constants).

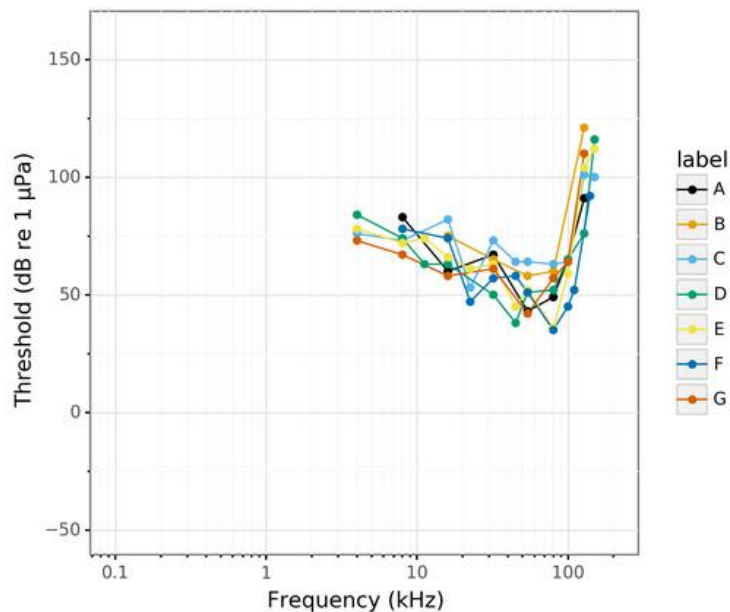
Audiogram representations were prototyped using Jupyter notebooks to allow domain experts to check the product during development. Indeed, this software development method consists in creating a final product (here the AAD) through a series of instalments, each adding a partial functionality until the final product with the full functionality is delivered. The audiogram

database prototypes were discussed and validated by the project team. The validated prototypes were implemented using scientific libraries in R and Python to ensure the highest precision and correctness. The source code of the audiogram database (database schema, frontend module, REST data service) has been released under open-source license (GPL) in MfN's GitHub account.

The AAD allows the visualization of single audiograms as well as the overlay of several audiograms from different individuals to facilitate comparison (**Figure 15**). For each study, the specifications listed above can also be accessed. Finally, a data service allows the data to be downloaded for further analysis.

The AAD went online in September 2020, coinciding with the symposium dedicated to the project during the annual meeting of the German Ornithological Society. The database gathers 235 audiograms that have been measured in 34 aquatic vertebrates (mostly cetaceans and pinnipeds) so far and are available in the scientific literature. The database is designed as a repository for studies measuring and publishing audiograms in any animal species. Towards this end, an online workshop was organized in early 2021 with audiogram experts from around the World to discuss possible suggestions for improvement and requests regarding the database. This workshop encountered a wide interest from the expert community, which offered its help for the future editing of the AAD. Twenty-seven survey participants mostly had a positive impression on the AAD, but still suggested that it should include more audiograms and not be limited to marine vertebrates (thereby showing that the interest for such a database goes beyond the marine environment).

Figure 15: Animal Audiogram Database web front end



#	Species (English name)	Species (Latin name)	Method	Publication
A	Beluga whale	<i>Delphinapterus leucas</i>	Electrophysiological: auditory evoked potentials (AEP)	Castellote et al., 2014
B	Beluga whale	<i>Delphinapterus leucas</i>	Electrophysiological: auditory evoked potentials (AEP)	Castellote et al., 2014
C	Beluga whale	<i>Delphinapterus leucas</i>	Electrophysiological: auditory evoked potentials (AEP)	Castellote et al., 2014
D	Beluga whale	<i>Delphinapterus leucas</i>	Electrophysiological: auditory evoked potentials (AEP)	Castellote et al., 2014
E	Beluga whale	<i>Delphinapterus leucas</i>	Electrophysiological: auditory evoked potentials (AEP)	Castellote et al., 2014
F	Beluga whale	<i>Delphinapterus leucas</i>	Electrophysiological: auditory evoked potentials (AEP)	Castellote et al., 2014
G	Beluga whale	<i>Delphinapterus leucas</i>	Electrophysiological: auditory evoked potentials (AEP)	Castellote et al., 2014

The Animal Audiogram Database web frontend displays the auditory range of several audiograms of a beluga whale and the bibliographic details of the associated publication. Source: own illustration, MfN

To increase the visibility of the AAD, it was presented at the ASA (Acoustic Society of America) Conference "Acoustics Virtually Everywhere" in December 2020, and an article on the AAD was published in the *Journal of the Acoustical Society of America* in early 2022 (Jäckel *et al.* 2022). The article is included at the end of this report in Appendix A.

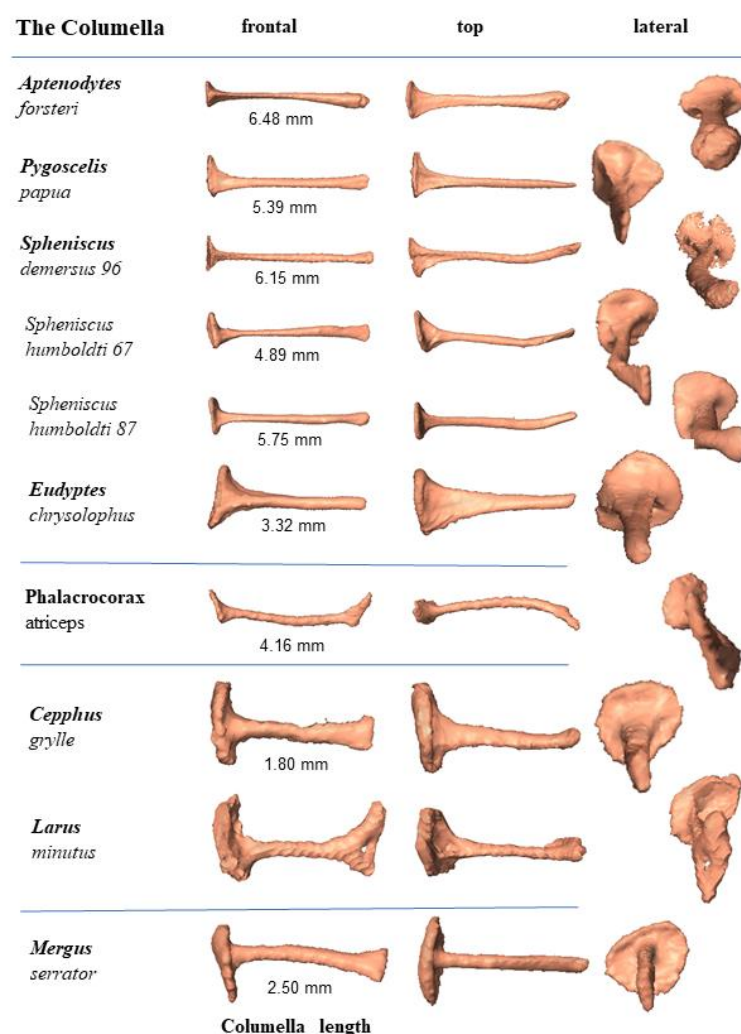
Following the end of the involvement of the MfN in the project in April 2021 (as originally planned), it was decided that the DMM will manage the AAD in the future and the database was then transferred to a DMM server.

5 Further scientific activities conducted in “Hearing in Penguins”

5.1 CT images of the bony structures of penguin ears

As part of a Master's thesis at the University of Rostock (Lindner 2018), the bony structures of the inner and middle ear of penguins were analysed using the CT equipment available at the MfN. Museum specimens of nine different penguin species and waterbird species from three different orders (Suliformes: imperial cormorant; *Phalacrocorax atriceps*, Charadriiformes: black guillemot; *Cepphus grylle*, little gull; *Larus minutus*, Anseriformes: red-breasted merganser; *Mergus serrator*) were examined. The skulls came from the bird collection available at the MfN and to a lesser extent from the DMM.

Figure 16: Columella of different species of penguins and waterbirds



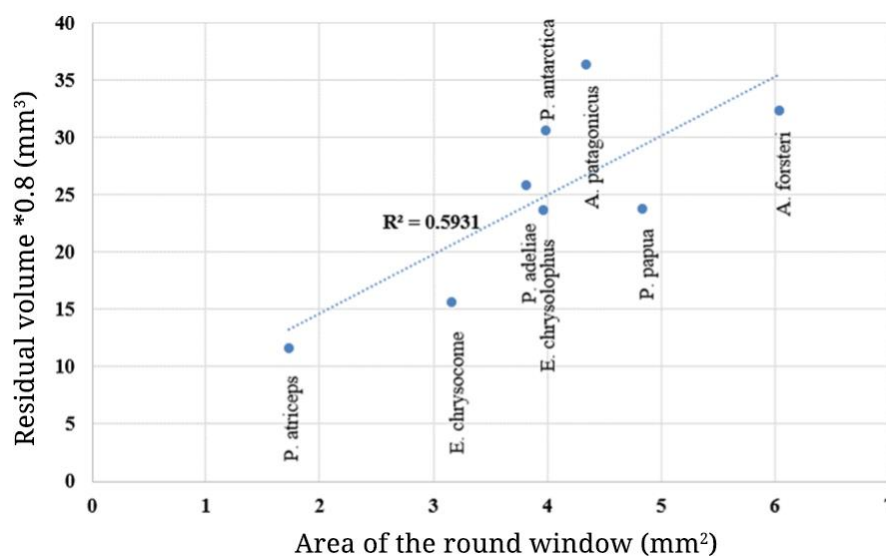
Source: own illustration, DMM (Lindner et al. 2018)

In general, we found that in birds, the columella directs sound from the tympanic membrane through the columella's footplate and oval window to the inner ear, amplifying the signal (Figure 16). The tympanic membrane of diving species such as cormorants is thickened, presumably to maintain its integrity during diving. While the typical ratio in birds is 15-40:1, the

ratio in the penguins studied was 13:1, suggesting that the small size of the eardrum of penguins may represent a protection mechanism against high pressure while diving. These results were further confirmed by a recent study comparing the middle ear of 127 bird species, and that found that, within aquatic bird species, increased dive depth was associated with smaller tympanic membrane-to-footplate area ratios, but also smaller tympanic membrane areas, footplate areas, columella offsets, and larger cochlear aqueduct areas (Zeyl et al. 2022). Moreover, this study also found that, compared to terrestrial birds, aquatic birds show smaller tympanic membrane area, reduced columella offset, tympanic membrane angle and round window area (Zeyl et al. 2022).

Penguins may have a similar pressure equalization mechanism as seals. Indeed, in seals, a cavenous tissue is filled with blood during diving, so that the cavity of the middle ear is reduced while under water. For the ear to function properly, an air bubble must still remain at the round window, which can then buffer pressure fluctuations from the inner ear. The size of this air bubble, called the residual volume, was calculated for penguins using CT scans. It was found that the residual volume is proportional to the surface area of the round window (Figure 17). Although this relationship may only reflect an allometric relationship between the size of ear structures (Peacock et al. 2020; Zeyl et al. 2022), it also suggest that the hearing ability of penguins can be preserved during diving.

Figure 17: Residual volume and area of the round window of different penguin species



Source: own illustration, MfN

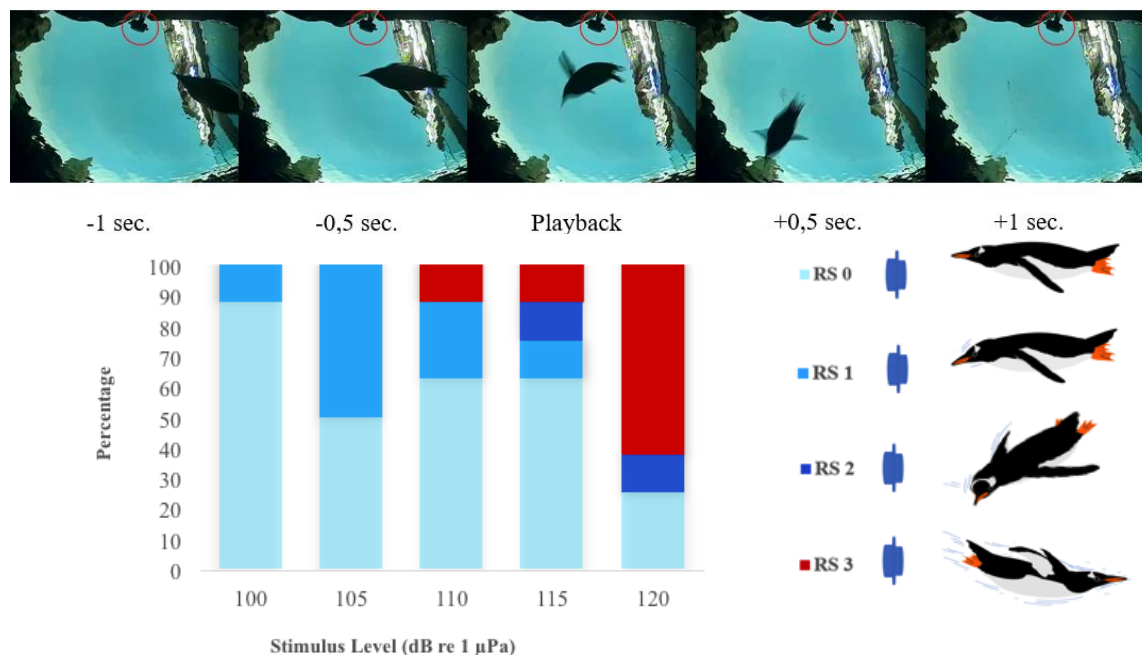
In addition to the examination of the bony structures of the inner ear of penguins, three specimens (*Aptenodytes forsteri*, *Spheniscus demersus*, *Pygoscelis papua*) were stained to visualize soft tissues. The scans of *A. forsteri* and *S. demersus* were used to reconstruct the internal auditory organs using specialized software. Videos of the 3D models showing the auditory organs were created from the scans and were published online as freely available data publications under a free license for scientific and non-scientific reuse ([Visualisation of the auditory system of *Spheniscus demersus*](https://doi.naturkundemuseum.berlin/data/10.7479/qaj0-1a29); <https://doi.naturkundemuseum.berlin/data/10.7479/qaj0-1a29>, [Visualisation of the auditory system of *Aptenodytes forsteri*](https://doi.naturkundemuseum.berlin/data/10.7479/qaj0-1a29)). The individual scans were published as data publications at the end of the project. Additional explanations of the inner ear structures have been added with an audiotrack.

An article about the results of CT scans was published in the open-access journal *Proceedings of Meetings on Acoustics* in August 2020 (Frahner *et al.* 2020). The article is included at the end of this report in Appendix A.

5.2 Underwater-playback experiment in Gentoo penguins

In the fall of 2018, an underwater playback experiment on gentoo penguins (*Pygoscelis papua*) was conducted at the SDU, as part of Kenneth Sørensen's PhD thesis. Toward this end, white noise bursts (0.2-6 kHz; 500 ms; reception level varying between 100 and 120 dB re 1 μ Pa in 5-dB increments) were played when penguins were under water in the vicinity of the loudspeaker. No behavioural response was observed to the lower intensity sounds, while strong startle responses were observed at the highest sound levels. This clearly shows that Gentoo penguins can hear sounds underwater and suggests that they may also perceive their direction (**Figure 18**). This was the first evidence that penguins actually perceive sounds underwater. An article on these results was published in the open access journal *Royal Society Open Science* in February 2020 (Sørensen *et al.* 2020). The article is included at the end of this report in Appendix A.

Figure 18: Main results of the underwater-playback experiment



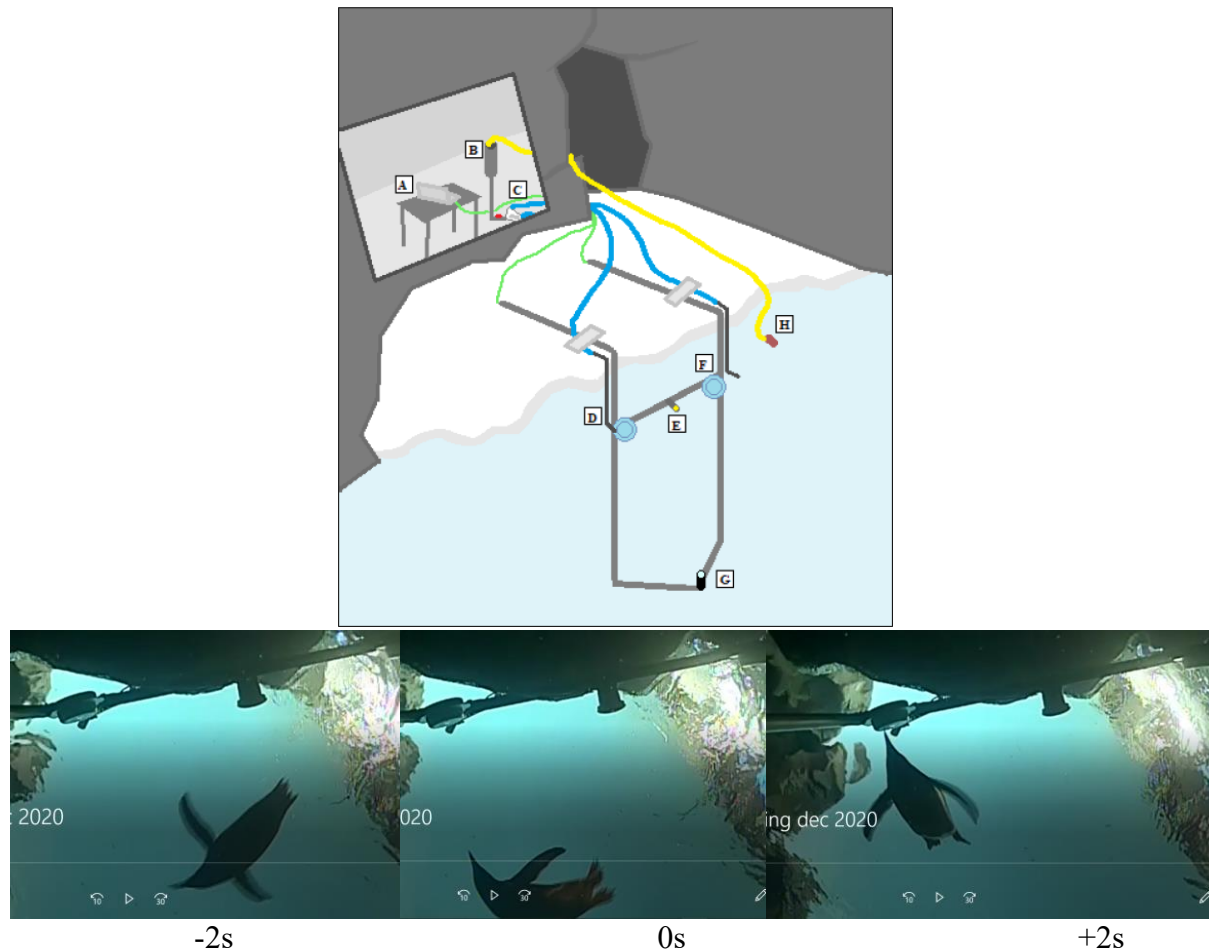
Top: Photo sequence with photos at 0.5 s intervals, taken from the bottom of the pool with an upward-facing camera. The sound source is marked with a red ring. A gentoo penguin passes the speaker and responds immediately after the playback by swimming away from the source. Bottom: Percentage of playbacks of different stimulus levels eliciting different responses in donkey penguins swimming past, from RS0 (no response) to RS3 (strong aversive response, like the one shown above). Source: own illustration, SDU

5.3 Underwater sound conditioning in Gentoo penguins

This work was conducted within the framework of the Master thesis of Maria Skov Rasmussen at the SDU. In February 2019, an experiment was initiated to link underwater sound stimuli with a reward in gentoo penguins at the Odense Zoo. The goal was to examine whether penguins can be conditioned to indicate if they hear a sound by swimming to a location where the reward is given. The experimental setup (**Figure 19**) consisted of a PVC rig with an underwater trial light, a fish flush, a loudspeaker and an underwater camera directed upwards towards the

loudspeaker and fish flush terminal. A laptop equipped with LabView was connected to the loudspeaker via an amplifier to administer the sound stimulus. The laptop was also connected via a video capturing device to an underwater camera. The fish flush consisted of a water reservoir, a valve, a plastic hose and a PVC pipe ending right above the loudspeaker (**Figure 19**).

Figure 19: Visualization of the underwater sound conditioning experiment in Gentoo penguins



Upper panel: A: Laptop, B: PVC pipe cannister for water flush, C: Manual valve, D: Hose and PVC pipe for flushing fish, E: Trial light, F: Loudspeaker, G: Underwater camera, H: Bilge pump. Only the left speaker and fish flushing hose were used. Lower panel: Penguin before, during and after playing a signal from the loudspeaker, which can be seen in the left corner of the pictures. The outlet of the fish flush is barely visible above the speaker. The lamp indicating to the penguin that a trial is in progress is also visible. Source: own illustration, SDU

Between trials, the water reservoir was filled using a bilge pump, connected to the reservoir via another hose. The operator was positioned behind a wall, out of sight of the penguins, and used a custom-made LabVIEW program and video software on a laptop computer to administer sound emissions, fish flushing and refilling the water reservoir. The trial light was turned on at the start of each session and turned off when the session ended, to indicate to the penguins that an experiment was ongoing. During a session (25-60 minutes), the experimenter observed the penguins in the water using the underwater video camera to choose the right time to play the sound stimulus. When two seconds had passed after a sound stimulus had been played out, an indicator lamp was lit on the computer screen, indicating for the experimenter to flush the fish. After each trial, the valve was closed, the reservoir was filled, and the system was charged with a fish to be ready for the next trial. Using this approach, the penguins were conditioned to the

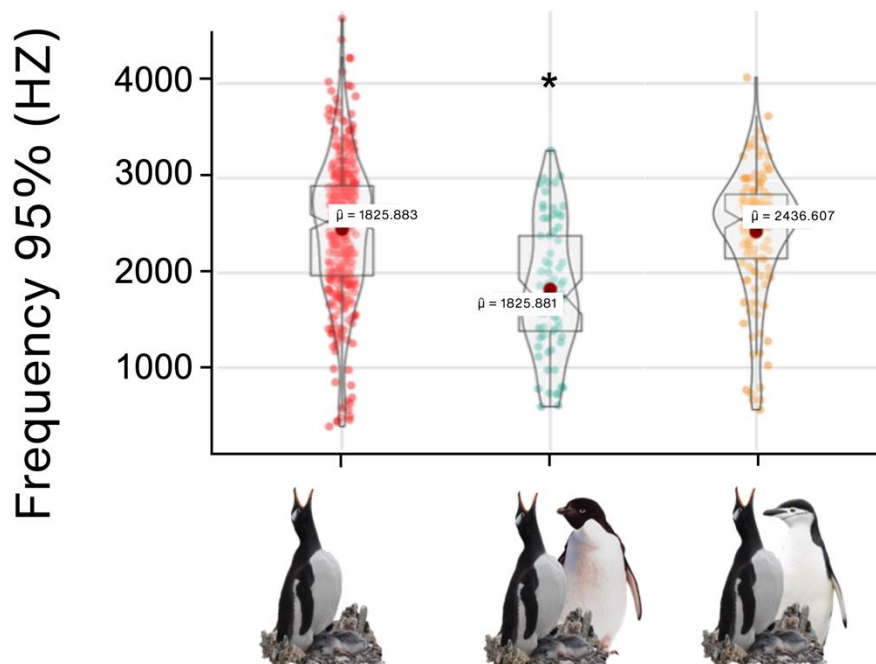
sound stimulus between December 2020 and March 2021 (*i.e.*, 1000 trials distributed over > 50 sessions) before data collection. During data collection, each session consisted of 35 sound trials and 3-7 control trials randomly intermixed within each session, during which the reaction of penguins was examined after sound was played (or not in the case of control trials). Out of 230 sound trials and 43 control trials selected for analysis, it was found that the proportion of penguins reacting during sound trials (*i.e.*, approaching the loudspeaker; 78%) was significantly higher than that during control trials (0%), thereby suggesting that penguins can utilize underwater sound cues and associate them with food resources. This opens the possibility that diving penguins can locate their prey underwater based on the sound they perceive from their prey. The results of this study were published in the open-access journal *Biology Open* in 2022.

5.4 Sound recording in Antarctica

Two field studies on the vocalizations of *Pygoscelis* penguins were conducted in Antarctica in collaboration with the project “Hearing in Penguins” because of their acoustic aspects.

During the austral summers 2018-19 and 2019-2020, members of the project took part in expeditions along the Antarctic Peninsula as visiting scientists during two tourist trips aboard Quixote Expeditions' sailing vessel “Ocean Tramp”. During these two expeditions, the vocalizations of gentoo penguins were recorded in various colonies and were subsequently analyzed at the DMM. The main finding of these analyses is that Gentoo penguins appear to adjust the acoustic properties of their vocalizations by reducing their frequency in response to the presence of Adélie penguins (*P. adeliae*) sympatrically breeding in the same colonies (**Figure 20**). This strategy likely reduces vocal overlap between the two species, allowing for better intraspecific vocal recognition. An article on these results has been published in the journal *Auk* in 2022 (Appendix A, Rößler et al. 2022). Another goal of these trips was to record underwater sounds that were subsequently used for the underwater sound mixer.

Figure 20: Frequency of the vocalizations of Gentoo penguins



Frequency of vocalizations of Gentoo penguins breeding alone (left), with Adélie penguins (middle), or with chinstrap penguins (right). Source: own illustration, DMM

During the austral summer 2019-2020, fieldwork was also conducted at the Dumont d'Urville Polar Station (Adélie Land) to conduct sound recordings thanks to a collaboration with the Chizé Center for Biological Studies (CNRS, France) and the French Polar Institute Paul Emile Victor. The main purpose was to investigate the interplay between nest vocalizations (recorded with sound recorders placed close to penguins' nests across the whole breeding season) and foraging strategies at sea (as assessed through the use of GPS device recording the trajectories of penguins during several consecutive foraging trips) in Adélie penguins. This study revealed significant relationships between some acoustic characteristics of the vocalizations produced by penguins on their nest and some characteristics of their foraging trajectories at sea, suggesting that nest vocalizations may influence foraging strategies in this species. For instance, the frequency of the vocalizations produced by partners on their nest before the departure of males to forage was found to be significantly related to the sinuosity of the foraging trip the males will subsequently do at sea. This relationship was not found in females, suggesting that males may be more sensitive to nest vocalizations than females. Part of these results were used for the Bachelor thesis of Jane Köpp at the University of Greifswald, and an article on these results was published in *Animal Behaviour* in 2021 (Beaulieu *et al.* 2021). Another goal of this fieldwork was to assess the feasibility of conducting AEP measurements on free-living Adélie penguins at Dumont d'Urville in the future.

6 Environmental education and communication conducted by “Hearing in Penguins”

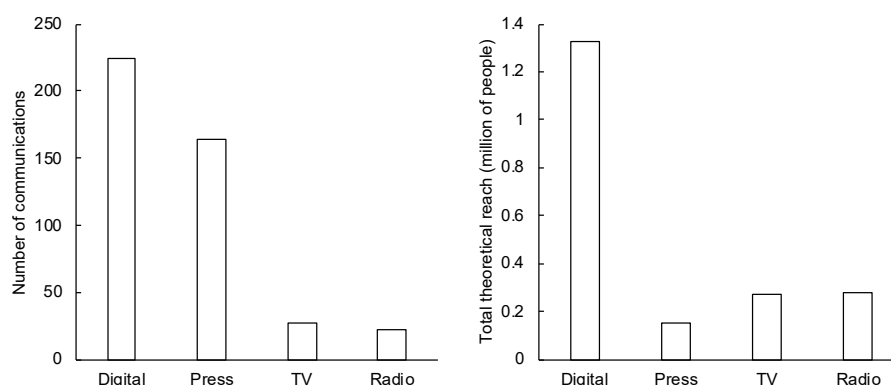
In parallel to the scientific approaches used in the project “Hearing in Penguins”, a great effort was made to communicate about the project itself and about underwater noise pollution more generally. Toward this end, a great variety of approaches was used by both the MfN and the DMM between May 2018 and April 2021. This communication strategy made the project and the topic “underwater noise” highly visible to both the scientific community and the general public. The goal was to raise awareness of the following topics:

- ▶ Diversity of natural underwater sounds
- ▶ Biological functions of sounds for underwater organisms.
- ▶ Perception of sounds by underwater organisms.
- ▶ Diversity of underwater sounds of anthropogenic origin
- ▶ Impact of anthropogenic sounds on biological processes
- ▶ Political, technical, and individual approaches to mitigate artificial underwater noise.

6.1 Communication with media

In close coordination with the press and public relations department at the DMM, potential media partners were identified and contacted. Between January 2018 and April 2021 (*i.e.*, end of the communication strategy of the project), media communicated approximately 450 times about the project reaching a total theoretical reach of more than 150 million people. The project was mostly communicated online but also in the press (*e.g.*, *die Zeit*, *die Welt*), on television (*e.g.*, NDR, Arte) and on the radio (*e.g.*, Deutschlandfunk Kultur, WDR; **Figure 21**). In Denmark, the project was also communicated both in national radio and TV as well as on Odense Zoo’s Facebook page.

Figure 21: Communication distribution among media categories

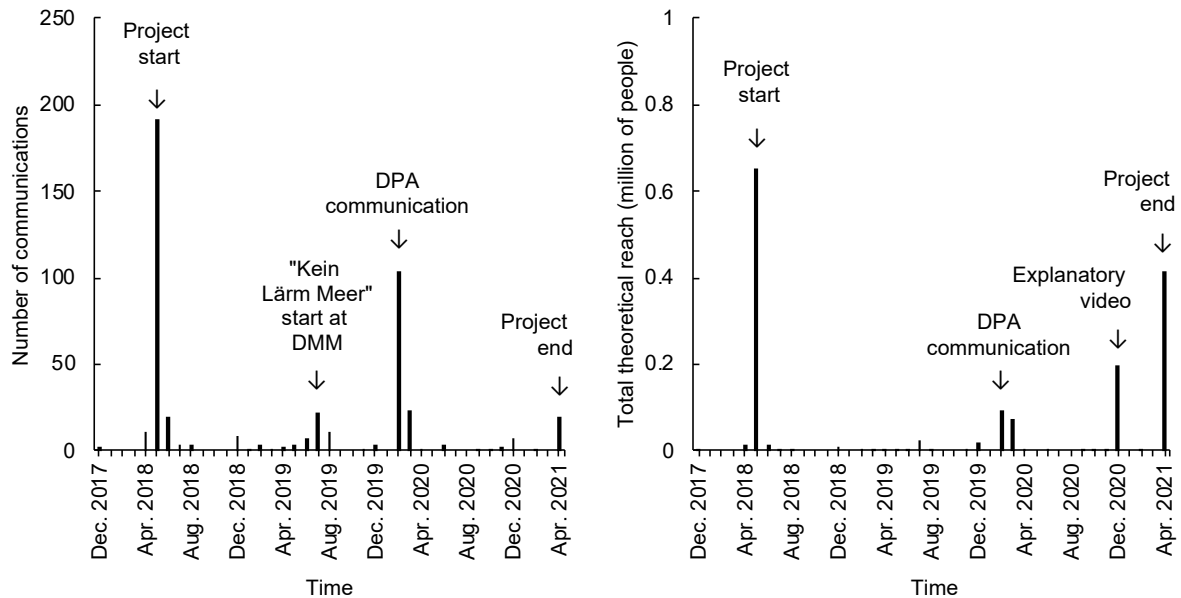


Left panel: Representation of the number of communications per media category. Right panel: Representation of the total theoretical reach per media category. Source: own illustration, DMM

Media mostly communicated about the project when it was officially launched in May 2018, following a communication by the Deutsche Presse Agentur (DPA), following the start of the communication topic “Kein Lärm Meer” at the DMM, and at the end of the communication strategy of the project in April 2021 when different events were organized (see. 6.2, 6.3, 6.4

below). The publication of the explanatory video online (see below) was also associated with a substantial increased theoretical reach (**Figure 22**).

Figure 22: Communication temporal variation



Left panel: temporal variation in the number of communications made each month. Right panel: temporal variation in the monthly theoretical reach. Project end refers to the originally-planned end of the project (April 2021). Source: own illustration, DMM

6.2 Public events

For the World Penguin Day (April 25) in 2019, an action booth on the penguin terrace of the Ozeaneum (DMM) provided information about the project, underwater noise and penguins in general. On August 31st, 2019, the "Long Night of Museums" took place at the MfN where a booth was installed to present the project and the results of the CT-scans. In addition, the 3D models and the corresponding penguin vocalizations from the animal voice archive were presented. A total of 10,500 visitors came to the MfN, making it the most visited place in Berlin during this event. The booth was busy throughout the night and was visited by about 500 people interested in the project and underwater noise pollution. In September 2019, an information booth was also installed at the Ozeaneum for the "Long Night of Museums", which was visited by 2800 visitors.

At the DMM, commented training sessions were conducted for 228 visitors during the 2019 "Family Summer". Since July 2019, a showcase on the project has been installed in the "World Oceans" exhibition room of the Ozeaneum, showing an edited video of the soft tissue scan of the ear of emperor penguins.

As part of the regular evening lectures in the choir of the Katharinenhalle at the DMM, a popular science lecture was given about the Antarctic expeditions conducted in the framework of the project "Hearing in Penguins" (see 4.4 above). With more than 100 guests, this was not only one of the lectures with the highest attendance but it was also accompanied journalistically by the TV broadcaster "Stralsund TV" (FaS).

6.3 Panel discussion

A panel discussion was originally planned in April 2020 as part of the "Week against Noise in the Ocean". Due to the coronavirus pandemic, the event could not take place and the action week was postponed by one year and took place in April 2021 in a digital format instead. For the panel discussion on April 27th, 2021, the following experts were invited:

- ▶ Dr. Lilian Busse (German Environment Agency, UBA),
- ▶ Nadja Ziebarth (German Federation for the Environment and Nature Conservation, BUND),
- ▶ Dr. Dietrich Wittekind (DW-ShipConsult),
- ▶ Steffi Lemke MdB (Bündnis 90/Die Grünen),
- ▶ Prof. Antje Boetius (Alfred-Wegener Institute, AWI).

The panel discussed questions and possible solutions to the issue of underwater noise. The discussion was digitally broadcast and was open to the general public. Thirty-two participants attended this online event.

6.4 Scientific closing conference

Because of the pandemic situation in early 2021, it was decided to hold the closing meeting of the project "Hearing in Penguins" online instead of in presence as originally planned. The closing meeting was part of the "Week against Noise in the Ocean" and was held over two days. The first day was dedicated to the general presentation of the project and to the notion of audiograms. In this context, we presented the work we conducted to gather already-published audiograms and to collect new data during and after the project. Our presentations on audiograms were complemented by a talk by Dr. Aran Mooney (Woods Hole Oceanographic Institution, USA) working on the hearing capacity of Alcids. On the second day, we broadened the scope of our meeting by considering underwater noise in Antarctica (talk given by Prof. Christine Erbe, Curtin University, Australia) and by presenting complementary approaches to examine the hearing capacity of penguins (examination of the ear morphology of penguins and of their behavioural reaction in response to sound exposure). Our presentations on the behaviour of penguins were complemented by a talk by Dr. Andrea Thiebault (Université Paris-Saclay, France), who presented the effects of seismic activities on the foraging behaviour of free-ranging African penguins, and by a talk by Prof. Boris Culik (Christian-Albrechts Universität Kiel) on the potential use of acoustic methods to reduce the bycatch of penguins. All the talks given by external speakers strongly enriched the content of the meeting. The holding of the closing meeting was communicated to different mailings lists (Deutsche Ornithologische Gesellschaft, International Penguin Conference) and was therefore open to external participants. About 35 participants (fluctuating between 32 and 37) attended the meeting.

6.5 Digital media

6.5.1 Social media

In May 2019, an Instagram account about the project (@hearing_in_penguins) where news about the project were regularly posted. Likewise, Kenneth Sørensen (SDU) created his own Instagram account about his PhD project (@hearing_in_penguins_sdu). Fifty and 84 articles were posted on both Instagram accounts, respectively. Since the creation of the two Instagram accounts, the number of followers increased steadily (Apr. 2021, N = 312 and 305, respectively). Because of

the termination of the communication actions for the project in April 2021, the Instagram account related to the project was deleted at the end of July 2021.

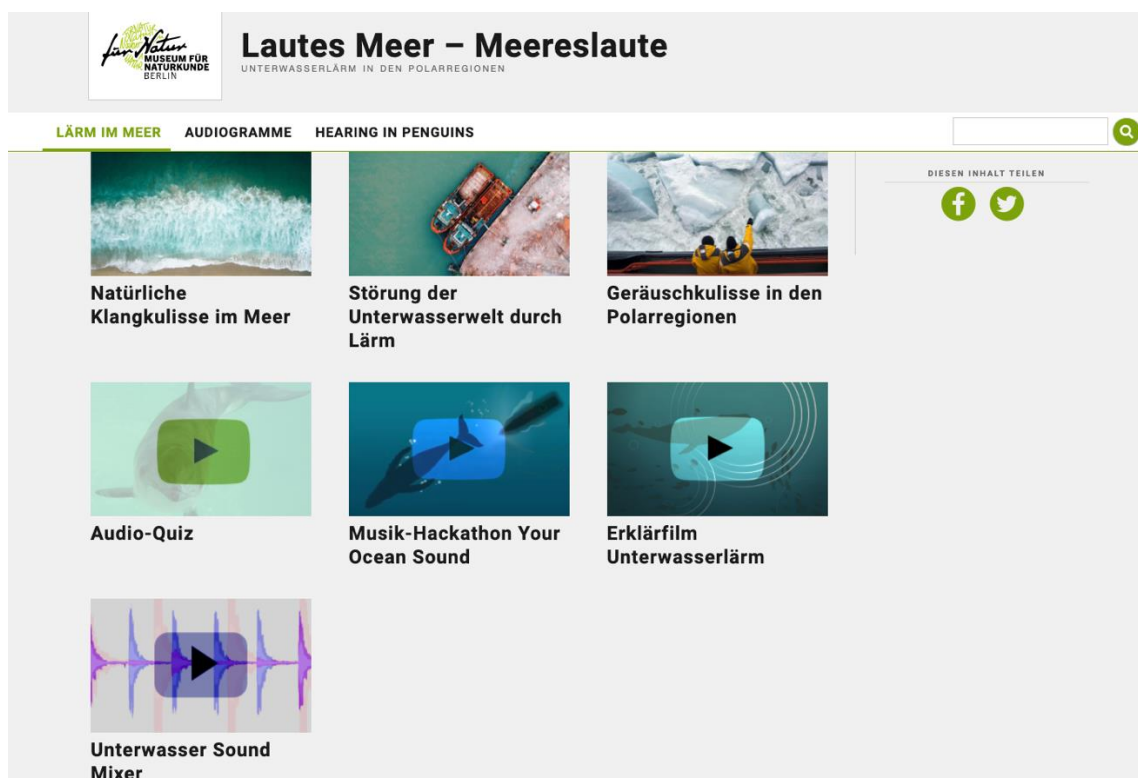
In addition, the social media channels (Instagram, Twitter, Facebook) of the MfN (with a total of 50,000 followers) and of the DMM (with around 14,000 followers) were primarily used to inform about the project and to disseminate content. Social media campaigns were conducted on various occasions: World Penguin Day (April 2019, 2020, 2021), World Oceans Day (June 2019), release of making-of video (September 2019), Antarctic Treaty Anniversary (December 2019), World Penguin Day (April 2020), release of audiogram database (September 2020), release of explainer video (December 2020), release of podcast (March 2021), Week Against Noise in the Ocean (April 2021).

6.5.2 Information platform

Due to a cyber attack on the MfN website on 20 February 2024, access to the project pages is not possible at the time of publication. The pages will be successively put back into operation.

The MfN developed the concept for an information platform on underwater noise pollution (see Table 4 below). The general structure and content were determined in coordination with the DMM. The information platform was launched online in April 2020 on the occasion of the “International Noise Awareness Day” (see [Lautes Meer-Meereslaute](https://unterwasserlaerm.museumfuernaturkunde.berlin/); <https://unterwasserlaerm.museumfuernaturkunde.berlin/>; **Figure 23**). The platform includes informative background on underwater noise, an audio quiz with underwater sounds, an underwater sound mixer (see below), a link to the video on underwater noise pollution (see below), and information about the project including a blog with 20 articles about the project. The online version of the audio quiz was released on April 28th, 2020. A stand-alone (offline) version of the quiz was made available and successfully installed by DMM in August 2020.

Figure 23: Homepage of the online information platform on underwater noise pollution



Source: own illustration, MfN (<https://unterwasserlaerm.museumfuernaturkunde.berlin/>)

To create an explanatory video about underwater noise pollution, the film company "Panda Pictures" was selected and commissioned. The three-minute video was released in German and English. It was promoted on UBA's and DMM's social media channels. Between December 2020 and April 2021, the video had been viewed 788 times in German and 578 times in English.

The underwater sound mixer was developed for the visual and acoustic representation of the noises experienced by marine animals, enabling the public to experience underwater soundscapes and noise pollution from the perspective of marine animals. The mixer contains the underwater vocalizations of 10 selected marine species (whales and Antarctic seals), and overlays with 11 anthropogenic noise sources (*e.g.*, motorboats at different distances, pile driving, airguns). The acoustic results can then be heard in the way humans or marine animals hear the sounds. Sounds were selected among 130 recordings based on their quality and license agreement. The corresponding metadata was also available in varying degrees of detail, although the exact distance to the sound source was rarely known. Another selection criterion was the pre-knowledge of the animals' hearing curve, so that the hearing ability of the species could be approximated by hearing physiology modeling.

6.5.3 Sonic Chair

6.5.3.1 Timeline

The Sonic Chair was created under the direction of the DMM. The MfN and UBA were also involved in the creation and realization. Over the first 8 months (April – December 2020), the planning, tendering, and commissioning of an agency took place. The company "wir machen bunt" (<https://wirmachenbunt.de/>) was selected and commissioned to develop new concepts and designs. Then, over the following 8 months (January – August 2021), the rough concept was created and the main content, accessible for all users of the Sonic Chair through an interactive touch screen, was developed and programmed. Additional content providing more detailed information was also designed for experts (expert level) and implemented within three months (September – November 2021). An interactive interface, accessible on a touch screen when sat in the Sonic Chair (**Fig. 24**), was also developed for users to switch between different contents. The final completion took place from October to December 2021. For the launch of the Sonic Chair in spring 2022, a teaser (<https://www.youtube.com/watch?v=zS5phfPq4CE>) was created that presents the location at the DMM as well as at the UBA in Dessau. Since its completion, the Sonic Chair has already been presented at several national and international meetings (*e.g.*, museum4punkt0 conference, Stralsund (April 2022); 44th Antarctic Treaty Consultative Meeting (ATCM), Berlin (April-May 2022); Ocean Future Day, Stralsund (May 2022); Baltic Sea Day, Rostock (June 2022)) and received much recognition and praise.

6.5.3.2 Content

In the Sonic Chair, the sea soundscape can be heard, seen and felt in an unprecedented way. To create this holistic experience for users, the sound membrane in the back transmits the vibrations directly to the visitors. The main content include 9 levels (1 - Oceanic soundscapes are as diverse as those on land; 2 - Sound travels faster in water than it does in air; 3 - Marine animals make and receive various sounds; 4 - Humans cause more and more noise in all oceans; 5 - Sound interferences cause harm to animals; 6 - During the last ten years, noise in the sea has doubled; 7 - Oceans require political measures and technical solutions; 8 - "Your Ocean Sound" Soundscapes Remixed; 9 - Credits) between which users can switch using the interactive touch screen. Thus, not only the deep songs of blue whales or the buzzing sounds of crabs and fish can be experienced in the Sonic Chair, but also man-made noises, while at the end of their sound journey, visitors can relax and listen to the winning entries of the international art competition

"Your Ocean Sound" (see 6.5.6 below). Finally, for seven levels of the main content, it is possible for users to have access to expert information (1 - Coral reef blues; 2 - Long-range communication; 3 - Songs travel around the world; 4: Silence up there!; 5 – Cacophony at sea; 6 – Noise level red; 7 - Noise protection for the seas). The Sonic Chair therefore represents a rich and diversified acoustic experience to all kind of users (from those just willing to relax to demanding ones willing to increase their knowledge).

Figure 24: Visualization of the Sonic Chair



Source: own illustration, DMM/wirmachenbunt

6.5.4 Making-of video

A making-of video (<https://www.youtube.com/watch?v=ecRbS0KLi3o>) about the project focusing on the CT scans was completed in August 2019. This accompanying video highlights the scientific process at MfN and provides a brief overview of the project and the educational aspects of training the penguins at DMM. Short sequences of the 3D models and images from the accompanying video were used for social media campaigns for the World Penguin Day (April 2019) and the World Oceans Day (June 2019), reaching a total of more than 17,000 people via MfN's social media channels (Twitter, Instagram, Facebook). To advertise the video, a social media campaign was conducted in September 2019 to promote the first results of the project (3D models) and the special exhibition "Kein Lärm Meer" at the DMM. In total, this video has reached 40,000 people through MfN social media channels so far (20,000 through Twitter, 12,000 through Facebook, 8,000 through Instagram) and more than 4,000 people have viewed this video (MfN social media channels combined, as of February, 2021). UBA promoted the 3D models and associated video on its Twitter channel, reaching more than 14,000 additional people (as of September 26, 2019).

6.5.5 Online talks & podcasts

To promote the new information platform, we organized two online lectures by M. Dähne (DMM) and S. Frahnert (MfN) on the occasion of the World Penguin Day (April 25, 2020) and the Day Against Noise (April 29, 2020) and organized an online campaign on MfN's social media

channels (total reach: 75,000 people). Other presentations (panel discussion, closing meeting) were also presented online for the "Week against Noise in the Ocean" at the end of April 2021.

Cora Albrecht (environmental educator of the project) recorded a podcast in the series "Beats & Bones", which is produced by MfN and was published in February 2021. In addition, she recorded two episodes of the podcast "Sweet or Dinosaur," which is addressed to children.

6.5.6 Music hackathon

A music hackathon, entitled "Your Ocean Sound", was organized and launched in March 2021. Audio recordings of underwater sounds (biotic, abiotic, and anthropogenic) collected at MfN over the course of the project were made available through MfN's data portal (as allowed by the licenses of the recordings). Participants in the hackathon were asked to use these recordings to create their own samples that included underwater sounds. In total, 28 music compositions were submitted. The jury was composed of renowned musicians and bio-acousticians. The best three submissions were awarded during an online event at the beginning of the "Week against Noise in the Ocean" in April 2021. This event gathered online 61 participants. The first winner was awarded € 500 for the composition "Penguin Dive", the second € 300 for the composition "Under Water", and the third € 200 for the composition "Singing Ice". These compositions can be heard here (<https://unterwasserlaerm.museumfuernaturkunde.berlin/projekt-hearing-in-penguins/blog/gewinner-des-musik-hackathons-your-ocean-sound>) and are part of the sounds the public can hear in the Sonic Chair.

6.5.7 Meetings, conferences and publications

The project was presented in the following scientific conferences:

- ▶ "The Effect of Aquatic Noise" The Hague, Netherlands, July 2019 (two oral presentations),
- ▶ "10th International Penguin Conference" Dunedin, New Zealand, August 2019 (one oral presentation, one poster),
- ▶ "International Conference on Acoustics", Aachen, Germany, September 2019 (one oral presentation),
- ▶ "Meeting of the German Ornithological Society", online September 2020 (an entire symposium, with six oral presentations, was dedicated to the project on this occasion).
- ▶ "African Bioacoustic Conference", online November 2020 (keynote oral speaker)

Moreover, the project was presented to the professional association of animal keepers at the Opel Zoo in Kronberg as part of a penguin workshop in September 2019, during an elephant seal meeting at the Chizé Center for Biological Studies (CNRS, France) in October 2019, and during the Summer School on Acoustic Communication organized by the SDU in August 2019.

7 Academic outcome

The project “Hearing in Penguins” has allowed six students to complete their Bachelor, Master or PhD thesis in Germany and in Denmark (**Table 1**).

Table 1: Theses completed during the project "Hearing in Penguins"

Author	Thesis title	Year	University	Degree
Lindner M.	Comparative morphology of the middle and inner ear in extant Penguins (<i>Spheniscidae</i>) and other diving birds	2018	University of Rostock	MSc
Köpp J.	Verhaltensorganisationen von nest relief ceremonies über die gesamte Brutzeit von Adeliepinguinen (<i>Pygoscelis adeliae</i>)	2020	University of Greifswald	BSc
Friis Vittrup M.	In-air hearing of the Northern Rockhopper Penguin (<i>Eudyptes moseleyi</i>)	2021	SDU	MSc
Skov Rasmussen M.	Penguin hearing under water	2021	SDU	MSc
Sørensen K.	Hearing in penguins	2021	SDU	PhD
Rößler H.	Acoustic communication and hearing in penguins	In progress	University of Greifswald	PhD

The project has also resulted in the publication of seven peer-reviewed articles and in the preparation of one other article to peer-reviewed journals (**Table 2**).

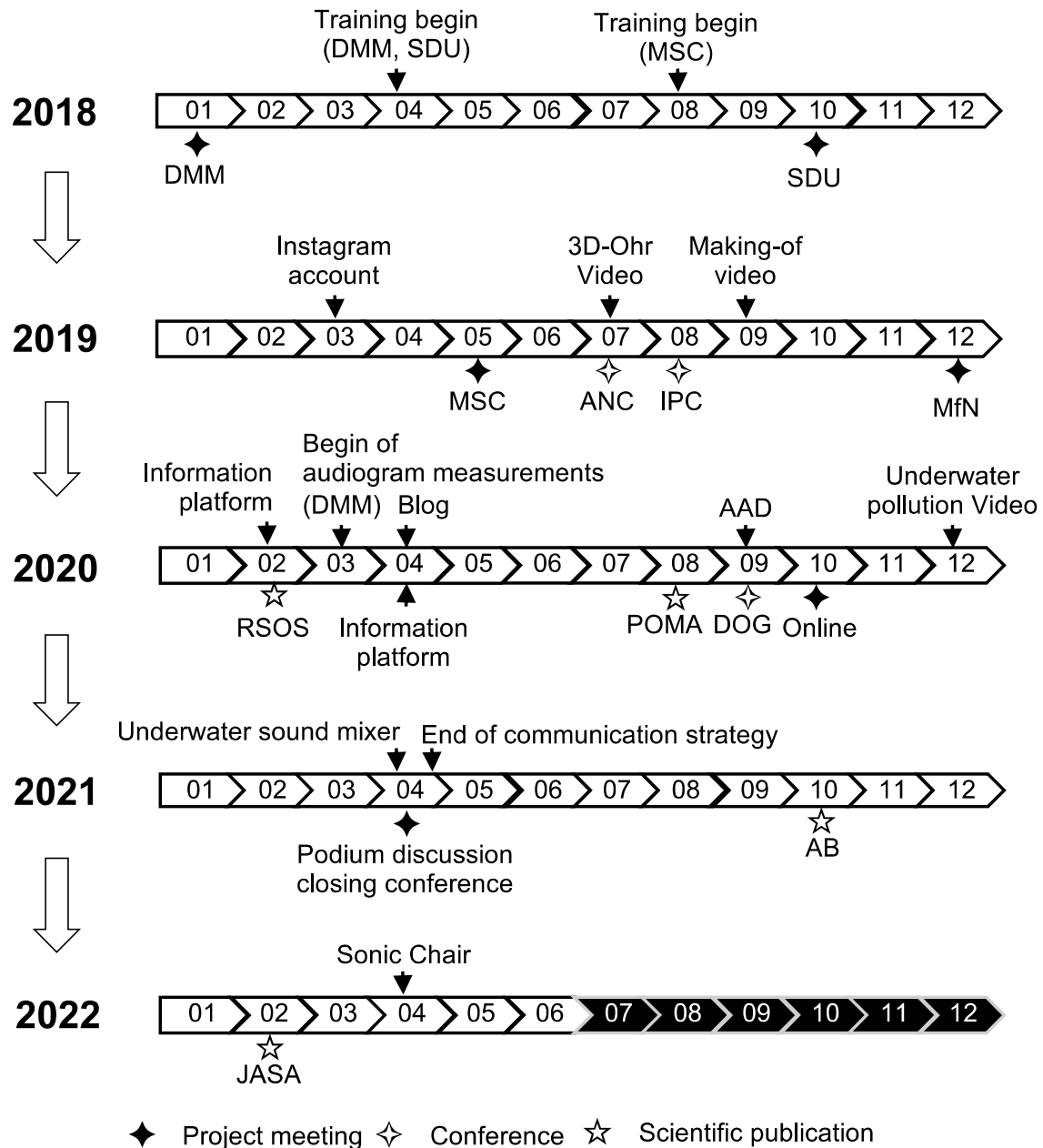
Table 2: Scientific articles written during the project "Hearing in Penguins"

Authors	Article title	Year	Journal	Volume: pages
Frahnert S., Lindner M., Bendel E.M., Frahnert K.H., Westphal N., Dähne M.	3D-visualization of the ear morphology of penguins (<i>Spheniscidae</i>): implications for hearing abilities in air and underwater	2020	Proc. Meet. Acoust.	37: 10018
Sørensen K., Neumann C., Dähne M., Hansen K.A., Wahlberg M.	Gentoo penguins (<i>Pygoscelis papua</i>) react to underwater sounds	2020	R. Soc. Open Sci	7: 191988
Beaulieu M., Dähne M., Köpp J., Marciau C., Kato A., Ropert-Coudert Y., Raclet T.	Exploring the interplay between nest vocalizations and foraging behaviour in breeding birds	2021	Anim. Behav.	180: 375-391
Jäckel D., Ortiz Troncoso A., Dähne M., Bölling C.	The Animal Audiogram Database: A community-based resource for consolidated audiogram data and metadata	2022	J. Acoust. Soc. Am.	151: 1125-1132

Rößler H., Lynch M., Ortiz S.T., Larsen O.N., Beaulieu M.	Neighbors matter: vocal variation in colonies shared by sympatric <i>Pygoscelis</i> penguin species	2022	Ornithology	139 (4):
Rasmussen M.S., Sørensen K., Vittrup M.F., Wahlberg M.	Pavlovian conditioning of gentoo penguins (<i>Pygoscelis papua</i>) to underwater sound	2022	Biol. Open	11 (11)
Rößler H., May A., Dähne M., Beaulieu M.	Long and winding road: Training progress and trainability variation across a psychoacoustic experiment in penguins	2022	Appl. Anim. Behav. Sc.	256(2): 105764
Rößler H., May A., Wahlberg M., Dähne M.	In-air audiograms of penguins measured through psycho-acoustic methods	In prep.	J. Acoust. Soc. Am.	-

8 Overview of the main achievements of the project “Hearing in Penguins”

Figure 25: Time scale of the main events of the project „Hearing in Penguins”



AB: article publication in Animal Behaviour (journal), ANC: presentation at the Acoustic Noise Conference, DOG: presentation at the Deutsche Ornithologische Gesellschaft (German Ornithological Society), IPC: presentation at the International Penguin Conference, JASA: article publication in Journal of the Acoustical Society of America, POMA: article publication in Proceedings of Meetings on Acoustics (journal), RSOS: article publication in Royal Society Open Science (journal). Source: own illustration, DMM

9 Difficulties during the project

Before the project "Hearing in Penguins" began, penguins had never been trained for scientific purposes. It was therefore difficult to anticipate the potential problems associated with penguin training to measure audiograms. Moreover, this training was planned for the period from 2018 to 2021, which was partly during the coronavirus crisis. A list of difficulties associated with training penguins in the project "Hearing in Penguins" is presented in **Table 3**.

Table 3: Difficulties encountered during the project "Hearing in Penguins"

Description	DMM	SDU	MSC	MfN
Reluctance of penguins to be trained	x	xx	xx	
Need for new infrastructures		xx	xx	
Work restrictions due to coronavirus	x	xx	xxx	xx
Ornithosis outbreak		xx	xxx	

The number of "x" indicates how severely institutions were affected

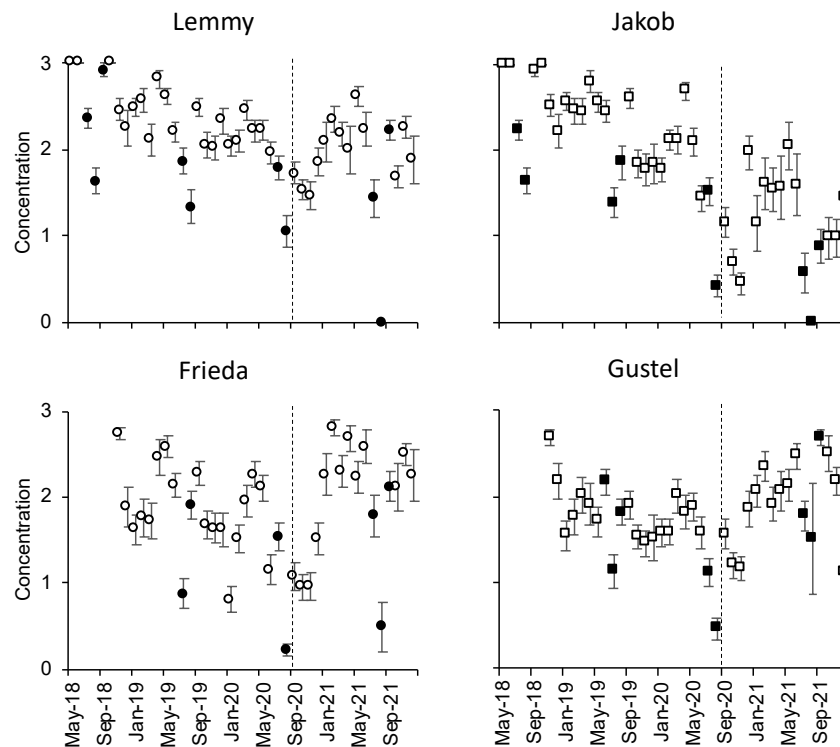
9.1 Reluctance of penguins to be trained

The original plan was to measure the audiograms of king penguins under water at the Odense Zoo. However, king penguins were very reluctant to dive into the water pool for training. It was therefore decided to conduct the training of king penguins exclusively in air to eventually measure in-air audiograms. However, even in the air, the king penguins' progress was so slow that it was decided to discontinue their training after more than two years of intensive effort.

Unlike the king penguins at the SDU, the Humboldt penguins at the MSC all wanted to stay in the water. During training, the penguins had to be separated by keeping the training penguin in the water and moving the other three animals to the land compartment. However, the three separated penguins showed a strong aversion to being locked out of the water (presumably because they could not escape into the water in case of danger). As a result, it was completely impossible to force them out of the water. The penguins also disturbed each other during training sessions.

Penguins showed marked seasonal variation in their motivation to be trained. For example, the presence of naturally occurring fish in summer at the MSC greatly reduced their motivation to participate in training activities. In addition, penguins were very difficult to train during the moult in summer (**Figure 26**), presumably because of the high energy required to produce new feathers and because penguins' feathers were no longer waterproof (thereby preventing underwater training).

Figure 26: Temporal variation of the concentration of four individual Humboldt penguins trained at the DMM



Black dots represent months when penguins were moulting and the vertical dashed line represents the month when penguins showed pairing interest for the first time. Monthly mean values ($\pm$ SE) are represented. Source: own illustration, DMM

9.2 Need for new infrastructures

In March 2020, the penguins at the Odense Zoo were moved to a quarantine area due to a complete restoration of their enclosure. Due to the first coronavirus lockdown (see below), the restoration of the penguin enclosure was postponed for one month before the penguins could return to the enclosure and be trained.

Due to training issues that arose in late 2019, a new penguin enclosure became necessary at the MSC (see 2.1.3 above). This new enclosure was designed to allow one penguin to be trained in one water compartment while the other penguins had access to the second water compartment. Because of the restrictions due to the first coronavirus lockdown, completion of the new enclosure was postponed.

9.3 Work restrictions due to coronavirus

Although the DMM was closed to visitors during the coronavirus crisis, training sessions were modified to reduce the likelihood of contamination between penguin trainers and other animal caretakers. As a result, the number of daily training sessions was reduced from three to two.

In Denmark, training at the SDU was interrupted for several weeks (due to coronavirus restrictions and penguin enclosure restoration). When training finally resumed after the first lockdown, the penguins were highly stressed and lacked motivation. This may have been due to

the long period without training and the fact that Kenneth Sørensen had to wear a face mask during the training sessions (king penguins appear very wary of novel objects).

During the first lockdown, the University of Rostock had also closed all its institutes (among which the MSC). During the first six weeks of the lockdown, only emergency care of the animals was allowed at the MSC. The MSC had to take additional measures to ensure the continued care of its animals (seals and penguins), and only one team of keepers could care for the animals in two shifts per day. The large amount of work required to care for the animals with a minimal number of people did not allow penguins to be trained.

It is important to note that all breaks in the training of penguins result in a "recovery period" (from several weeks to months) for the penguins to re-enter experimental training. The penguin species differed greatly in this regard; while the king penguins responded drastically to any interruption, the Humboldt penguins responded rather unproblematically. In addition, the end of the first lockdown coincided with the beginning of the penguins' moulting season, during which penguins are difficult (in the air) or impossible (underwater) to train. This combination of events further postponed the resumption of penguin training (especially at MSC).

Trials with the AEP electrodes also had to be postponed due to mobility restrictions (travel bans) during the lockdowns.

At the MfN and the DMM, the number of originally-planned communication formats had to be reduced due to the Covid 19 pandemic. All communication formats that occurred online were maintained. Some formats that were planned to occur in person or during exhibitions were either partially achieved because they had started before the pandemic (*e.g.*, commented training) or completely achieved because they could be postponed and transferred online (*e.g.*, panel discussion). However, most of the in-person formats had to be cancelled (**Table 4**).

Table 4: Originally-planned communication formats

Format	Description	Completed	Partially completed	Cancelled
Social media	Articles and news about the project posted on Instagram, Twitter, DMM and MfN canals and on the project blog	x		
Information platform	Website informing about underwater noise and linked to social media, project blog, music hackaton, mixer and videos	x		
Underwater sound mixer	Online program allowing the public to experience how marine animals perceive underwater noise	x		
Sound quiz	Online quiz about underwater sounds	x		
Musik hackathon	Competition between musicians using underwater sounds to create music compositions	x		
Ear scan presentation	Online publication of CT-scans, 3D models and making-of video	x		
Explanatory video	Online publication of a video about underwater noise pollution	x		
Panel discussion	Debate about underwater noise pollution with a focus on polar regions	x		

Format	Description	Completed	Partially completed	Cancelled
Sonic chair	Mobile unit (chair) for the public to experience underwater noise	x		
Commented training	Public explanation of the training of penguins during actual training sessions at the DMM		x	
"Long Night of the Museums"	Explanation booth about the project at DMM and MfN during the "Long Night of the Museum"		x	
Parliamentary evening	Public evening bringing scientists and politicians together to discuss about underwater noise			x
Science slam	Short oral presentations on acoustic research by young researchers			x
"Meet a Scientist"	Discussion with the general public in the public space about underwater noise			x
Competition at music colleges	Competition between music colleges to create musical compositions			x
"Long Night of the Sciences"	Explanation booth about the project at DMM and MfN during the "Long Night of the Sciences"			x
Participation at "Re:publica"	Meeting between bloggers, influencers, scientists, politicians and artists to debate about digital topics			x
Acoustic Box	Mobile unit (room) for the public to experience underwater noise			x

9.4 Ornithosis outbreak

As part of his PhD at SDU, Kenneth Sørensen had to spend part of his time at a foreign research institution. He naturally chose to spend this time at the MSC and started in October 2020. In early November 2020, he showed severe flu symptoms for which he was first treated in Rostock, returned to Denmark and was subsequently hospitalized in Denmark for several weeks. The results of medical examinations revealed an infection with *Chlamydia psittaci*, the causative agent of ornithosis. The investigation of the course of the disease was complicated by the simultaneous outbreak of coronavirus (with similar symptoms) and avian influenza. A late start of treatment with antibiotics significantly complicated the course of the disease. Kenneth Sørensen was therefore unable to complete his PhD within the project's funding period.

Two other employees of the MSC were also hospitalized in Rostock, and another was treated in at-home quarantine after showing similar (although less severe) symptoms. The MSC was therefore immediately quarantined, and the animals were tested for various diseases. Since two penguins tested positive for *Chlamydia psittaci* (while others tested positive for *Chlamydia sp.*), the penguins could no longer stay at the MSC. They were therefore transferred to the DMM, where they were quarantined. All research activities within the project "Hearing in Penguins" were therefore permanently stopped at the MSC. The penguins that were transferred back from the MSC to the DMM showed no signs of disease and were treated with antibiotics (Baytril®). After this treatment, they tested negative for Chlamydia (similar to all penguins at the DMM). They were transferred to a new zoo in Denmark in April 2021.

9.5 Consequences

Despite all these difficulties, the training of Humboldt penguins at the DMM and the development of the AEP electrodes at the SDU significantly progressed but did not result in concrete results before April 2021, when the project “Hearing in Penguins” was originally supposed to end. For this reason, the scientific part of the project was prolonged until June 2022 thanks to a cost-neutral extension granted by the UBA. These 14 additional months were used to finalize psychoacoustic data collection and to collect data with the AEP electrodes from the Humboldt penguins at the DMM in collaboration with the SDU.

10 Conclusion

The main aim of the project “Hearing in Penguins” was to measure audiograms in captive penguins both in the air and under water in several research institutions. Because no training had been previously performed on penguins for scientific purposes, it was unknown how long this process would take. Perhaps accordingly, we did not manage to measure audiograms in king penguins that appear refractory to training activities. However, within the 54 months of the project, we were able to measure for the first time audiograms in Humboldt penguins. These audiograms indicate that Humboldt penguins hear best between 1 and 4 kHz in the air. This is comparable to the other few audiograms measured in cormorants through psycho-acoustic methods, thereby suggesting that the diving activity of seabirds similarly affect their hearing ability. Moreover, the use of electrodes that we developed during the project to measure AEPs on awake penguins represents a promising and rapid approach to measure the hearing capacity of penguins in the future, and the creation of an animal audiogram databank that we launched online during the course of the project will facilitate the comparison between audiograms measured in penguins and those measured in other aquatic animals. Hearing adaptations in penguins were also investigated by visualizing their inner ear with CT-scans. This anatomical investigation suggested that the hearing capacity of penguins is likely preserved during diving. Accordingly, we found during an underwater playback experiment that penguins avoid noise sources underwater with a surprisingly low reaction threshold. Unfortunately, despite the ability of Humboldt penguins to be trained under water, we were not able to measure underwater audiograms because of a variety of unexpected difficulties that we faced during our project (*e.g.*, coronavirus restrictions, ornithosis). In parallel to the scientific approaches used in the project, a great effort was made to communicate about it and about underwater noise pollution. The implemented formats were divided into different categories: public events (*e.g.*, panel discussion), interactive offerings (*e.g.*, music hackathon), project and theme presentations (*e.g.*, Long Night of the Museums), digital formats (*e.g.*, [information platform](#)), exhibition formats (*e.g.*, Sonic Chair). A variety of approaches were used to implement these formats: in person (*e.g.*, participation in public events and conferences), in the press (*e.g.*, articles published in regional and national media) and online (*e.g.*, creation of online videos, Instagram accounts, information platform). Perhaps the most innovative communication approach that we used during our project was the creation of an online “underwater sound mixer” allowing the general public to grasp for the first time how animals perceive their acoustical environment under water. Overall, we were able to reach very diverse target groups with the mediation formats we used and, through the cooperation of two strong museums, were able to positively bundle the strengths of both institutions. Overall, the project “Hearing in Penguins” was successful, as the vast majority of the originally planned objectives were reached (**Table 5**). Most importantly, our project laid the foundation for future studies on the hearing capacity of diving birds with potential applications in the wild.

11 List of references

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A Appendix: peer-reviewed articles

A.1 Sørensen et al. (2020) *R. Soc. Open Sci.*

Sørensen, K., Neumann, C., Dähne, M., Hansen, K.A. & Wahlberg, M. (2020). Gentoo penguins (*Pygoscelis papua*) react to underwater sounds. *R. Soc. Open Sci.*, 7

A.2 Frahnert et al. (2020) Proc. Meet. Acoust.

Frahnert, S., Lindner, M., Bendel, E.-M., Frahnert, K.H., Westphal, N. & Dähne, M. (2020). 3D-Visualization of the Ear Morphology of Penguins (Spheniscidae): Implications for Hearing Abilities in Air and Underwater. *Proc. Meet. Acoust.*, 37, 010018

A.3 Beaulieu et al. (2021) Animal Behaviour

Beaulieu M., Dähne M., Köpp J., Marciau C., Kato A., Ropert-Coudert Y., Raclot T. (2021). Exploring the interplay between nest vocalizations and foraging behaviour in breeding birds. *Animal Behaviour*, 180, 375-391

A.4 Jäckel et al. (2022) *J. Acoust. Soc. Am.*

Jäckel D., Ortiz Troncoso A., Dähne M., Bölling C. (2022). The Animal Audiogram Database: A community-based resource for consolidated audiogram data and metadata, *J. Acoust. Soc. Am.* 151, 1125-1132.

A.5 Rößler et al. (2022) Ornithology (The Auk)

Rößler H., Lynch M., Ortiz S.T., Larsen O.N., Beaulieu M. (2022). Neighbors matter: vocal variation in colonies shared by sympatric *Pygoscelis* penguin species. *Ornithology*, 139 (4).

A.6 Rasmussen et al. (2022) Biol. Open

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A.7 Rößler et al. (2022) Appl. Anim. Behav. Sci.

Rößler H., May A., Dähne M., Beaulieu M. (2022). Long and winding road: Training progress and trainability variation across a psychoacoustic experiment in penguins. *Appl. Anim. Behav. Sc.*, 256 (2): 105764.

B Appendix: clipping number

Published on	Headline	Media title	Station	Media genre	Media type	Outreach
28.12.2017	Neues Forschungsprojekt am Deutschen Meeresmuseum	Ostsee Anzeiger zwischen Boddenregion und Recknitz		Print-medien	Anzeigenblätter mit Redaktion	15.563
28.12.2017	Neues Forschungsprojekt am Deutschen Meeresmuseum	Ostsee Anzeiger Hansestadt Stralsund		Print-medien	Anzeigenblätter mit Redaktion	23.703
24.04.2018	Wie gut können Pinguine hören?	Umweltbundesamt		Online-Medien	Behörden und Verbände	17.797
25.04.2018	Pinguine beim Hörtest	Der Nordschleswiger		Print-medien	Regional mit Vollredaktion	4.458
25.04.2018	Wie gut können Pinguine hören?	WR Westfälische Rundschau Hagen		Print-medien	Regional mit Teilredaktion	34.329
25.04.2018	Wie gut können Pinguine hören?	Westfalenpost Zeitung für Hagen		Print-medien	Regional mit Vollredaktion	34.329
25.04.2018	Wie gut können Pinguine hören?	Lübecker Nachrichten Lübecker-General-Anzeiger		Print-medien	Regional mit Vollredaktion	87.929
25.04.2018	Wie gut können Pinguine hören?	NRZ Neue Ruhr Zeitung Essen		Print-medien	Regional mit Vollredaktion	97.254
25.04.2018	Forscher starten Projekt zum Hörvermögen von Pinguinen	Hamburger Abendblatt		Print-medien	Regional mit Vollredaktion	250.199
25.04.2018	Forscher starten Projekt zum Hörvermögen von Pinguinen	Hamburger Abendblatt		Online-Medien	Printmedien online	301.109
25.04.2018	Forscher, u.a. des Meeresmuseums Stralsund, wollen Hörtests mit Pinguinen durchführen	Der Gute Morgen	Ostseewelle Hit-Radio Mecklenburg-Vorpommern	Hörfunk	Begleitprogramm	150.000
25.04.2018	Wie gut hören Pinguine?/ U.a. im Ozeaneum Stralsund wird das untersucht	Leonardo: Wissenschaft und mehr	WDR 5	Hörfunk	Magazine	240.000
28.04.2018 20:00	Neues Projekt	Stralsund TV	BB-MV Lokal-TV	TV	Regional-magazine	

Published on	Headline	Media title	Station	Media genre	Media type	Outreach
12.05.2018 06:45	Stralsunder Meeresmuseum erforscht Hörvermögen von Pinguinen	Krankenkassen Deutschland		Online-Medien	Ratgeber, Service, Produktinformationen	7.671
12.05.2018 07:25	Wie wirkt der Unterwasserlärm? - Pinguine sollen zum Hörtest Von Martina Rathke, dpa	Krankenkassen Deutschland		Online-Medien	Ratgeber, Service, Produktinformationen	7.671
12.05.2018 08:16	Stralsund Meeresmuseum erforscht Hörvermögen von Pinguinen	Südkurier Online		Online-Medien	Printmedien online	90.234
12.05.2018 08:17	Meeresmuseum erforscht Hörvermögen von Pinguinen	Reutlinger General-Anzeiger		Online-Medien	Printmedien online	17353
12.05.2018 08:20	Einfluss von Unterwasserlärm Meeresmuseum erforscht Hörvermögen von Pinguinen	Volksstimme.de		Online-Medien	Printmedienverbund online	58698
12.05.2018 08:20	Meeresmuseum: Pinguine müssen zum Hörtest	Peiner Nachrichten		Online-Medien	Printmedien online	724
12.05.2018 08:20	Meeresmuseum: Pinguine müssen zum Hörtest	WP - Westfalenpost		Online-Medien	Printmedien online	29090
12.05.2018 08:21	Meeresmuseum erforscht Hörvermögen von Pinguinen	General-Anzeiger Ostfriesland		Online-Medien	Printmedien online	4981
12.05.2018 08:21	Meeresmuseum erforscht Hörvermögen von Pinguinen	Süddeutsche.de		Online-Medien	Printmedien online	2125727
12.05.2018 08:22	Meeresmuseum erforscht Hörvermögen von Pinguinen	Ostfriesische Nachrichten		Online-Medien	Printmedien online	6324

Published on	Headline	Media title	Station	Media genre	Media type	Outreach
12.05.2018 08:23	Meeresmuseum erforscht Hörvermögen von Pinguinen	Badisches Tagblatt		Online-Medien	Printmedien online	5421
12.05.2018 08:23	Meeresmuseum: Pinguine müssen zum Hörtest	Salzgitter Zeitung		Online-Medien	Printmedien online	2753
12.05.2018 08:23	Meeresmuseum erforscht Hörvermögen von Pinguinen	Mindener Tageblatt		Online-Medien	Printmedien online	36986
12.05.2018 08:23	Einfluss von Unterwasserlärm Meeresmuseum erforscht Hörvermögen von Pinguinen	Nordwest-Zeitung		Online-Medien	Printmedien online	112213
12.05.2018 08:23	Meeresmuseum erforscht Hörvermögen von Pinguinen	Heidelberg24		Online-Medien	Reine e-zines	28400
12.05.2018 08:24	Meeresmuseum erforscht Hörvermögen von Pinguinen	innsalzach24.de		Online-Medien	Reine e-zines	64399
12.05.2018 08:24	Meeresmuseum erforscht Hörvermögen von Pinguinen	Main-Post		Online-Medien	Printmedien online	80461
12.05.2018 08:25	Einfluss von Unterwasserlärm : Meeresmuseum erforscht Hörvermögen von Pinguinen	SHZ.de		Online-Medien	Printmedien-verbund online	188411
12.05.2018 08:25	Meeresmuseum: Pinguine müssen zum Hörtest	Wolfenbütteler Zeitung		Online-Medien	Printmedien online	1284
12.05.2018 08:25	Meeresmuseum erforscht Hörvermögen von Pinguinen	SauerlandKurier		Online-Medien	Printmedien online	4492
12.05.2018 08:26	Meeresmuseum erforscht	nordbayern.de		Online-Medien	Reine e-zines	244974

Published on	Headline	Media title	Station	Media genre	Media type	Outreach
	Hörvermögen von Pinguinen					
12.05.2018 08:26	Meeresmuseum erforscht Hörvermögen von Pinguinen	Bad Vilbeler Neue Presse		Online-Medien	Printmedien online	102446
12.05.2018 08:26	Einfluss von Unterwasserlärm Meeresmuseum erforscht Hörvermögen von Pinguinen	Westfalen-Blatt		Online-Medien	Printmedien online	39618
12.05.2018 08:27	Meeresmuseum erforscht Hörvermögen von Pinguinen	Ludwigsburger Kreiszeitung		Online-Medien	Printmedien online	10468
12.05.2018 08:27	Unterwasserkrach: Bei Pinguinen wird jetzt erforscht, wie Meerestiere hören – und ob sie so schlau sind wie gedacht.	Bergedorfer Zeitung		Online-Medien	Printmedien online	5722
12.05.2018 08:27	Meeresmuseum erforscht Hörvermögen von Pinguinen	regio-news.de		Online-Medien	Reine e-zines	5527
12.05.2018 08:29	Einfluss von Unterwasserlärm Meeresmuseum erforscht Hörvermögen von Pinguinen	Neue Westfälische		Online-Medien	Printmedien online	170616
12.05.2018 08:29	Meeresmuseum erforscht Hörvermögen von Pinguinen	Soester Anzeiger		Online-Medien	Printmedien online	29365
12.05.2018 08:29	Meeresmuseum erforscht Hörvermögen von Pinguinen	Westdeutsche Zeitung		Online-Medien	Printmedien online	76535
12.05.2018 08:29	Meeresmuseum erforscht Hörvermögen von Pinguinen	Lippische Landeszeitung		Online-Medien	Printmedien online	36632

Published on	Headline	Media title	Station	Media genre	Media type	Outreach
12.05.2018 08:29	Meeresmuseum erforscht Hörvermögen von Pinguinen	morgenweb		Online-Medien	Printmedien online	51877
12.05.2018 08:29	Meeresmuseum: Pinguine müssen zum Hörtest	IKZ - Iserlohner Kreisanzeiger		Online-Medien	Printmedien online	
12.05.2018 08:29	Meeresmuseum erforscht Hörvermögen von Pinguinen	MünsterlandZeitung.de		Online-Medien	Printmedien online	4956
12.05.2018 08:30	Meeresmuseum erforscht Hörvermögen von Pinguinen	General-Anzeiger Bonn		Online-Medien	Printmedien online	97668
12.05.2018 08:31	Tiere: Meeresmuseum erforscht Hörvermögen von Pinguinen	FOCUS Online		Online-Medien	Printmedien online	5622283
12.05.2018 08:31	Meeresmuseum erforscht Hörvermögen von Pinguinen	SOL.DE - Saarland Online		Online-Medien	Reine e-zines	3674
12.05.2018 08:31	Einfluss von Unterwasserlärm : Meeresmuseum erforscht Hörvermögen von Pinguinen	SVZ.de Schweriner Volkszeitung		Online-Medien	Printmedien online	72334
12.05.2018 08:31	Meeresmuseum erforscht Hörvermögen von Pinguinen	Radio Duisburg Online		Online-Medien	Radio online	3114
12.05.2018 08:32	Meeresmuseum erforscht Hörvermögen von Pinguinen	Zeit Online		Online-Medien	Printmedien online	2344991
12.05.2018 08:32	Unterwasserkrach: Bei Pinguinen wird jetzt erforscht, wie Meerestiere hören – und ob sie so schlau sind wie gedacht.	Hamburger Abendblatt		Online-Medien	Printmedien online	301109

Published on	Headline	Media title	Station	Media genre	Media type	Outreach
12.05.2018 08:32	Meeresmuseum erforscht Hörvermögen von Pinguinen	Walsroder Zeitung		Online-Medien	Printmedien online	2520
12.05.2018 08:33	Meeresmuseum erforscht Hörvermögen von Pinguinen	92.9 radio mülheim		Online-Medien	Radio online	1265
12.05.2018 08:33	Einfluss von Unterwasserlärm Meeresmuseum erforscht Hörvermögen von Pinguinen	Südwest Presse		Online-Medien	Printmedien online	135262
12.05.2018 08:33	Einfluss von Unterwasserlärm: Meeresmuseum erforscht Hörvermögen von Pinguinen	Neue Osnabrücker Zeitung		Online-Medien	Printmedien online	237134
12.05.2018 08:33	Meeresmuseum erforscht Hörvermögen von Pinguinen	Rüsselsheimer Echo		Online-Medien	Printmedien online	
12.05.2018 08:33	Meeresmuseum erforscht Hörvermögen von Pinguinen	Der Patriot		Online-Medien	Printmedien online	5004
12.05.2018 08:34	Meeresmuseum erforscht Hörvermögen von Pinguinen	Eßlinger Zeitung		Online-Medien	Printmedien online	15164
12.05.2018 08:34	Meeresmuseum erforscht Hörvermögen von Pinguinen	ARCOR		Online-Medien	Online-Dienste, prof. Portale	193891
12.05.2018 08:34	Meeresmuseum erforscht Hörvermögen von Pinguinen	chiemgau24.de		Online-Medien	Reine e-zines	49517
12.05.2018 08:34	Meeresmuseum erforscht Hörvermögen von Pinguinen	Mittelbayerische Zeitung		Online-Medien	Printmedien online	92404

Published on	Headline	Media title	Station	Media genre	Media type	Outreach
12.05.2018 08:35	Meeresmuseum erforscht Hörvermögen von Pinguinen	Cannstatter Zeitung		Online-Medien	Printmedien online	
12.05.2018 08:35	Meeresmuseum erforscht Hörvermögen von Pinguinen	Recklinghäuser Zeitung		Online-Medien	Printmedien-verbund online	2447
12.05.2018 08:35	Meeresmuseum erforscht Hörvermögen von Pinguinen	in Südthüringen.de		Online-Medien	Printmedien online	28398
12.05.2018 08:36	Meeresmuseum erforscht Hörvermögen von Pinguinen	nq online - Die Neckarquelle		Online-Medien	Printmedien-verbund online	450
12.05.2018 08:36	Meeresmuseum erforscht Hörvermögen von Pinguinen	Taunus Zeitung Usinger Neue Presse		Online-Medien	Printmedien online	
12.05.2018 08:36	Meeresmuseum erforscht Hörvermögen von Pinguinen	ZVW - Zeitungsverlag Waiblingen		Online-Medien	Printmedien-verbund online	38966
12.05.2018 08:37	Meeresmuseum erforscht Hörvermögen von Pinguinen	Pipeline		Online-Medien	Sonstige Dienste und Agenturen	
12.05.2018 08:37	Einfluss von Unterwasserlärm : Meeresmuseum erforscht Hörvermögen von Pinguinen	Prignitzer.de		Online-Medien	Printmedien online	16427
12.05.2018 08:38	Meeresmuseum erforscht Hörvermögen von Pinguinen	Schwarzwaelder Bote		Online-Medien	Printmedien online	99348
12.05.2018 08:38	Meeresmuseum erforscht Hörvermögen von Pinguinen	az-online.de		Online-Medien	Printmedien online	27652
12.05.2018 08:38	Meeresmuseum erforscht	radio vest		Online-Medien	Radio online	5371

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	Hörvermögen von Pinguinen					
12.05.2018 08:38	Wissen : Meeresmuseum erforscht Hörvermögen von Pinguinen	antenne unna		Online-Medien	Radio online	1835
12.05.2018 08:39	Wissenschaft (DPA) Meeresmuseum erforscht Hörvermögen von Pinguinen	DIE WELT		Online-Medien	Printmedien online	4138738
12.05.2018 08:39	Meeresmuseum erforscht Hörvermögen von Pinguinen	Gäubote		Online-Medien	Printmedien online	6165
12.05.2018 08:39	Meeresmuseum erforscht Hörvermögen von Pinguinen	Ostfriesen-Zeitung		Online-Medien	Printmedien online	21274
12.05.2018 08:39	Meeresmuseum erforscht Hörvermögen von Pinguinen	Frankfurter Neue Presse		Online-Medien	Printmedien-verbund online	102446
12.05.2018 08:40	Meeresmuseum erforscht Hörvermögen von Pinguinen	rosenheim24.de		Online-Medien	Reine e-zines	36473
12.05.2018 08:40	Meeresmuseum erforscht Hörvermögen von Pinguinen	Taunus Zeitung		Online-Medien	Printmedien online	102446
12.05.2018 08:40	Meeresmuseum erforscht Hörvermögen von Pinguinen	nordbuzz		Online-Medien	Printmedien online	9856
12.05.2018 08:40	Meeresmuseum erforscht Hörvermögen von Pinguinen	Stuttgarter Nachrichten		Online-Medien	Printmedien-verbund online	116402
12.05.2018 08:41	Tiere Meeresmuseum erforscht Hörvermögen von Pinguinen	Märkische Oderzeitung		Online-Medien	Printmedien online	43862

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12.05.2018 08:41	Meeresmuseum erforscht Hörvermögen von Pinguinen	106.2 radio oberhausen		Online-Medien	Radio online	1799
12.05.2018 08:42	Meeresmuseum erforscht Hörvermögen von Pinguinen	Rhein-Zeitung		Online-Medien	Printmedien online	57680
12.05.2018 08:43	Meeresmuseum erforscht Hörvermögen von Pinguinen	suedost-news.de		Online-Medien	Printmedien-verbund online	6000
12.05.2018 08:43	Meeresmuseum erforscht Hörvermögen von Pinguinen	Hertener Allgemeine		Online-Medien	Printmedien online	1544
12.05.2018 08:43	Meeresmuseum erforscht Hörvermögen von Pinguinen	Radio Sauerland		Online-Medien	Radio online	2022
12.05.2018 08:43	Meeresmuseum: Pinguine müssen zum Hörtest	WR - Westfälische Rundschau		Online-Medien	Printmedien online	24762
12.05.2018 08:43	Meeresmuseum erforscht Hörvermögen von Pinguinen	Gießener Anzeiger		Online-Medien	Printmedien online	2851
12.05.2018 08:44	Meeresmuseum erforscht Hörvermögen von Pinguinen	Remscheider General-Anzeiger		Online-Medien	Printmedien online	16550
12.05.2018 08:44	Meeresmuseum erforscht Hörvermögen von Pinguinen	freiepresse.de		Online-Medien	Printmedien online	100213
12.05.2018 08:44	Meeresmuseum: Pinguine müssen zum Hörtest	Gifhorner Rundschau		Online-Medien	Printmedien online	274
12.05.2018 08:44	Meeresmuseum: Pinguine müssen zum Hörtest	Wolfsburger Nachrichten		Online-Medien	Printmedien online	3290
12.05.2018 08:45	Meeresmuseum erforscht Hörvermögen von Pinguinen	Passauer Neue Presse		Online-Medien	Printmedien online	194964

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12.05.2018 08:45	Einfluss von Unterwasserlärm Meeresmuseum erforscht Hörvermögen von Pinguinen	Münstersche Zeitung.de		Online-Medien	Printmedien online	7482
12.05.2018 08:45	Einfluss von Unterwasserlärm : Meeresmuseum erforscht Hörvermögen von Pinguinen	Norddeutsche Neueste Nachrichten		Online-Medien	Printmedien online	2438
12.05.2018 08:46	Meeresmuseum erforscht Hörvermögen von Pinguinen	Schwäbische Zeitung		Online-Medien	Printmedien online	133071
12.05.2018 08:46	Meeresmuseum erforscht Hörvermögen von Pinguinen	Rhein-Neckar-Zeitung		Online-Medien	Printmedien online	55205
12.05.2018 08:46	Meeresmuseum erforscht Hörvermögen von Pinguinen	Neu-Isenburger Neue Presse		Online-Medien	Printmedien online	102446
12.05.2018 08:47	Ozeaneum Meeresmuseum: Pinguine müssen zum Hörtest	Berliner Morgenpost		Online-Medien	Printmedien online	249207
12.05.2018 08:48	Meeresmuseum erforscht Hörvermögen von Pinguinen	Yahoo! Nachrichten		Online-Medien	Online-Dienste, prof. Portale	1400124
12.05.2018 08:48	Einfluss von Unterwasserlärm Meeresmuseum erforscht Hörvermögen von Pinguinen	Lausitzer Rundschau		Online-Medien	Printmedien online	50617
12.05.2018 08:49	Stralsund Unterwasserkrach: Bei Pinguinen wird jetzt erforscht, wie Meerestiere hören – und ob sie so schlau sind wie gedacht.	WAZ - Westdeutsche Allgemeine Zeitung		Online-Medien	Printmedien online	207736

Published on	Headline	Media title	Station	Media genre	Media type	Outreach
12.05.2018 08:49	Meeresmuseum erforscht Hörvermögen von Pinguinen	come-on.de		Online-Medien	Printmedien-verbund online	24332
12.05.2018 08:50	Meeresmuseum erforscht Hörvermögen von Pinguinen	Frankenpost		Online-Medien	Printmedien online	38379
12.05.2018 08:50	Stralsund - Meeresmuseum erforscht Hörvermögen von Pinguinen	Aachener Nachrichten		Online-Medien	Printmedien online	22117
12.05.2018 08:50	Meeresmuseum erforscht Hörvermögen von Pinguinen	TZ online		Online-Medien	Printmedien online	615449
12.05.2018 08:51	Meeresmuseum erforscht Hörvermögen von Pinguinen Jeder fünfte Deutsche nimmt Online-Ratenkredit auf Schokolade für Frau Bühr Wo, wenn nicht hier Wie klug ist Ihr Haus? Darauf sollten Sie beim Besuch einer Spielbank achten	Marler Zeitung		Online-Medien	Printmedien online	2887
12.05.2018 08:51	Meeresmuseum erforscht Hörvermögen von Pinguinen	Web Nachrichten		Online-Medien	Reine e-zines	
12.05.2018 08:51	Meeresmuseum erforscht Hörvermögen von Pinguinen	Stuttgarter Zeitung		Online-Medien	Printmedien-verbund online	152626
12.05.2018 08:51	Meeresmuseum erforscht Hörvermögen von Pinguinen	Nassauische Neue Presse		Online-Medien	Printmedien online	102446
12.05.2018 08:52	Meeresmuseum: Pinguine müssen zum Hörtest	Harz Kurier		Online-Medien	Printmedien online	2874

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12.05.2018 08:52	Meeresmuseum erforscht Hörvermögen von Pinguinen	mittelhessen		Online-Medien	Printmedien-verbund online	31457
12.05.2018 08:52	Meeresmuseum: Pinguine müssen zum Hörtest	NRZ - Neue Ruhr Zeitung		Online-Medien	Printmedien online	602481
12.05.2018 08:52	Meeresmuseum erforscht Hörvermögen von Pinguinen	Höchster Kreisblatt		Online-Medien	Printmedien online	102446
12.05.2018 08:53	Meeresmuseum erforscht Hörvermögen von Pinguinen	Allgemeine Zeitung Coesfeld		Online-Medien	Printmedien-verbund online	6437
12.05.2018 08:53	Meeresmuseum erforscht Hörvermögen von Pinguinen	Die Harke		Online-Medien	Printmedien online	4107
12.05.2018 08:54	Meeresmuseum erforscht Hörvermögen von Pinguinen	HalternerZeitung.de		Online-Medien	Printmedien online	4271
12.05.2018 08:55	Meeresmuseum erforscht Hörvermögen von Pinguinen	Ruhr Nachrichten.de		Online-Medien	Printmedien online	85525
12.05.2018 08:55	Einfluss von Unterwasserlärm Meeresmuseum erforscht Hörvermögen von Pinguinen	Dülmener Zeitung		Online-Medien	Printmedien online	3309
12.05.2018 08:55	Meeresmuseum erforscht Hörvermögen von Pinguinen	Main-Echo		Online-Medien	Printmedien online	49033
12.05.2018 08:55	Meeresmuseum erforscht Hörvermögen von Pinguinen	Oberhessische Zeitung		Online-Medien	Printmedien online	450
12.05.2018 08:55	Meeresmuseum erforscht Hörvermögen von Pinguinen	Main-Spitze		Online-Medien	Printmedien online	1887

Published on	Headline	Media title	Station	Media genre	Media type	Outreach
12.05.2018 08:56	Meeresmuseum erforscht Hörvermögen von Pinguinen	Die Glocke		Online-Medien	Printmedien online	18748
12.05.2018 08:56	Meeresmuseum erforscht Hörvermögen von Pinguinen	Wiesbadener Tagblatt		Online-Medien	Printmedien online	2072
12.05.2018 08:56	Meeresmuseum erforscht Hörvermögen von Pinguinen	DorstenerZeitung.de		Online-Medien	Printmedien online	4145
12.05.2018 08:57	Einfluss von Unterwasserlärm Meeresmuseum erforscht Hörvermögen von Pinguinen	Die Oberbadische		Online-Medien	Printmedien online	2280
12.05.2018 08:59	Meeresmuseum erforscht Hörvermögen von Pinguinen	BKZ Online		Online-Medien	Printmedien-verbund online	4398
12.05.2018 09:00	Wissen Meeresmuseum erforscht Hörvermögen von Pinguinen	LN Online - Lübecker Nachrichten		Online-Medien	Printmedien online	31555
12.05.2018 09:01	Meeresmuseum erforscht Hörvermögen von Pinguinen	Lauterbacher Anzeiger		Online-Medien	Printmedien online	531
12.05.2018 09:01	Meeresmuseum erforscht Hörvermögen von Pinguinen	Abendzeitung München		Online-Medien	Printmedien online	230920
12.05.2018 09:01	Meeresmuseum erforscht Hörvermögen von Pinguinen	Lampertheimer Zeitung		Online-Medien	Printmedien online	563
12.05.2018 09:02	Meeresmuseum erforscht Hörvermögen von Pinguinen	Gelnhäuser Tageblatt		Online-Medien	Printmedien online	657

Published on	Headline	Media title	Station	Media genre	Media type	Outreach
12.05.2018 09:03	Meeresmuseum erforscht Hörvermögen von Pinguinen	BBV-net Bocholter-Borkener Volksblatt		Online-Medien	Printmedien online	11556
12.05.2018 09:05	Meeresmuseum erforscht Hörvermögen von Pinguinen	Usinger Anzeiger		Online-Medien	Printmedien online	820
12.05.2018 09:05	Meeresmuseum erforscht Hörvermögen von Pinguinen	Nürtinger Zeitung		Online-Medien	Printmedien online	4885
12.05.2018 09:06	Meeresmuseum erforscht Hörvermögen von Pinguinen	Kreis-Anzeiger (Wetterau)		Online-Medien	Printmedien online	872
12.05.2018 09:07	Meeresmuseum erforscht Hörvermögen von Pinguinen	Wormser Zeitung		Online-Medien	Printmedien online	2679
12.05.2018 09:09	Meeresmuseum erforscht Hörvermögen von Pinguinen	Saarbrücker Zeitung		Online-Medien	Printmedien online	24576
12.05.2018 09:09	Meeresmuseum erforscht Hörvermögen von Pinguinen	Schaumburger Zeitung & Landes-Zeitung		Online-Medien	Printmedien online	8787
12.05.2018 09:15	Meeresmuseum erforscht Hörvermögen von Pinguinen	Allgemeine Zeitung (Rhein Main Presse)		Online-Medien	Printmedien online	21865
12.05.2018 09:17	Meeresmuseum erforscht Hörvermögen von Pinguinen	Echo Online		Online-Medien	Printmedien-verbund online	36552
12.05.2018 09:26	Meeresmuseum erforscht Hörvermögen von Pinguinen	Wiesbadener Kurier		Online-Medien	Printmedien online	13143
12.05.2018 09:31	Meeresmuseum erforscht Hörvermögen von Pinguinen	Emder Zeitung		Online-Medien	Printmedien online	11063

Published on	Headline	Media title	Station	Media genre	Media type	Outreach
12.05.2018 09:59	Tiere : Stralsunder Meeresmuseum erforscht Hörvermögen von Pinguinen	Prignitzer.de		Online-Medien	Printmedien online	16427
12.05.2018 10:01	Mecklenburg-Vorpommern Stralsunder Meeresmuseum erforscht Hörvermögen von Pinguinen	DIE WELT		Online-Medien	Printmedien online	4138738
12.05.2018 10:05	Stralsunder Meeresmuseum erforscht Hörvermögen von Pinguinen	RTL.de		Online-Medien	TV online	935448
12.05.2018 10:07	Stralsunder Meeresmuseum erforscht Hörvermögen von Pinguinen	T-Online		Online-Medien	Online-Dienste, prof. Portale	11564290
12.05.2018 10:08	Tiere : Stralsunder Meeresmuseum erforscht Hörvermögen von Pinguinen	Norddeutsche Neueste Nachrichten		Online-Medien	Printmedien online	2438
12.05.2018 10:13	Tiere : Stralsunder Meeresmuseum erforscht Hörvermögen von Pinguinen	SVZ.de Schweriner Volkszeitung		Online-Medien	Printmedien online	72334
12.05.2018 10:19	Tiere Stralsunder Meeresmuseum erforscht Hörvermögen von Pinguinen	Hamburger Abendblatt		Online-Medien	Printmedien online	301109
12.05.2018 10:24	Stralsunder Meeresmuseum erforscht Hörvermögen von Pinguinen	Süddeutsche.de		Online-Medien	Printmedien online	2125727
12.05.2018 10:27	Tiere: Stralsunder Meeresmuseum erforscht Hörvermögen von Pinguinen	FOCUS Online		Online-Medien	Printmedien online	5622283

Published on	Headline	Media title	Station	Media genre	Media type	Outreach
12.05.2018 10:36	Stralsunder Meeresmuseum erforscht Hörvermögen von Pinguinen	ARCOR		Online-Medien	Online-Dienste, prof. Portale	193891
12.05.2018 10:49	Pinguine sollen zum Hörtest	T-Online		Online-Medien	Online-Dienste, prof. Portale	11564290
12.05.2018 10:55	Pinguine sollen zum Hörtest: Forscher untersuchen Auswirkungen von Unterwasserlärm	1&1		Online-Medien	Online-Dienste, prof. Portale	173142
12.05.2018 11:00	Pinguine sollen zum Hörtest: Forscher untersuchen Auswirkungen von Unterwasserlärm	GMX		Online-Medien	Online-Dienste, prof. Portale	1543292
12.05.2018 11:04	Pinguine sollen zum Hörtest: Forscher untersuchen Auswirkungen von Unterwasserlärm	WEB.DE		Online-Medien	Online-Dienste, prof. Portale	806571
12.05.2018 12:06	Stralsund Stralsunder Meeresmuseum erforscht Hörvermögen von Pinguinen	Ostsee-Zeitung		Online-Medien	Printmedien online	44862
12.05.2018 12:51	Forschung in Stralsund : Pinguine sollen zum Hörtest	Norddeutsche Neueste Nachrichten		Online-Medien	Printmedien online	2438
12.05.2018 12:57	Forschung in Stralsund : Pinguine sollen zum Hörtest	SVZ.de Schweriner Volkszeitung		Online-Medien	Printmedien online	72334
12.05.2018 13:24	Forschung in Stralsund : Pinguine sollen zum Hörtest	Prignitzer.de		Online-Medien	Printmedien online	16427
12.05.2018 14:26	Meeresmuseum erforscht Hörvermögen von Pinguinen	Bürostädter Zeitung		Online-Medien	Printmedien online	496
12.05.2018 16:07	Meeresmuseum: Wie und was hören Pinguine?	The Epoch Times Deutschland		Online-Medien	Printmedien online	147211

Published on	Headline	Media title	Station	Media genre	Media type	Outreach
12.05.2018 19:32	Hörvermögen von Pinguinen erforscht	Mittelbayerische Zeitung		Online-Medien	Printmedien online	92404
12.05.2018 19:59	Lärm in den Meeren	RTL II News	RTL II Fernsehen GmbH & Co. KG	TV	Nachrichten allgemein	270000
13.05.2018 10:55	Pinguine verbringen einen Großteil ihres Lebens im Wasser, wo sie immer mehr Lärm ausgesetzt sind. Aber wie hören sie überhaupt?	Augsburger Allgemeine		Online-Medien	Printmedien online	218404
13.05.2018 21:34	Hörtest für Pinguine	Neues Deutschland		Online-Medien	Printmedien online	39425
14.05.2018	Hörst du das, Pinguin?	STZ Südthüringer Zeitung Bad Salzungen		Print-medien	Regional mit Teilredaktion	18132
14.05.2018	Hörtest für Pinguine	Neues Deutschland Bundesausgabe		Print-medien	Überregional mit Vollredaktion	36659
14.05.2018	Forscher testen das Hörvermögen der Pinguine	Main-Echo		Print-medien	Regional mit Vollredaktion	203999
14.05.2018	Hörst du das, Pinguin?	Neue Presse Coburg		Print-medien	Regional mit Vollredaktion	28319
14.05.2018	Pinguine sollen zum Hörtest	Rheinische Post D Düsseldorf		Print-medien	Regional mit Vollredaktion	236635
14.05.2018	Pinguine sollen zum Hörtest	Rotenburger Kreiszeitung		Print-medien	Regional mit Vollredaktion	24186
14.05.2018	Vier kleine Pinguine gehen dem Lärm auf die Spur	Neue Presse Coburg		Print-medien	Regional mit Vollredaktion	28319
14.05.2018	Pinguine sollen zum Hörtest	Ostfriesische Nachrichten		Print-medien	Regional mit Vollredaktion	36504
14.05.2018	Hörst du das, Pinguin?	Freies Wort Suhl		Print-medien	Regional mit Vollredaktion	25231
14.05.2018	Was können Pinguine eigentlich hören?	General-Anzeiger Bonner Stadtanzeiger		Print-medien	Regional mit Vollredaktion	197999
14.05.2018	Hörst du das, Pinguin?	Frankenpost Hofer Anzeiger		Print-medien	Regional mit Vollredaktion	33908

Published on	Headline	Media title	Station	Media genre	Media type	Outreach
14.05.2018	Hör-Test für Pinguine	Badische Neueste Nachrichten ST		Print-medien	Regional mit Vollredaktion	102528
14.05.2018	Warum Pinguine zum Hörtest müssen	Rhein-Zeitung Koblenz		Print-medien	Regional mit Vollredaktion	101316
14.05.2018	Vier kleine Pinguine gehen dem Lärm auf die Spur	Frankenpost Hofer Anzeiger		Print-medien	Regional mit Vollredaktion	33908
14.05.2018	Vier kleine Pinguine gehen dem Lärm auf die Spur	Vogtland-Anzeiger		Print-medien	Regional mit Vollredaktion	12620
14.05.2018	Pinguine sollen zum Hörtest	Altmark Zeitung Salzwedeler Nachrichten		Print-medien	Regional mit Teilredaktion	15027
14.05.2018	Hörst du das, Pinguin?	Meininger Tageblatt		Print-medien	Regional mit Teilredaktion	29727
14.05.2018	Pinguine sollen zum Hörtest	Fehmarnsches Tageblatt		Print-medien	Regional mit Vollredaktion	5921
14.05.2018	Pinguine sollen zum Hörtest	Fuldaer Zeitung		Print-medien	Regional mit Vollredaktion	77155
14.05.2018 00:24	Meeresmuseum erforscht Hörvermögen von Pinguinen	Gäubote		Online-Medien	Printmedien online	6487
15.05.2018	Pinguine beim Hörtraining	Stuttgarter Zeitung D		Print-medien	Überregional mit Vollredaktion	363435
15.05.2018	lieber Pinguin, hörst du das?	Neue Westfälische Bielefelder Tageblatt OH		Print-medien	Regional mit Vollredaktion	20301
15.05.2018	Pinguine beim Hörtraining	Eßlinger Zeitung		Print-medien	Regional mit Vollredaktion	96056
15.05.2018	Pinguine beim Hörtraining	Stuttgarter Nachrichten (Fernausgabe)		Print-medien	Regional mit Vollredaktion	181717
15.05.2018	Pinguine sollen zum Hörtest	Trierischer Volksfreund		Print-medien	Regional mit Vollredaktion	57706
16.05.2018	Pinguine sollen zum Hörtest	Fränkischer Tag		Print-medien	Regional mit Vollredaktion	95679
16.05.2018	Pinguine sollen zum Hörtest	Bayerische Rundschau		Print-medien	Regional mit Teilredaktion	35642

Published on	Headline	Media title	Station	Media genre	Media type	Outreach
16.05.2018 00:39	MV aktuell Viel Lärm unter Wasser: Stört das die Pinguine?	Ostsee-Zeitung		Online-Medien	Printmedien online	44862
16.05.2018 21:02	Pinguine sollen zum Hörtest	Sächsische Zeitung - SZ-Online.de		Online-Medien	Printmedien online	143283
17.05.2018	Pinguine sollen zum Hörtest	Sächsische Zeitung Dresden		Print-medien	Regional mit Vollredaktion	119572
18.05.2018	Hörtest für Pinguine	Gießener Allgemeine		Print-medien	Regional mit Vollredaktion	64676
18.05.2018 08:17	Wie hören Grenzgänger? – Pinguine sollen zum Hörtest	Biermann Medizin		Online-Medien	Branchendienste	
26.05.2018 09:05	Deutsches Meeresmuseum in Stralsund untersucht Hören der Pinguine	Die Profis	radioeins (RBB)	Hörfunk	Magazine	90000
29.05.2018	Hörtest für Pinguine	Badische Neueste Nachrichten ST		Print-medien	Regional mit Vollredaktion	102528
30.05.2018	Forscher untersuchen das Gehör von Pinguinen	Augsburger Allgemeine AS		Print-medien	Regional mit Vollredaktion	93939
01.06.2018	Forscher untersuchen das Gehör von Pinguinen	Allgäuer Zeitung Kempten		Print-medien	Regional mit Vollredaktion	54272
02.06.2018	Hörtest für Pinguine	Schwäbisches Tagblatt Tübinger Chronik		Print-medien	Regional mit Teilredaktion	54849
02.06.2018	Hörtest für Pinguine	Südwest Presse Ulm		Print-medien	Regional mit Vollredaktion	134430
02.06.2018	Forscher untersuchen das Gehör von Pinguinen	Allgäuer Zeitung Marktoberdorf		Print-medien	Regional mit Teilredaktion	22540
06.06.2018	Hörtest für Pinguine	Märkische Oderzeitung Frankfurter Stadtbote		Print-medien	Regional mit Vollredaktion	23541
07.06.2018	Hörtest für Pinguine	Geislinger Zeitung		Print-medien	Regional mit Teilredaktion	28211
09.06.2018	Das Hörvergnügen der Pinguine	General-Anzeiger Bonner Stadtanzeiger		Print-medien	Regional mit Vollredaktion	197999

Published on	Headline	Media title	Station	Media genre	Media type	Outreach
13.06.2018	Hörtest für Pinguine	Bietigheimer Zeitung		Print-medien	Regional mit Teilredaktion	9492
14.06.2018	Hörtest für Pinguine	Hohenloher Tagblatt		Print-medien	Regional mit Teilredaktion	35524
14.06.2018 13:05	Im Ozeaneum Stralsund findet ein Hörtraining für Pinguine statt	Ihr Lieblingsmix am Nachmittag	NDR 1 Mecklenburg-Vorpommern	Hörfunk	Tagesmagazine, Informationsstricken	140000
14.06.2018 18:01	Humboldtpinguine	Land und Leute	NDR Mecklenburg-Vorpommern	TV	Regionalmagazine	10000
15.06.2018	Hörtest für Pinguine	Oranienburger Generalanzeiger		Print-medien	Regional mit Vollredaktion	26550
16.06.2018 19:31	Humboldtpinguine	Nordmagazin	NDR Mecklenburg-Vorpommern	TV	Regionalmagazine	200000
17.06.2018 03:15	Humboldtpinguine	Nordmagazin (Mo-So 03:45)	NDR Norddeutscher Rundfunk Anstalt des öffentlichen Rechts	TV	Regionalmagazine	80000
17.06.2018 09:00	Humboldtpinguine	Nordmagazin (Mo-So 09:00)	NDR Norddeutscher Rundfunk Anstalt des öffentlichen Rechts	TV	Regionalmagazine	40000
18.06.2018 18:00	Humboldtpinguine	rbb um Sechs	RBB Rundfunk Berlin Brandenburg Anstalt des öffentlichen Rechts	TV	Regionalmagazine	100000
19.06.2018	Hörtest für Pinguine	Zollern-Alb Kurier Südwestpresse		Print-medien	Regional mit Teilredaktion	49537
19.06.2018 04:55	Humboldtpinguine	rbb um Sechs (Di-Sa 03:40)	RBB Rundfunk Berlin	TV	Regionalmagazine	10000

Published on	Headline	Media title	Station	Media genre	Media type	Outreach
			Brandenburg Anstalt des öffentlichen Rechts			
27.06.2018	Wie gut können Pinguine hören?	Ruhr Nachrichten Castrop-Rauxeler Zeitung		Print-medien	Regional mit Teilredaktion	
30.06.2018	Wie gut können Pinguine hören?	Ruhr Nachrichten Dorstener Zeitung		Print-medien	Regional mit Teilredaktion	50131
03.07.2018	Wie gut können Pinguine hören?	Ruhr Nachrichten Ausgabe Lünen		Print-medien	Regional mit Teilredaktion	
09.07.2018	Wie gut können Pinguine hören?	Münstersche Zeitung Westfalen-Anzeiger		Print-medien	Regional mit Vollredaktion	84772
31.07.2018 05:03	Hörtest mit Pinguinen im Marine Science Center/ Tiere wurden ausgeliehen vom Ozeaneum Stralsund	Der Gute Morgen	Ostseewelle Hit-Radio Mecklenburg-Vorpommern	Hörfunk	Begleitprogramm	130000
04.08.2018	Unter Wasser sieht die Welt ganz anders aus	Schwarzwälder Bote Oberndorf R1		Print-medien	Regional mit Vollredaktion	37522
04.08.2018	Unter Wasser sieht die Welt ganz anders aus	Die Oberbadische		Print-medien	Regional mit Vollredaktion	31236
04.08.2018 13:05	Für Pinguine im Stralsunder Ozeaneum ist Hitze kein Problem	Für uns in Mecklenburg-Vorpommern 13:00	NDR 1 Mecklenburg-Vorpommern	Hörfunk	Begleitprogramm	140000
10.12.2018 13:15	Stralsunder Forscher bricht in Antarktis auf	Norddeutsche Neueste Nachrichten		Online-Medien	Printmedien online	2511
10.12.2018 13:15	Stralsunder Forscher bricht in Antarktis auf	Prignitzer.de		Online-Medien	Printmedien online	16427
10.12.2018 13:39	Stralsunder Forscher bricht in Antarktis auf	SVZ.de Schweriner Volkszeitung		Online-Medien	Printmedien online	89381
11.12.2018	Stralsunder Biologe erforscht Gehör der Pinguine	Bild Mecklenburg-Vorpommern		Print-medien	Boulevard-Kaufzeitungen mit Vollred.	241000
11.12.2018	Wie hören eigentlich Pinguine?	Die Welt überregional		Print-medien	Überregional mit Vollredaktion	656699

Published on	Headline	Media title	Station	Media genre	Media type	Outreach
11.12.2018 20:00	Stralsunder untersucht Geräusche der Antarktis	Stralsund TV	BB-MV Lokal-TV	TV	Regional-magazine	
12.12.2018	Lauschangriff in der Antarktis	Ostsee Anzeiger Der Rügäner		Print-medien	Anzeigenblätter mit Redaktion	20095
15.12.2018	Wie hören Pinguine?	Oberhessische Presse		Print-medien	Regional mit Vollredaktion	71109
26.01.2019 20:30	Wissenschaftler zurück	Stralsund TV	BB-MV Lokal-TV	TV	Regional-magazine	
21.02.2019 00:00	FORSCHUNG/487: Stralsunder Wissenschaftler mit Antarktis-Geräuschen von Forschungsreise zurück (DMM)	Schattenblick		Online-Medien	Reine e-zines	743
28.02.2019 18:07	Ruhe war gestern	Deutschlandfunk Kultur		Online-Medien	Radio online	63409
28.02.2019 19:07	Michael Dähne vom Deutschen Meeresmuseum Stralsund zum Projekt 'Hearing in Penguins'	Zeitfragen - Forschung und Gesellschaft	Deutschland funk Kultur	Hörfunk	Magazine	120000
04.03.2019 15:05	Bei den Pinguinen im Ozeaneum Stralsund/ Hörfähigkeit der Tiere wird erforscht	Kakadu	Deutschland funk Kultur	Hörfunk	Magazine	120000
25.04.2019 19:30	Welt-Pinguin-Tag	Nordmagazin	NDR Mecklenburg-Vorpommern	TV	Regional-magazine	220000
26.04.2019 09:00	Welt-Pinguin-Tag	Nordmagazin (Mo-So 09:00)	NDR Norddeutscher Rundfunk Anstalt des öffentlichen Rechts	TV	Regional-magazine	30000
25.05.2019 16:01	Was hören Pinguine unter Wasser?	Prignitzer.de		Online-Medien	Printmedien online	16427
25.05.2019 16:05	Forschungsprojekt: Was hören Pinguine unter Wasser?	Norddeutsche Neueste Nachrichten		Online-Medien	Printmedien online	2511

Published on	Headline	Media title	Station	Media genre	Media type	Outreach
25.05.2019 16:08	Was hören Pinguine unter Wasser?	SVZ.de Schweriner Volkszeitung		Online-Medien	Printmedien online	75126
18.06.2019 00:00	BILDUNG/235: NABU und OZEANEUM laden zum virtuellen Tauchgang (NABU)	Schattenblick		Online-Medien	Reine e-zines	835
18.06.2019 13:23	NABU und OZEANEUM laden zum virtuellen Tauchgang / Mit OstseeLIFE können Museumsbesucher Seegraswiesen und Schweinswale erleben	FinanzNachrichten.de		Online-Medien	Branchendienste	156742
18.06.2019 15:44	NABU und OZEANEUM laden zum virtuellen Tauchgang / Mit OstseeLIFE können Museumsbesucher Seegraswiesen und Schweinswale erleben	topfreizeit.de		Online-Medien	Reine e-zines	394
18.06.2019 20:03	Ozeaneum: Virtuell abtauchen zu Wal und Wrack	Ostsee-Zeitung		Online-Medien	Printmedien online	24246
18.06.2019 22:53	NABU und OZEANEUM laden zum virtuellen Tauchgang	scharf links		Online-Medien	Reine e-zines	2628
19.06.2019 13:16	Führungen, Fütterungen und Forschung	Ostsee-Zeitung		Online-Medien	Printmedien online	24246
25.06.2019 13:02	Kein Lärm im Meer	UmweltBundesamt		Online-Medien	Behörden und Verbände	17797
01.07.2019	Unter dem Meer	Hörakustik		Printmedien	Fachzeitschriften	16298
03.07.2019 06:05	Stellnetze: Projekt STELLA vom Thünen-Institut, Ursula Verfuß vom Deutschen Meersmuseum hört Wale	Das Informationsprogramm 06:05	NDR Info	Hörfunk	Tagesmagazine, Informationsstrecken	190000
03.07.2019 08:23	Faszination Unterwasserwelt im Ozeaneum	QIEZ		Online-Medien	Online-Dienste, prof. Portale	8475

Published on	Headline	Media title	Station	Media genre	Media type	Outreach
03.07.2019 18:33	Dieser Schwertwal ist der neue Lärm-Botschafter des Ozeaneums	Ostsee-Zeitung		Online-Medien	Printmedien online	24246
03.07.2019 18:40	Das ist der neue Schwertwal im Ozeaneum	Ostsee-Zeitung		Online-Medien	Printmedien online	24246
03.07.2019 19:30	Vom Lärm gestört	Nordmagazin	NDR Mecklenburg-Vorpommern	TV	Regional-magazine	250000
03.07.2019 21:08	Ozeaneum will Meeresbewohnern Gehör verschaffen	NDR		Online-Medien	Mischsites Rundfunk	607803
04.07.2019 03:16	Vom Lärm gestört	Nordmagazin (Mo-So 03:45)	NDR Nord-deutscher Rundfunk Anstalt des öffentlichen Rechts	TV	Regional-magazine	40000
04.07.2019 09:00	Vom Lärm gestört	Nordmagazin (Mo-So 09:00)	NDR Nord-deutscher Rundfunk Anstalt des öffentlichen Rechts	TV	Regional-magazine	50000
04.07.2019 12:03	Kein Lärm Meer' - neue Ausstellung über Lärmverschmutzung der Meere im Ozeaneum Stralsund	Kultur Aktuell 12:03	NDR Kultur	Hörfunk	Nachrichten	80000
04.07.2019 18:00	Steigende Lärmbelästigung	rbb um Sechs	RBB Rundfunk Berlin Brandenburg Anstalt des öffentlichen Rechts	TV	Regional-magazine	190000
05.07.2019 04:45	Steigende Lärmbelästigung	rbb um Sechs (Di-Sa 03:40)	RBB Rundfunk Berlin Brandenburg Anstalt des öffentlichen Rechts	TV	Regional-magazine	20000

Published on	Headline	Media title	Station	Media genre	Media type	Outreach
05.07.2019 06:12	Ozeaneum in Stralsund will „Kein Lärm Meer“	Nordkurier		Online-Medien	Printmedien online	118404
05.07.2019 06:20	Ozeaneum in Stralsund will „Kein Lärm Meer“	Uckermark Kurier		Online-Medien	Printmedien online	26283
05.07.2019 18:05	Wissenschaftler vom Meeresmuseum versuchen das Gehör von Pinguinen zu erforschen	IQ - Wissenschaft und Forschung	Bayern 2 (BR)	Hörfunk	Magazine	170000
06.07.2019 19:01	Unterwasser-Lärm	Gut zu wissen	BR Bayerischer Rundfunk Anstalt des öffentlichen Rechtes	TV	Magazine	350000
07.07.2019 04:15	Unterwasser-Lärm	Gut zu wissen (So)	BR Bayerischer Rundfunk Anstalt des öffentlichen Rechtes	TV	Magazine	40000
08.07.2019 11:03	Kein Lärm Meer	Fisch und Fang		Online-Medien	Printmedien online	3208
12.07.2019 16:30	Unterwasser-Lärm	Gut zu wissen (Fr)	ARD-alpha	TV	Magazine	
13.07.2019 02:45	Unterwasser-Lärm	Gut zu wissen (Sa)	ARD-alpha	TV	Magazine	
15.07.2019 17:00	Kein Lärm Meer	Rügen TV	BB-MV Lokal-TV	TV	Regional-magazine	
26.07.2019 06:05	Meeresakustiker vom Ozeaneum und Meeresmuseum untersuchen Hörvermögen von Pinguinen	Das Informationsprogramm 06:05	NDR Info	Hörfunk	Tagesmagazine, Informations-strecken	190000
15.08.2019 15:25	Ein Hörtest für Pinguine	Deutschlandfunk Kultur		Online-Medien	Radio online	63409

Published on	Headline	Media title	Station	Media genre	Media type	Outreach
15.08.2019 19:07	Forscher vom Meeresmuseum Stralsund untersuchen das Hörvermögen von Pinguinen	Zeitfragen - Forschung und Gesellschaft	Deutschlandfunk Kultur	Hörfunk	Magazine	150000
16.08.2019 13:43	Ökologie Meeresbewohner leiden unter Lärm	Deutschlandfunk		Online-Medien	Radio online	
16.08.2019 17:33	Ökologie Auch Meeresbewohner leiden unter Lärm	Deutschlandfunk		Online-Medien	Radio online	
19.08.2019 18:30	Deutsches Meeresmuseum erforscht Gehör von Pinguinen	nano	3sat	TV	Magazine	150000
20.08.2019 03:10	Deutsches Meeresmuseum erforscht Gehör von Pinguinen	nano (Di-Sa)	ARD-alpha	TV	Magazine	10000
20.08.2019 07:00	Deutsches Meeresmuseum erforscht Gehör von Pinguinen	nano (Di-Sa 07:00)	3sat	TV	Magazine	20000
20.08.2019 09:45	Deutsches Meeresmuseum erforscht Gehör von Pinguinen	nano (Mo-Fr 09:45)	3sat	TV	Magazine	20000
20.08.2019 17:45	Deutsches Meeresmuseum erforscht Gehör von Pinguinen	nano (Mo-Fr)	ARD-alpha	TV	Magazine	10000
24.08.2019 09:05	Dr. Michael Dähne vom Deutschen Meeresmuseum Stralsund testet das Gehör von Pinguinen	Die Profis	radioeins (RBB)	Hörfunk	Magazine	110000
24.08.2019 10:13	Das Gehör von Pinguinen	radioeins		Online-Medien	Radio online	
21.11.2019 13:12	Wissenschaftler des Meeresmuseums forschen in der Antarktis	Ostsee-Zeitung		Online-Medien	Printmedien online	24246

Published on	Headline	Media title	Station	Media genre	Media type	Outreach
09.12.2019 09:43	Stralsunder Meereskundler forschen wieder in der Antarktis	Uckermark Kurier		Online-Medien	Printmedien online	26283
09.12.2019 09:46	Stralsunder Meereskundler forschen wieder in der Antarktis	Nordkurier		Online-Medien	Printmedien online	109934
25.12.2019 13:08	Humboldtpinguine aus Stralsunder Ozeaneum nehmen an Test zur Bedrohung von Meerestieren teil	Informationsradio 13:08	B5 aktuell (BR)	Hörfunk	Tagesmagazine, Informationsstrecken	180000
27.12.2019	Wie wird geforscht im Norden?	DIE ZEIT		Printmedien	Überregionale Wochenzeitungen	1507199
21.02.2020 05:03	Projekt 'Wie gut können Pinguine hören' am Meeresmuseum Stralsund	Der Gute Morgen	Ostseewelle Hit-Radio Mecklenburg-Vorpommern	Hörfunk	Begleitprogramm	150000
21.02.2020 07:34	Pinguine trainieren für die Wissenschaft: Fit für Hörtests	1&1		Online-Medien	Online-Dienste, prof. Portale	40739
21.02.2020 07:35	Pinguine trainieren für die Wissenschaft: Fit für Hörtests	ARCOR		Online-Medien	Online-Dienste, prof. Portale	126543
21.02.2020 08:54	NC Warum diese Pinguine jetzt zum Hörtest müssen!	TAG24		Online-Medien	Reine e-zines	984663
21.02.2020 10:05	Hörtests für Pinguine am Ozeaneum Stralsund und an der Uni Rostock	Grünstreifen	Deutschlandfunk Nova	Hörfunk	Tagesmagazine, Informationsstrecken	10000
21.02.2020 10:14	Pinguine trainieren für die Wissenschaft: Fit für Hörtests	Berliner Sonntagsblatt		Online-Medien	Reine e-zines	47468
21.02.2020 12:55	Pinguine trainieren für die Wissenschaft	Volksstimme.de		Online-Medien	Printmedienverbund online	160435
21.02.2020 15:16	NC Wie gut hören Pinguine?	Westdeutsche Zeitung		Online-Medien	Printmedien online	140861

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21.02.2020 15:23	Pinguine trainieren für die Wissenschaft	Uckermark Kurier		Online-Medien	Printmedien online	26283
21.02.2020 15:26	So hören Pinguine unter Wasser	Nordkurier		Online-Medien	Printmedien online	175980
21.02.2020 17:33	NC Hörtests für Pinguine	Westdeutscher Rundfunk		Online-Medien	Mischsites Rundfunk	415277
21.02.2020 19:05	Forscher des Meeresmuseums Stralsund untersuchen Hörvermögen von Pinguinen	KiRaKa - Radio für Kinder	WDR 5	Hörfunk	Magazine	230000
22.02.2020	Pinguine sind ganz Ohr	Magdeburger Volksstimme Magdeburgische Zeitung		Print-medien	Regional mit Vollredaktion	109744
22.02.2020	Pinguine im Hörtest	Mitteldeutsche Zeitung Halle / Saalekreis		Print-medien	Regional mit Vollredaktion	116270
22.02.2020	Hörtest bei Pinguinen	Pirmasenser Zeitung		Print-medien	Regional mit Vollredaktion	26840
22.02.2020	Lauscher auf, Pinguin:	Dithmarscher Landeszeitung		Print-medien	Regional mit Vollredaktion	47662
22.02.2020	Pinguine im Dienst der Wissenschaft	Badische Neueste Nachrichten ST		Print-medien	Regional mit Vollredaktion	85813
22.02.2020	MOMENTAUFNAHME	Hamburger Morgenpost		Print-medien	Regional mit Vollredaktion	276200
22.02.2020	Wie gut hören Pinguine?	Oranienburger Generalanzeiger		Print-medien	Regional mit Vollredaktion	23892
22.02.2020	Lauscher auf!	Die Harke		Print-medien	Regional mit Teilredaktion	46947
22.02.2020	Lauscher auf!	Lübecker Nachrichten Lübecker-General-Anzeiger		Print-medien	Regional mit Vollredaktion	74226
22.02.2020	Lauscher auf!	DEWEZET Deister-und Weserzeitung		Print-medien	Regional mit Vollredaktion	54047
22.02.2020	Lauscher auf, kleiner Pingu!	Badisches Tagblatt		Print-medien	Regional mit Vollredaktion	17331
22.02.2020	Wie gut hören Pinguine?	Schwäbische Post Aalen		Print-medien	Regional mit Teilredaktion	70438

Published on	Headline	Media title	Station	Media genre	Media type	Outreach
22.02.2020	Lauscher auf!	Hildesheimer Allgemeine Zeitung		Print-medien	Regional mit Teilredaktion	91377
22.02.2020	Lauscher auf!	Märkische Allgemeine Potsdamer Tageszeitung		Print-medien	Regional mit Vollredaktion	84319
22.02.2020	Lauscher auf!	Schaumburger Zeitung		Print-medien	Regional mit Vollredaktion	17073
22.02.2020	Lauscher auf!	Schaumburger Nachrichten		Print-medien	Regional mit Teilredaktion	37470
22.02.2020	Lauscher auf!	Leipziger Volkszeitung Stadtausgabe		Print-medien	Regional mit Vollredaktion	309067
22.02.2020	Wie gut hören Pinguine?	Südwest Presse Ulm		Print-medien	Regional mit Vollredaktion	130159
22.02.2020	Lauscher auf!	Hannoversche Allgemeine Zeitung		Print-medien	Regional mit Vollredaktion	148743
22.02.2020	Lauscher auf!	Cellesche Zeitung		Print-medien	Regional mit Vollredaktion	71810
22.02.2020	Wie gut hören Pinguine?	Schwäbisches Tagblatt Tübinger Chronik		Print-medien	Regional mit Teilredaktion	52681
22.02.2020	Wie gut Pinguine hören können	Lausitzer Rundschau		Print-medien	Regional mit Vollredaktion	57173
22.02.2020	Wie gut hören Pinguine?	Märkische Oderzeitung Frankfurter Stadtbote		Print-medien	Regional mit Vollredaktion	22174
22.02.2020	Watscheln zum Hörtest	Sächsische Zeitung Dresden		Print-medien	Regional mit Vollredaktion	157011
22.02.2020	Im Dienst der Forschung	Recklinghäuser Zeitung		Print-medien	Regional mit Vollredaktion	139999
22.02.2020	Lauscher auf!	Segeberger Zeitung		Print-medien	Regional mit Vollredaktion	31182
22.02.2020	Lauscher auf!	Einbecker Morgenpost		Print-medien	Regional mit Vollredaktion	20701
22.02.2020	Lauscher auf!	Peiner Allgemeine Zeitung		Print-medien	Regional mit Teilredaktion	43196
22.02.2020	lauscher auf!	Dresdner Neueste Nachrichten		Print-medien	Regional mit Vollredaktion	52073
22.02.2020	Lauscher auf!	Neue Presse		Print-medien	Regional mit Vollredaktion	46577

Published on	Headline	Media title	Station	Media genre	Media type	Outreach
22.02.2020	Lauscher auf!	Göttinger Tageblatt		Print-medien	Regional mit Vollredaktion	67932
22.02.2020	Lauscher auf!	Kieler Nachrichten		Print-medien	Regional mit Vollredaktion	207554
22.02.2020	Lauscher auf!	Alfelder Zeitung		Print-medien	Regional mit Teilredaktion	18253
22.02.2020	Lauscher auf!	Gelnhäuser Neue Zeitung		Print-medien	Regional mit Teilredaktion	31716
22.02.2020	Pinguine trainieren für Wissenschaft	Ruhr Nachrichten Dortmund Zeitung Süd (D1)		Print-medien	Regional mit Teilredaktion	31740
22.02.2020	Lauscher auf, Pinguin:	Ruhr Nachrichten Ausgabe Lünen		Print-medien	Regional mit Teilredaktion	31740
22.02.2020	Hörtest für Pinguine	Schwäbische Zeitung Ravensburg		Print-medien	Regional mit Teilredaktion	50876
22.02.2020	Hörtest für Pinguine	Altmark Zeitung Salzwedeler Nachrichten		Print-medien	Regional mit Teilredaktion	13896
22.02.2020	Ab ins Wasser, Ohren auf!	Nürnberger Nachrichten		Print-medien	Regional mit Vollredaktion	97390
22.02.2020	Hörtest für Pinguine	Kreiszeitung Syker Zeitung		Print-medien	Regional mit Teilredaktion	53073
22.02.2020	Hörtest für Pinguine	Oldenburgische Volkszeitung		Print-medien	Regional mit Vollredaktion	60430
22.02.2020	Hörtest für Pinguine	Westfälischer Anzeiger - Hammer Zeitung		Print-medien	Regional mit Vollredaktion	61867
22.02.2020	Hörtest für Pinguine	Rotenburger Kreiszeitung		Print-medien	Regional mit Vollredaktion	22374
22.02.2020	Alle mal gut zuhören!	Pforzheimer Zeitung		Print-medien	Regional mit Vollredaktion	101999
22.02.2020	Hörtests für Pinguine	Kölner Stadt-Anzeiger SK		Print-medien	Regional mit Vollredaktion	239264
22.02.2020	Hörtest für Pinguine	Fehmarnsches Tageblatt		Print-medien	Regional mit Vollredaktion	5817
22.02.2020	Hörtest für Pinguine	Münsterländische Tageszeitung		Print-medien	Regional mit Teilredaktion	69384
22.02.2020	Wusstest du, dass ...?	Freies Wort Suhl		Print-medien	Regional mit Vollredaktion	23281

Published on	Headline	Media title	Station	Media genre	Media type	Outreach
22.02.2020	Pinguine trainieren für Wissenschaft	Hellweger Anzeiger Unna		Print-medien	Regional mit Vollredaktion	11721
22.02.2020	TIERE	Berliner Zeitung		Print-medien	Regional mit Vollredaktion	283000
22.02.2020	Mach doch mal die Lauscher auf, Pingu!	Emder Zeitung		Print-medien	Regional mit Vollredaktion	13000
22.02.2020	Wie Pinguine für Hörtests trainieren	GN Grafschafter Nachrichten		Print-medien	Regional mit Teilredaktion	61176
22.02.2020	Wie Pinguine für Hörtests trainieren	Ostfriesische Nachrichten		Print-medien	Regional mit Vollredaktion	35301
22.02.2020	Pinguine sind fit für Hörtests	Ostthüringer Zeitung OTZ Geraer Zeitung		Print-medien	Regional mit Vollredaktion	24487
22.02.2020	Mit Pinguin Lemmy das Hören üben	NZ Nürnberger Zeitung NZS		Print-medien	Regional mit Vollredaktion	67657
22.02.2020	Pinguine trainieren für Hörtests	Delmenhorster Kreisblatt		Print-medien	Regional mit Vollredaktion	41279
22.02.2020	Wie Pinguine für Hörtests trainieren	Neue Osnabrücker Zeitung Stadt Osnabrück		Print-medien	Regional mit Vollredaktion	143340
22.02.2020	Pinguine watscheln zum Hörtest	Express Köln		Print-medien	Boulevard-Kaufzeitungen mit Vollred.	295083
22.02.2020 07:50	Wie gut hören Pinguine?	Schwäbische Post		Online-Medien	Printmedien online	28883
22.02.2020 07:51	Wie gut hören Pinguine?	GMÜNDER TAGESPOST		Online-Medien	Printmedien online	12984
22.02.2020 09:28	Wie gut hören Pinguine?	Neckar Chronik		Online-Medien	Printmedien online	1538
23.02.2020	Expedition Antarktis	Stralsunder Blitz am Sonntag		Print-medien	Anzeigenblätter mit Redaktion	24395
23.02.2020 08:55	NC Pinguine trainieren für die Wissenschaft	Donaukurier		Online-Medien	Printmedien online	150524
24.02.2020	Pinguine trainieren im Auftrag der Wissenschaft	Frankfurter Neue Presse Stadt		Print-medien	Regional mit Vollredaktion	71187
24.02.2020	Die Unterwasserlauscher	Eßlinger Zeitung		Print-medien	Regional mit Vollredaktion	88840

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24.02.2020	Wie gut können Pinguine hören?	Saale-Zeitung		Print-medien	Regional mit Vollredaktion	30990
24.02.2020	Wie gut können Pinguine hören?	Fränkischer Tag		Print-medien	Regional mit Vollredaktion	90493
24.02.2020	Wie gut können Pinguine hören?	Bayerische Rundschau		Print-medien	Regional mit Teilredaktion	33711
25.02.2020	Pinguine müssen zum Hörtest	Aachener Zeitung		Print-medien	Regional mit Vollredaktion	27209
25.02.2020	Lemmys Gespür für Töne	Fuldaer Zeitung		Print-medien	Regional mit Vollredaktion	75756
25.02.2020	Fit für Hörtests: Pinguine trainieren für die Wissenschaft	Hamburger Abendblatt		Print-medien	Regional mit Vollredaktion	279054
25.02.2020	Pinguine müssen zum Hörtest	Aachener Nachrichten		Print-medien	Regional mit Vollredaktion	27209
26.02.2020	Hörtests für Pinguine	Rhein-Neckar-Zeitung		Print-medien	Regional mit Vollredaktion	137406
26.02.2020 12:21	Neue Studie: Unterwasserlärm bedroht Pinguine	Ostsee-Zeitung		Online-Medien	Printmedien online	24246
26.02.2020 15:04	Ozeaneum exklusiv: Von mäkeligen Haien und kuschligen Pinguinen	Ostsee-Zeitung		Online-Medien	Printmedien online	24246
26.02.2020 15:08	Ein Tag im Ozeaneum	Ostsee-Zeitung		Online-Medien	Printmedien online	24246
26.02.2020 16:40	Vortrag über Pinguine von Dr. Michaël Beaulieu im Meeresmuseum Stralsund	Kultur im Norden 16:40	NDR Kultur	Hörfunk	Nachrichten	80000
27.02.2020	Pinguine im Dienste der Wissenschaft	Die Kitzinger		Print-medien	Regional mit Vollredaktion	8368
27.02.2020	Hörtest für Pinguine	Rhein-Neckar-Zeitung Nordbadische Nachrichten		Print-medien	Regional mit Teilredaktion	19711
27.02.2020	Pinguine im Dienste der Wissenschaft	Rhön- und Saalepost		Print-medien	Regional mit Teilredaktion	12983
27.02.2020	Pinguine reagieren auf Unterwasserlärm	Lübecker Nachrichten Lübecker-General-Anzeiger		Print-medien	Regional mit Vollredaktion	74226

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27.02.2020	Pinguine trainieren für die Wissenschaft: Fit für Hörtests	Märkische Allgemeine Potsdamer Tageszeitung		Print-medien	Regional mit Vollredaktion	84319
27.02.2020	Lärm im Meer NERVT Piguine SEHR	Bild Mecklenburg-Vorpommern		Print-medien	Boulevard-Kaufzeitungen mit Vollred.	191000
27.02.2020 09:40	Heute findet ein Vortrag über Pinguine von Dr. Michaël Beaulieu im Meeresmuseum Stralsund statt	Kultur im Norden 09:40	NDR Kultur	Hörfunk	Nachrichten	80000
29.02.2020	Pinguine werden für Hörtests trainiert	Ostfriesen Zeitung		Print-medien	Regional mit Teilredaktion	93596
29.02.2020	Stresstest für Seevögel	NRZ Neue Ruhr Zeitung Essen		Print-medien	Regional mit Vollredaktion	86544
29.02.2020	Stresstest für Seevögel	Iserlohner Kreisanzeiger und Zeitung		Print-medien	Regional mit Vollredaktion	43560
29.02.2020	Stresstest für Seevögel	Westdeutsche Allgemeine Essen		Print-medien	Regional mit Vollredaktion	86544
29.02.2020	Stresstest für Seevögel	Westfalenpost Zeitung für Hagen		Print-medien	Regional mit Vollredaktion	30132
29.02.2020	Stresstest für Seevögel	WR Westfälische Rundschau Dortmund		Print-medien	Regional mit Vollredaktion	26180
29.02.2020	Pinguine beim Hörtest	Neues Deutschland Bundesausgabe		Print-medien	Überregional mit Vollredaktion	59810
29.02.2020	Pinguine werden für Hörtests trainiert	General-Anzeiger (Rhauderfehn)		Print-medien	Regional mit Vollredaktion	23433
01.03.2020	Pinguine zum Hörtest	OWL am Sonntag Herford, Bünde, Enger, Spenge		Print-medien	Anzeigenblätter mit Redaktion	49593
03.03.2020	Wie gut hören Pinguine?	Main-Echo		Print-medien	Regional mit Vollredaktion	210999
03.03.2020	Pinguine reagieren auf Unterwasser lärm	Die Welt überregional		Print-medien	Überregional mit Vollredaktion	658899
03.03.2020 08:00	Wissen Kompakt	DIE WELT		Online-Medien	Printmedien online	5035644

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04.03.2020	Streicheleinheiten nach dem Hörtest	Berliner Zeitung		Print-medien	Regional mit Vollredaktion	283000
05.03.2020	Lauscher auf, Pingu!	Bocholter-Borkener Volksblatt		Print-medien	Regional mit Vollredaktion	75455
06.03.2020 20:30	Tierisch Unterwegs'	Greifswald TV-Sendung	Greifswald TV GmbH	TV	Sonstige Sendungen	
08.03.2020	Pinguine trainieren für die Wissenschaft	Sonntagsjournal der Bremervörder Zeitung		Print-medien	Anzeigenblätter mit Redaktion	10105
09.03.2020	Ein Hörtest für Pinguine	Stuttgarter Zeitung D		Print-medien	Überregional mit Vollredaktion	397746
09.03.2020	Pinguine trainieren für die Wissenschaft	WZ Westdeutsche Zeitung Düsseldorf		Print-medien	Regional mit Vollredaktion	50827
12.03.2020 20:15	Folgen von Lärm	Wissen aktuell	3sat	TV	Magazine	100000
14.03.2020	Pinguine trainieren für Hörtests	Badisches Tagblatt		Print-medien	Regional mit Vollredaktion	17331
19.03.2020	Pinguine trainieren für die Wissenschaft	HNA Frankenberger Allgemeine		Print-medien	Regional mit Teilredaktion	31776
19.03.2020	Pinguine arbeiten für die Wissenschaft	Flensburger Tageblatt		Print-medien	Regional mit Vollredaktion	106515
19.03.2020	Pinguine arbeiten für die Wissenschaft	Der Nordschleswiger		Print-medien	Regional mit Vollredaktion	3966
19.03.2020	Pinguine arbeiten für die Wissenschaft	Stormarner Tageblatt		Print-medien	Regional mit Teilredaktion	12518
19.03.2020	Pinguine arbeiten für die Wissenschaft	Pinneberger Tageblatt		Print-medien	Regional mit Vollredaktion	23384
20.03.2020	Den Lauschern der Pinguine auf der Spur	Freie Presse Chemnitzer Zeitung		Print-medien	Regional mit Vollredaktion	83070
23.03.2020	Pinguine trainieren für die Wissenschaft	Waldeckische Landeszeitung		Print-medien	Regional mit Vollredaktion	84547
23.03.2020	Pinguine trainieren für die Wissenschaft	HZ Hersfelder Zeitung		Print-medien	Regional mit Teilredaktion	43132
26.03.2020	Pinguine trainieren für die Wissenschaft	Solinger Tageblatt		Print-medien	Regional mit Teilredaktion	91267
27.03.2020	Pinguine trainieren für die Wissenschaft	HNA Witzenhäuser Allgemeine		Print-medien	Regional mit Teilredaktion	22172

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27.03.2020 20:53	Hearing in Penguins - Forschung im Stralsunder Ozeaneum	MV1 TV		Online-Medien	TV online	7917
25.04.2020	Beliebt und bedroht	Westfälischer Anzeiger - Hammer Zeitung		Print-medien	Regional mit Vollredaktion	62041
04.06.2020 14:00	Pinguin-Forschung	MDR um 2	MDR Mitteldeutscher Rundfunk - Anstalt des Öffentlichen Rechts	TV	Tagesmagazine	250000
05.06.2020 18:00	Pinguin-Forschung	rbb um Sechs	RBB Rundfunk Berlin Brandenburg Anstalt des öffentlichen Rechts	TV	Regional-magazine	90000
06.06.2020 03:40	Pinguin-Forschung	rbb um Sechs (Di-Sa 03:40)	RBB Rundfunk Berlin Brandenburg Anstalt des öffentlichen Rechts	TV	Regional-magazine	20000
22.09.2020 18:19	Die Bierkulturstadt in Wien	Schwäbische (Zeitung)		Online-Medien	Printmedien online	132917
25.10.2020 10:37	HÖR MAL!	LAND & MEER		Online-Medien	Printmedien online	153
01.11.2020 12:05	Hörtest - Deutsches Meeresmuseum untersucht das Stressempfinden von Pinguinen	Der Sonntagmittag	Bremen Zwei (Radio Bremen)	Hörfunk	Tagesmagazine, Informations-strecken	20000
07.11.2020 18:05	Hörtest - Deutsches Meeresmuseum untersucht ab welcher Lautstärke Pinguine Streß empfinden	Mare Radio	Bremen Zwei (Radio Bremen)	Hörfunk	Magazine	20000
01.12.2020 13:30	Wissensclip veranschaulicht	Süddeutsche.de		Online-Medien	Printmedien online	3036631

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	Unterwasserlärm in Meeren					
01.12.2020 13:32	Wissensclip veranschaulicht Unterwasserlärm in Meeren	T-Online		Online-Medien	Online-Dienste, prof. Portale	9140290
01.12.2020 13:33	Wissensclip veranschaulicht Unterwasserlärm in Meeren	WEB.DE		Online-Medien	Online-Dienste, prof. Portale	577248
01.12.2020 13:37	Wissensclip veranschaulicht Unterwasserlärm in Meeren	RTL.de		Online-Medien	TV online	3665631
01.12.2020 19:58	Wissensclip veranschaulicht Unterwasserlärm in Meeren	Zeit Online		Online-Medien	Printmedien online	3421482
13.12.2020	Unterwasserlärm	Stralsunder Blitz am Sonntag		Print-medien	Anzeigenblätter mit Redaktion	24395
16.12.2020 03:40	Museumsführer vom 15.12.2020 aus dem Deutschen Meeresmuseum Stralsund	MV1 TV		Online-Medien	TV online	
02.02.2021 16:55	Forschung an Pinguinen	X:enius	Arte G.E.I.E.	TV	Magazine	80000
03.04.2021 06:01	Hörtest mit Pinguinen	X:enius	BR Bayerischer Rundfunk Anstalt des öffentlichen Rechtes	TV	Magazine	50000
10.04.2021 18:09	Klang und Lärm der Ozeane	FAZ.net		Online-Medien	Printmedien online	3228294
20.04.2021 07:09	Tiere: Pinguine reagieren sensibel auf Geräusche	Norddeutsche Neueste Nachrichten		Online-Medien	Printmedien online	2511
20.04.2021 07:12	Pinguine reagieren sensibel auf Geräusche	GMX		Online-Medien	Online-Dienste, prof. Portale	1999856

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20.04.2021 07:12	Pinguine reagieren sensibel auf Geräusche	WEB.DE		Online-Medien	Online-Dienste, prof. Portale	695195
20.04.2021 07:12	Pinguine reagieren sensibel auf Geräusche	1&1		Online-Medien	Online-Dienste, prof. Portale	14456
20.04.2021 07:12	Pinguine reagieren sensibel auf Geräusche	Süddeutsche.de		Online-Medien	Printmedien online	3100135
20.04.2021 07:19	Pinguine reagieren sensibel auf Geräusche	Zeit Online		Online-Medien	Printmedien online	3500845
20.04.2021 07:19	Pinguine reagieren sensibel auf Geräusche	FOCUS Online		Online-Medien	Printmedien online	6344396
20.04.2021 07:20	Pinguine reagieren sensibel auf Geräusche	DIE WELT		Online-Medien	Printmedien online	6078193
20.04.2021 07:24	Pinguine reagieren sensibel auf Geräusche	T-Online		Online-Medien	Online-Dienste, prof. Portale	11437020
20.04.2021 07:46	Pinguine reagieren sensibel auf Geräusche	Ostseewelle HIT-RADIO Mecklenburg-Vorpommern		Online-Medien	Radio online	986
20.04.2021 09:00	Pinguine reagieren sensibel auf Geräusche	RTL.de		Online-Medien	TV online	3849385
20.04.2021 09:54	Pinguine reagieren sensibel auf Geräusche	koeln.de		Online-Medien	Öffentliche Kommunen, Amtsblätter	50328
20.04.2021 10:52	Pinguine reagieren sensibel auf Geräusche	GEO		Online-Medien	Printmedien online	105462
20.04.2021 14:44	Pinguine sind sensibel – über und unter Wasser	Berliner Zeitung		Online-Medien	Printmedien online	171930
22.04.2021 00:00	Unterwasserlärm betrifft Pinguine genauso wie Wale und Delfine	ECO-World		Online-Medien	Printmedien online	1327
26.04.2021 00:01	Aktionswoche gegen "Lärm im Meer"	Langeoog News		Online-Medien	Reine e-zines	3702

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27.04.2021	Mensch, mach leiser!	taz Die Tageszeitung		Print-medien	Überregional mit Vollredaktion	322600
27.04.2021 07:08	Mensch, mach leiser!	taz.de		Online-Medien	Printmedien online	316138