Cetacean bearing using a compact four-hydrophone array: echolocation and communication features highlighted for the free-ranging short-beaked common dolphin

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Abstract

Understanding the circumstances and mechanisms leading to bycatch events of small cetaceans is crucial for enabling mitigation measures. Short-beaked common dolphins (Delphinus delphis) are particularly exposed to this issue in the Bay of Biscay, France. This study aims at developing a method for tracking the movements of free-ranging odontocetes in 2D (with azimuth and elevation angles) using their echolocation clicks, recorded by a compact and portable tetrahedral hydrophone array (TETRA). This approach could help to provide insights into their interactions with fishing gear. In addition, whistle characteristics were extracted from the recordings in order to determine whether variations could be found, depending on the orientation of the dolphins determined by their 2D tracking. TETRA was deployed during field experiments to record echolocation clicks and whistles from wild dolphin groups. Time differences of arrival were estimated from the echolocation clicks in order to determine the dolphins' 2D angles relative to TETRA. Validation tests indicated mean offsets of 8.6° and 4.4° for azimuth and elevation angles, respectively, compared to GPS data. This demonstrates TETRA's potential for passive acoustic tracking. Analysis of dolphins travelling in straight lines revealed that their echolocation clicks were highly directional, with an estimated diffusion angle of 59.3° (bootstrap sampling, 95%CI [56.8–61.8]°). Furthermore, 411 whistles were manually annotated

Preprint submitted to Applied Acoustics *October 9, 2024*

to investigate potential variations in their characteristics based on dolphin orientation derived from the echolocation clicks. Our findings indicate that whistle characteristics exhibit only slight dependency on the orientation of the dolphins, suggesting that these whistles are almost omnidirectional. This work demonstrates the feasibility of using a compact hydrophone array for 2D positioning of wild dolphins from their echolocation clicks. More generally, our findings will help to prepare the ground for future experiments on the acoustic behaviour and movements of short-beaked common dolphins in the Bay of Biscay relative to bycatch.

Keywords: bio-acoustics, cetaceans, clicks, whistles, sound processing, sound source positioning

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1. Introduction

Among threats to marine mammals, bycatch is the main direct cause of death worldwide [1, 2]. In the Bay of Biscay, France, the mortality of short-beaked common dolphins *Delphinus delphis* (Linnaeus, 1758) has reached critical levels, particularly since 2016 [3]. The latest estimates indicate that 6,920 (95%CI [4,038;15,368]) individuals were caught in bycatch events during the winter of 2021-2022 [4]. For the same period, the population of short-beaked common dolphins in France's Atlantic coastal waters was estimated at 181,624 (95%CI [128,601;258,052]) individuals [5]. In comparison, the potential biological removal (PBR), used as a threshold to define unacceptable bycatch levels [6, 7] was computed at 4,927 individuals per year in 2020 [8]. It shows that current levels of short-beaked common dolphin bycatch are unsustainable for this population [4]. In response, the European Commission issued a formal notice to France in 2020, instructing the country to identify solutions to limit the bycatch of short-beaked common dolphins. Since 2016, France has launched several projects aimed at reducing dolphin bycatch. Most of these projects focus on mitigation techniques.

However, the interactions between dolphins and fishing nets are still poorly understood. In practice, the mechanism by which dolphins become entangled in fishing nets remains seriously understudied. The precise moment at which bycatch occurs during fishing operations and the circumstances surrounding these events remain unclear. In theory, dolphins should be able to detect a fishing net from a safe distance of a few metres [9], but the detection range is in fact highly dependent on the material of the net (i.e. reflectivity), the angle of arrival of their clicks on fishing nets [10], and varies with species [11]. Among the hypotheses to explain why dolphins are victims of bycatch are the following: echolocation clicks could be reflected by fishes in front of nets [9], therefore reducing their detectability, or they could be acoustically hidden by the noise generated by boat engines and/or by the bubbles produced by the propeller. The behaviour of the dolphin could also have an impact: foraging dolphins might not see fishing nets as dangerous [9] when searching for prey.

The DOLPHINFREE project ('Dolphins free from fishery bycatch') is aimed at developing a bio-inspired acoustic beacon [12] in order to explicitly inform short-beaked common dolphins of the presence of fishing nets and of their mortal danger. The idea is to enable dolphins to detect a net from further away, or despite being off-angle. During this project, audio recordings of the responses of short-beaked common dolphins to the bio-inspired beacon were analysed. Here, we focus on echolocation clicks and whistles. Echolocation clicks enable dolphins to navigate their environment and detect 'objects' such as prey [13]. Whistles are mainly used for social communication [14, 15], but they also play a role in the positioning of individuals in relation to each other within a group [16, 17, 18, 19, 20, 21].

Using a prototype of a compact antenna with 4 hydrophones, we were able to record both echolocation clicks and whistles of short-beaked common dolphins during the DOLPHINFREE experiments at sea. In order to understand the movements of dolphins around fishing nets, the aim of this work is to develop a method that will enable the determination of the position of short-beaked common dolphins, and more generally other odontocetes, in 2D using only their echolocation clicks. Such a method could be used to better understand the context leading to the bycatch of short-beaked common dolphins, using passive acoustic monitoring, to avoid the introduction of disturbances in bycatch contexts. Unfortunately, the determination of the position of a sound source is a complex task [22], especially by means of passive acoustic monitoring. Several methods have already been applied to free-ranging cetaceans in 3D [23, 24, 25, 26], including some on groups of *Orcinus orcas* or sperm whales using a large base hydrophone antenna [27] or a short base [28, 29, 30, 31, 32]. But, to our knowledge, no comparable method has been specifically developed for groups of free-ranging short-beaked common dolphins. This study results into a precise investigation of the whistles of these animals. It is known that high-frequency harmonics propagate differently depending on the orientation of a dolphin towards a receiver [18, 19, 20], and some level of directivity is expected for fundamental frequencies [18], but this was often not quantified empirically as we demonstrate in this article.

The main aim of this work is to determine the position of dolphins in 2D using a prototype of a small 4-hydrophone array, and then determine directivity features of echolocation clicks and whistles. This study will assess the extent to which whistles are omnidirectional, as their characteristics could vary depending on the orientation of the sound source. Results of this work will help to prepare the ground for future experiments on the acoustic behaviour and movements of dolphins tracked around fishing nets.

2. Materials and methods

2.1. Study area

The experiments were conducted during the summers of 2021 and 2022, a few miles off the coast of Penmarc'h, Brittany, France. According to previous studies, the temperature and salinity of surface waters vary slightly in the first 20 metres in this region [33, 34, 35]. From observations and modelling data, the mean surface temperature where the experiments were taking place in July was about 16°C ± 1°C [36, 37, 38]. Additionally, the thermocline oscillates between 15 and 50 metres in July in this area [33]. According to our visual observations, dolphins were mainly located in the surface layer of the ocean during our experiments. Therefore, they were located in a layer where the temperature and salinity gradients remained relatively low. As we could not measure these parameters during our experiments, we chose a temperature of 16°C as a reference, which gives a speed of sound underwater of about 1460 $\mathrm{m.s^{-1}}$.

2.2. Materials

Experiments were conducted from a 6.5 m semi-rigid pneumatic boat. We recorded the boat's position by GPS throughout the experiments. Visual observations were conducted by observers onboard and, when the conditions at sea permitted it, were supported by videos taken from a DJI Phantom drone above the boat (more details are provided in [12]).

We used our prototype of a compact 4-hydrophone array, tested and validated during previous studies [39, 40] (Fig. 1). Its sides are made of PVC tubes that are ≈90 cm in length and joined at their ends by 3D-printed parts. This tetrahedral antenna (TETRA) was deployed 3 m below the surface. A hydrophone is mounted on each of its vertex: three cylindrical SQ26 hydrophones, and one spherical hydrophones CR3 (that has a larger frequency band) from Cetacean Research™. The QHB motherboard [41], which is built by our team at the SMIoT laboratory, affiliated with the University of Toulon, enables the simultaneous recording of audio data of the 4 hydrophones at 256,000 Hz, and with 24 bit-depth. This motherboard also includes an Inertial Measurement Unit (IMU) that records the orientation of the system on the 3 axes of rotation (yaw, pitch, roll). This configuration makes it a portable device, very practical for deployment from a dinghy, but this also reduces its accuracy when determining positions. In order to assess the precision of the 2D positions estimated using TETRA, a bio-inspired CETASAVER-DOLPHINFREE acoustic beacon was used to simulate clicks emitted by dolphins from known GPS positions.

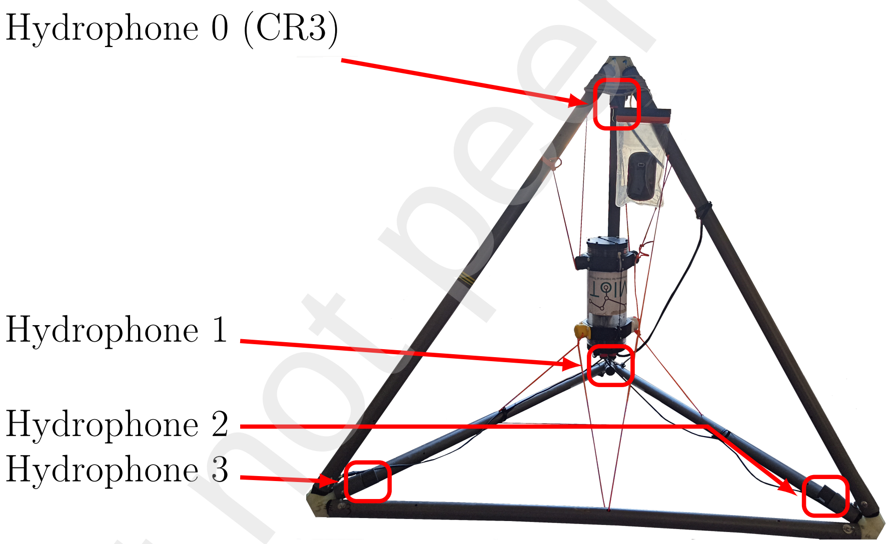


Figure 1: Annotated photo of the TETRA antenna used during the 2021 and 2022 surveys of the DOLPHINFREE project. TETRA's sides are ≈90 cm in length.

2.3. Data collection

Acoustic observational data were collected during the DOLPHINFREE experiments [12], which aimed at testing a prototype of a bio-inspired acoustic beacon (CETASAVER-DOLPHINFREE) designed by the University of Montpellier, IFREMER and the OCTech company. However, here, TETRA was deployed outside the protocol of the DOLPHINFREE experiments: when there were no recorded emissions from the beacon and no fishing net was deployed, as the aim was to monitor the dolphins during their natural behaviour. On-board observers collected observation data using the same methods as in [12]. In order to have similar conditions in all our recordings, we chose to keep only the sequences containing acoustic signals emitted by dolphins when they were moving around.

Thus, about 45 minutes of audio recordings matching our constraints were collected with the antenna. In addition, a recorded sequence of 15 minutes of artificial echolocation clicks emitted by the CETASAVER-DOLPHINFREE acoustic beacon from different angles was made, and served as a validation sequence for the determination of the Angle of Arrival (AoA) of the sounds to TETRA.

We use the echolocation clicks of dolphins to determine the Time Delays of Arrivals (TDoAs). Whistles could also be used for localisation [24], but clicks are easier to work with since they are very local acoustic events (lasting less than 0.3 ms). We automatised the detection of echolocation clicks using the same method as in [12], based on the Teager-Kaiser operator [42]. The detector was run on each one of the 4 channels recorded. Then, TDoAs were determined using a geometric steered response power (GSRP) method (script available via [43]), an alternative to the commonly used SRP-PHAT method [44]. TDoAs were estimated between each pair of hydrophones. With 4 hydrophones (H_0, H_1, H_2, H_3) we measured 3 TDoAs ($TDOA_{(0,1)}$, $TDOA_{(0,2)}$, $TDOA_{(0,3)}$). Knowing the position (x_i, y_i, z_i) of each hydrophone, the TDoAs can be used to determine the direction of the sound source (S) from TETRA by solving equation 2.

$$A = \begin{pmatrix} H_1 - H_0 \\ H_2 - H_0 \\ H_3 - H_0 \end{pmatrix}, \quad B = \begin{pmatrix} c \times TDOA_{(0,1)} \\ c \times TDOA_{(0,2)} \\ c \times TDOA_{(0,3)} \end{pmatrix}, \text{ with } c \text{ the celerity of sound.} \tag{1}$$

$$A \cdot S = B \quad \Leftrightarrow \quad S = A^{-1} \cdot B \tag{2}$$

$$S = [\cos(\theta)\cos(\phi), \cos(\theta)\sin(\phi), \sin(\theta)\sin(\phi)]\text{ , for } ||S|| = 1 \tag{3}$$

In theory, 3 TDoAs measurements are sufficient to determine the 3D position of a sound source. In practice, small empirical errors (measure of TDoAs, inter-hydrophone distances) prevent us from being able to determine the 3D position of each sound source; such a system should be over-determined in order to be solvable (4 TDoAs for 3 dimensions). Most similar studies on cetaceans use devices with a higher number of antennas and hydrophones and/or a higher distance between hydrophones (e.g. [23, 27, 45, 46, 32, 47, 25, 48]). Therefore here, we only aimed at extracting 2D positions for each sound source: the horizontal angle (azimuth 'ϕ') and the vertical angle (elevation 'θ'), but not the distance ('ρ').

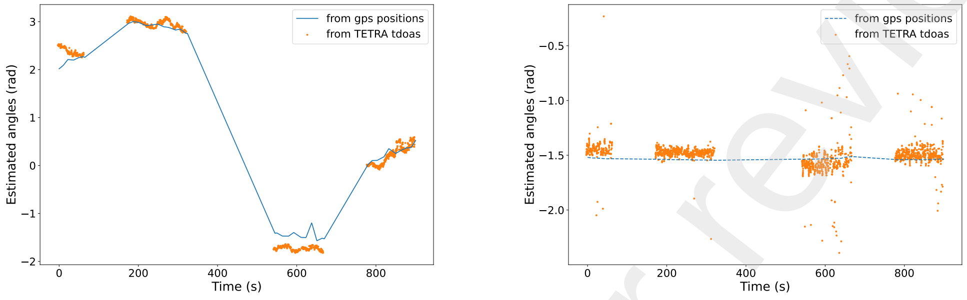
TETRA audio recordings also enabled us to collect whistles emitted during the experiments. In total, 452 whistle contours were manually annotated using a custom-made annotation tool (script available via [49]). Spectrograms were generated from raw audio recordings resampled at 64 kHz, with a frame size of 1024 samples and a hop length of 512 samples. In post-processing, only the whistles with a duration above 100 ms and a Signal-to-Noise Ratio (SNR) above 10 dB were kept for analysis, in order to avoid keeping fragments of whistles. 411 whistles corresponding to these constraints were selected. The following characteristics were extracted from each whistle: SNR (dB), duration (s), number of harmonics, minimum, maximum and mean frequencies (kHz). SNR is computed as the difference between the mean level of a signal and the mean level of ambient noise over a comparable time-frequency frame.

3. Results

3.1. Validation of the TETRA prototype

In order to measure the precision of TETRA in the determination of AoAs, several emissions of clicks artificially emitted by the CETASAVER-DOLPHINFREE beacon were recorded by TETRA during a test experiment. The relative position of TETRA and the beacon was computed from their GPS positions. Using our click detector, we determined the TDoAs and their associated AoAs for these sequences. Azimuths can be obtained directly from GPS positions but elevation angles were interpolated by considering the relative depth of the TETRA antenna and the beacon.

The results in Figure 2 demonstrate that the angle estimates obtained from TDoAs differ from GPS measurements by 0.15 radians (8.6°) for the azimuths, and 0.08 radians (4.4°) for the elevation angles. For the latter, we observe regular sinusoidal variations (Fig. 2b), which seem to be linked to the presence of swell and waves. During this calibration sequence (Fig. 2), the sound of the engines of passing boats were recorded around the 600 s timestamp. This noise affected our recording of dolphin clicks, which affected the determination of TDoAs and, ultimately, the estimation of azimuth and elevation angles. Overall, the differences measured are relatively small and can be overlooked when considering a large number of clicks.



(a)

(b)

Figure 2: Estimated azimuth (2a) and elevation angles (2b) of the DOLPHINFREE beacon measured from the TETRA antenna during a calibration experiment. *Dashed line corresponds to the beacon's elevation interpolated from GPS positions.*

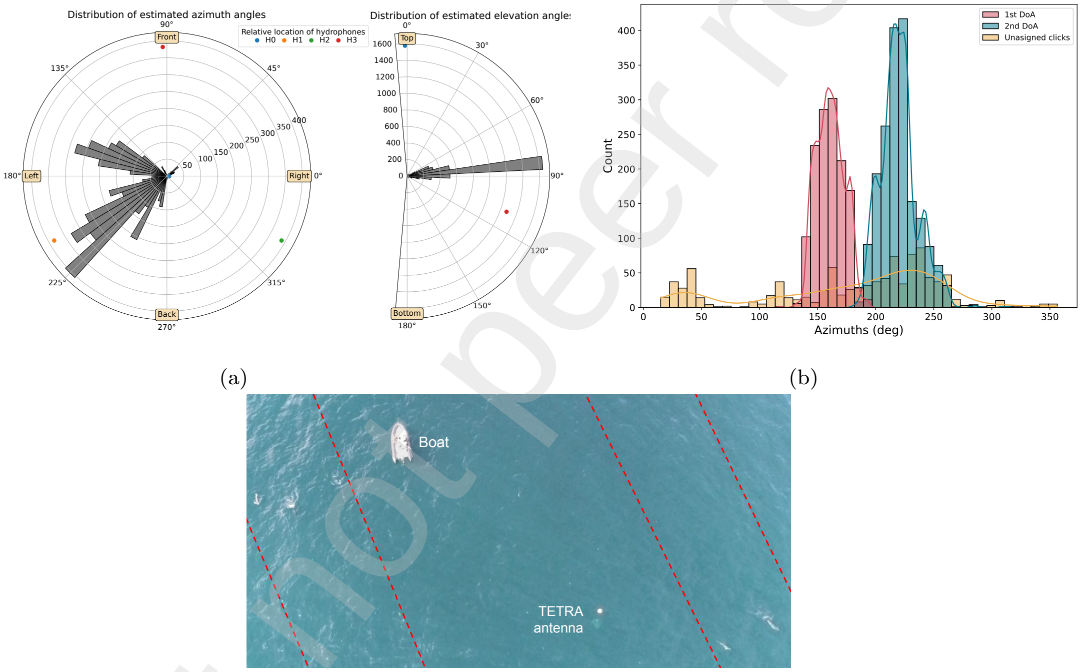
3.2. Click directivity

During one of the experimental sessions (the 2022/07/21 at 09:17 a.m.), we were able to record dolphins travelling in a straight line, passing almost right over the position of TETRA, while the drone was recording the scene. Thus, we were able to analyse the video and acoustic recordings together.

In the video, several groups of dolphins crossing the screen can be observed. They all followed approximately the same direction, at low speed and without stopping beside the antenna (dolphins passing by are usually interested in its presence.), individuals pass on either side of the antenna. A large number of clicks were detected from audio recordings of this session. This enabled us to determine the 2D position of each dolphin swimming past TETRA (Fig. 3a), and we were able to confirm their positions using the video recorded from the drone (Fig. 3c).

The polar plot of the estimated azimuth angles from this session (Fig. 3a) shows a bimodal distribution. Dolphins were following a quasi-straight line and passed on both sides of the antenna; this distribution reflects that dolphins approached the antenna from both sides. Click trains were then divided into two groups based on their DoAs, which highlights the bimodal distribution (Fig. 3b).

Since the dolphins followed the same relative paths, we can make the assumption that they were travelling in parallel trajectories. On the basis of this approximation, an estimation of the directivity of their echolocation clicks can be obtained. A difference in means of 59.3° (95%CI [56.8-61.8]°, from bootstrap resampling) is measured between the AoAs of the two paths. This value constitutes an approximation of the horizontal angle of diffusion for echolocation clicks of short-beaked common dolphins. With the video, we confirmed that once dolphins passed the antenna, their echolocation clicks were no longer recorded by the hydrophones.



(a)

(b)

(c)

Figure 3: Results extracted from the experimental session of the 2022/07/21. (3a) Estimated angles of arrival of detected echolocation clicks, (3b) azimuths grouped by trains of clicks and (3c) annotated screenshot. *Red lines represent the corridors in which the dolphins were travelling.*

Furthermore, the polar plot of the elevation angles (Fig. 3a) shows that the detected echolocation clicks were mostly estimated to come from an angle of 97° (90° being the plane parallel to the surface of the sea). This means that the detections came at a relatively small angle above the antenna. This observation is consistent with the visual observations: dolphins stayed on the surface most of the time during the experiments.

3.3. Whistles and dolphins' orientation

3.3.1. Whistle features

In addition to the determination of the 2D positions of dolphins from their echolocation clicks, we were able to manually annotate the contours of whistles produced at the same time. From Section 3.2, we know that if an echolocation click is detected, it is because a dolphin is facing the antenna. Dolphins facing the antenna are "on-axis" while dolphins facing outwards are "off-axis". Thus, we created 2 categories of whistles: those produced at the same time as echolocation clicks are referred to as "on-axis", and those without echolocation clicks produced at the same time are "unknown" (as they could be emitted both from dolphins that were not echolocating, or echolocating but not towards the antenna). In addition, using the angles computed from the echolocation clicks, we were able to associate "on-axis" whistles with an estimated 2D position of the group emitting clicks at the same time (0° is towards the antenna and 180° is outwards).

All variables, as well as the pairwise relationships characterising these 411 whistles, are represented in Figure 4. Note that the orientations were only computed for the whistles which had echolocation clicks emitted around the same time as the whistle was detected. There are 188 "on-axis" whistles, and 223 "unknown" whistles in total.

The Figure 4 shows that there were no relationships nor correlations between the estimated orientation angles of the dolphins and any of the features extracted from the whistles (no trend detected from lowess smoothing and highest Spearman's correlation coefficient (r) was only 0.17). However, maximum and mean frequencies were strongly related and correlated ($r = 0.82$), and so were the minimum and mean frequencies ($r = 0.75$). This result was expected since, mathematically, mean frequencies take into account minimum and maximum frequencies in their computation. There also seemed to be weaker correlations between duration and SNR ($r = 0.40$), minimum frequency ($r = -0.31$) and maximum frequency ($r = 0.42$).

Using GLMs, we modelled the relation between these last three couples of variables. We found no statistical evidence of a relation between SNR and minimum frequency (z=-1.32, d.f.=409, p=0.188) or SNR and maximum frequency (z=1.66, d.f.=409, p=0.097). However, a positive relationship held between SNR and duration of whistles (coef=0.35, z=2.02, d.f.=409, p=0.0435): the longer a whistle lasted, the higher was its SNR (Fig. 5).

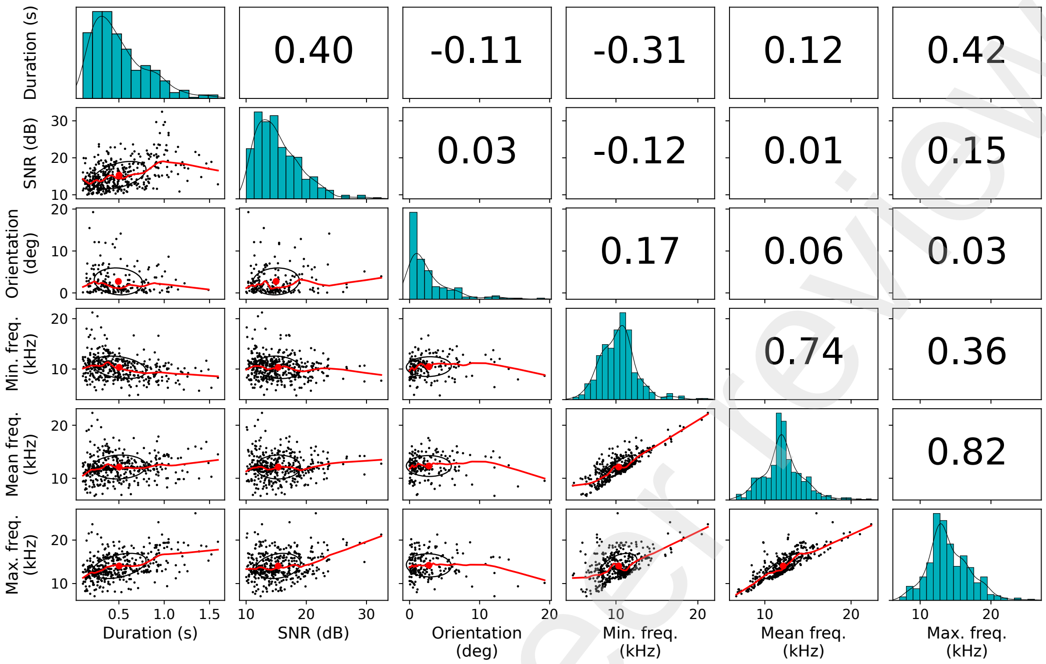


Figure 4: Draftsman's plot of the variables associated to the whistles annotated from TETRA recordings. *(Diagonal) Histogram and kernel density function. (Top triangle) Pairwise Spearman correlation coefficients. (Bottom triangle) Scatter plots with lowess smoothing (red line) and confidence ellipsis.*

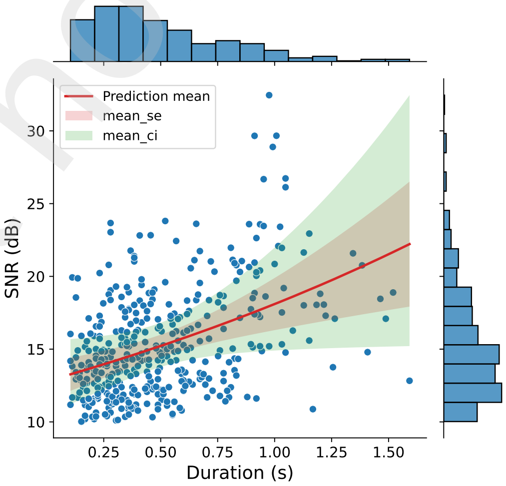
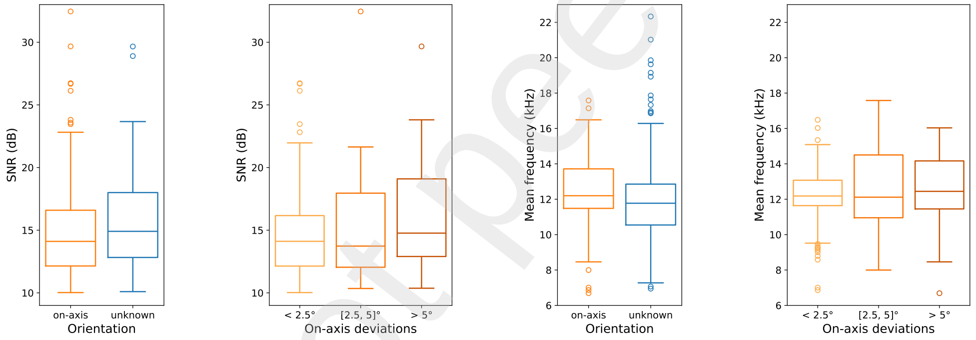


Figure 5: Modelling of the SNR as a function of the whistle duration. *Points show whistle measures (n=411).*

3.4. Influence of orientation

We compared whistles emitted on-axis with those having an unknown orientation (Figure 6). On-axis whistles were recorded with a higher SNR (14.2 dB) (Mann-Whitney U (MWU) test, U=18074, p=0.016, Fig. 6a) and at a lower mean frequency (12.32 kHz) (MWU test, U=24493, p=0.0033, Figure 6c) than whistles emitted from unknown orientations (15.08 dB and 11.75 kHz, respectively). On-axis whistles are also further categorised, according to the estimated angle from which dolphins were emitting sounds in relation to the antenna (see sub-categories of on-axis emissions in Figs. 6b & 6d). However, no effect of the orientation angle of the dolphins towards the antenna on their whistles were observed on measured SNRs (Kruskal-Wallis (K-W) test, H=1.37, d.f.=2, p=0.5), nor on measured mean frequencies (K-W tests, H=0.51, d.f.=2, p=0.78).



(a) (b) (c) (d)

Figure 6: Boxplots of SNRs (6a & 6b) and mean frequencies (6c & 6d) of annotated whistles depending on the estimated orientation of the dolphins emitting them in relation to the antenna. *'On-axis': dolphin facing the antenna, 'off-axis': dolphin facing away. Sub-divisions of 'on-axis' orientations detailed in (6b & 6d).*

We found harmonics in 4.4% of the annotated whistles (18 harmonics for 411 whistles), and detected harmonics had weaker signals than their fundamental frequencies. This dataset did not enable us to identify any difference between whistles emitted by on-axis dolphins and whistles emitted by dolphins whose orientation is unknown (MWU test, U=20503, p=0.28).

4. Discussion

The aim of this study was to use audio recordings collected with a portable prototype 4-hydrophones array (TETRA) to track the movements of short-beaked common dolphins in 2D. The TETRA antenna is similar to other classical hydrophone arrays designs [29, 32, 31, 30], but its aim here was to make precise angle estimates for close animals, as dolphins can make rapid turns and move fast, whereas other studies can use smoothing and consider longer periods of time. We were able to achieve this goal by estimating the DoAs of their echolocation clicks. Distances cannot be easily obtained with this compact array prototype. Further analyses showed that short-beaked common dolphins echolocation clicks are highly directive, a property that we used to prove that the features of recorded whistles can vary depending on the orientation of the dolphins towards TETRA.

Using TETRA for estimating angles of sound sources has certain advantages: it is a very practical and easy-to-use device. However, its limited number of hydrophones and its use in the sea surface layer makes the collected data complex to use: it records noise from waves, reflections of echolocation clicks [50], and the sea surface temperature can vary drastically. The offsets observed between GPS angles and estimations from TDoAs (Fig. 2) could be related to various aspects: GPSs not being synchronised, ambient acoustic noise, echolocation click reflections or variations in the inter-hydrophone distances. Despite all these potential sources of error, the mean offset measured between GPS and estimations of TDoAs is only 8.6°, which is satisfactory for such a device. In the future, a 5th hydrophone will be added to the antenna, enabling more precise estimates and, with further improvements, perhaps even an estimate of the distance, in order to track the movements of cetaceans in 3D.

During one experimental session at sea, we had the uncommon opportunity to record the movements of dolphins on both sides of the TETRA antenna, both in video and audio formats. This enabled us to analyse vocalisations and echolocation clicks of free-ranging animals with precision, which enabled us to estimate the horizontal diffusion angle of echolocation clicks emitted by wild short-beaked common dolphins ($\approx 60°$). This estimation is close to results obtained during experiments carried out on other closely related species, but cannot be considered as accurate as results from experiments on captive animals [51, 52, 19, 53, 54]. From these results, it appears that echolocation clicks are very directive and almost completely inaudible/not recorded when dolphins are off-axis. Therefore, in future experiments, localisation of dolphins using their echolocation clicks should use several similar small hydrophone arrays.

The whistles extracted from the audio recordings made with TETRA were subjected to analysis in order to investigate the variations their characteristics according to the orientation of the dolphins towards the antenna. We found that whistles emitted on-axis were more likely to have a lower SNR and a higher mean frequency than whistles emitted from an unknown orientation in relation to the antenna (mean difference of 0.9 dB and 570 Hz, respectively). This means that whistles of high frequency emitted by off-axis dolphins are less likely to be recorded, and that they need to be emitted at a higher energy level to be recorded properly. Even if variations were expected [19], it should be noted that we only record slight differences in characteristics between whistles emitted on-axis and off-axis. Therefore, whistles of short-beaked common dolphins should be considered quasi-omnidirectional rather than entirely omnidirectional, as the orientation of a dolphin emitting whistles affects the recording of these signals. Our conclusion is limited as we could not determine the orientations of the dolphins with precision. It should also be considered that whistles emitted by dolphins from unknown orientations could have been emitted both by off-axis dolphins or silent on-axis dolphins.

We found harmonics for 4.4% of the annotated whistles. Previous studies indicate that harmonics should be recorded less frequently when the dolphins are not echolocating towards the antenna [18, 20, 19], a feature that could help them coordinate their movements, as a group. However, very few harmonics with an SNR $>$ 10 dB were detectable in our recordings, which did not enable us to explore this statement.

Overall, this research demonstrates that a low cost portable array of 4 hydrophones is sufficient to determine the 2D position of free-ranging short-beaked common dolphins from their echolocation clicks. A larger array, or several TETRAs should be jointly used to track each individual in 3D, as planned in our future experiments. With TETRA, we showed that whistles of short-beaked common dolphins in the Bay of Biscay do not spread in the same way in all directions. However, further experiments are necessary to add precision to these empirical results. Overall, this kind of device could help to understand dolphins-fishers interactions, in particular the study of the movement of dolphins around fishing nets, which is essential in order to prevent bycatch. Two or more TETRA antennas deployed under buoys around the fishing nets could suffice to track the dolphins' movements, given that they emit echolocation clicks frequently enough. These systems would facilitate the tracking of the trajectory of these animals in murky waters using passive acoustic monitoring, without the need for tags.

Author contributions

Data acquisition: all authors; Conceptualisation, methodology, software, formal analysis, writing, review and editing: L.L., H.G. and B.M.; validation, supervision: B.M. and H.G.; data curation, writing, original draft preparation, visualisation, figures production: L.L.; concept, design and construction of Tetra antenna: H.G ; project administration: B.M.; All authors have read and agreed to the published version of the manuscript.

Funding

The DOLPHINFREE project coordinated by B.M. is funded by the European Maritime and Fisheries Fund (EMFF) and France Filière Pêche (FFP). L.L.'s PhD grant is provided by Montpellier University. This study was co-granted by the national Chair in Artificial Intelligence for bioacoustics ADSIL ANR-20-CHIA-0014-01 funded by DGA and AID (PI H.G.).

Institutional Review

The DOLPHINFREE project has been approved by (i) agreement 0-12520-2021/PREMAR_ATLANT/AEM/NP from the French Maritime Prefecture of the Atlantic "to conduct a survey for monitoring groups of common dolphins by means of scientific instruments off the south Finistère coast, following Décret n°2017-956 of the scientific marine research", (ii) favourable notification from the Ethical Committee in Animal Experiment of Languedoc Roussillon (CEEA-LR) for request 26568 "Behavioural study of wild dolphin groups in response to acoustic signals for limiting bycatch from professional fishery".

Data availability

Acoustic recordings and drone footage are available upon request, with the exception of audio records containing the bio-inspired signal, which is confidential. Scripts and results are available at `https://gitlab.lis-lab.fr/loic.lehnhoff/tetra-df` (accessed on 16 July 2024).

Acknowledgements

We thank Paul Best for his assistance in collecting some of the data. We thank Michael Paul for improving the English of the paper.

Conflicts of interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, nor in the decision to publish the results.

Abbreviations

AoA	Angle of Arrival
GSRP	Geometric Steered Response Power
IMU	Inertial Measurement Unit
K-W	Kruskal-Wallis
MWU	Mann-Whitney U
SNR	Signal-to-Noise Ratio
TDoA	Time Delay of Arrival
TETRA	tetrahedral antenna

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