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Jiang, J., Wang, X., Duan, F. et al. (7 more authors) (2019) Study of the relationship between pilot whale (Globicephala melas) behaviour and the ambiguity function of its sounds. Applied Acoustics, 146. pp. 31-37. ISSN 0003-682X

https://doi.org/10.1016/j.apacoust.2018.10.032

Study of the Relationship between Pilot Whale (Globicephala Melas) Behaviour and the Ambiguity Function of Its Sounds

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ABSTRACT

Pilot whales produce clicks, whistles and pulsed calls, which form a key component of their social lives. The three types of sound driven by their behavioural states are not directly observable. The mathematical tools which compute properties of sound are natural candidates for analysing the possible relationship between pilot whale sound and behaviour. In this paper, the wideband ambiguity function is used to compute the range resolution, speed resolution, Doppler tolerance, sidelobe-to-mainlobe suppression ratio of the range ambiguity function and sidelobe-to-mainlobe suppression ratio of the speed ambiguity function for pilot whale sound, which can be used to evaluate the abilities of pilot whale sound in detecting targets and resisting the influence of relative speed. Statistical results show that clicks have the best range resolution and its range ambiguity functions have the lowest sidelobe-to-mainlobe suppression ratio. Pulsed calls and part of the whistles have the best speed resolution and its speed ambiguity functions have the lowest sidelobe-to-mainlobe suppression ratio. The other part of whistles has a large Doppler tolerance. Analyzing the five parameters of different types ofsound and the corresponding behaviour, we then reach a better understanding of the relationship between pilot whale sound and pilot whale behaviour.

Keywords Wideband ambiguity function; Pilot whale; Sound

Introduction

Sound plays a vital role in odontocetes' daily lives, as indicated by Kellogg *et al*. in 1953[1]. Today, more than 60 years later, the odontocetes sound still attracts many researchers' attention. The long-finned pilot whale (*Globicephala melas* or *Globicephala melaena*), which is widespread from temperate to subpolar marine waters[2], is a medium-sized toothed whale and a member of the dolphin family[3]. It shares the Globicephala genus with the short-finned pilot whale (*Globicephala macrorhynchus*)[4]. The two can be distinguished by differences in flipper length and cranial characteristics [5,6]. In this paper "pilot whale" is only referred to as *Globicephala melas*.

Pilot whales, like other odontocetes, produce sound by passing compressed air through membranes. In an underwater environment, the sound vibrations in their tissues transfer directly into the surrounding water and they do not need to open their mouths or blowholes [7]. Pilot whales use sound for communication, travelling, and detection of predators and prey [1,8,9]. The sound used by pilot whales can be divided into three types (Fig. 1): clicks, whistles and pulsed calls [3,9,10]. Clicks are rapid and, usually, repetitive bursts of short, broadband sounds, primarily used for echolocation [1,11,12]; whistles are continuous tonal sounds with few or no harmonics, possibly used for maintaining the cohesion of the group during foraging or travel[10,13,14]; pulsed calls are rapidly broadband sound pulses, with distinct tonal properties caused by high pulse-repetition rates, possibly used for communication [3,10]. To obtain these conclusions, much significant work has been done: Kellogg *et al.*[1] proved that clicks are used for echolocation by analysing the time-domain waveform of odontocetes' sound; Au *et al.*[11] analysed the frequency spectra and source levels of clicks to prove that clicks can be used for echolocation; Fais *et al*.[12] found that sperm whales use high-frequency, low amplitude clicks to provide high-resolution biosonar updates during the last stages of capture; Nemiroff[3], Ford[10], and Weilgart and Whitehead[13] obtained the conclusion that whistles and pulsed calls can be used for communication by analysing the time-frequency spectra of odontocetes sound; Popov *et al.*[14] used hidden Markov models to prove that the long-finned pilot whale sound and short-finned pilot whale sound have communication ability, respectively.

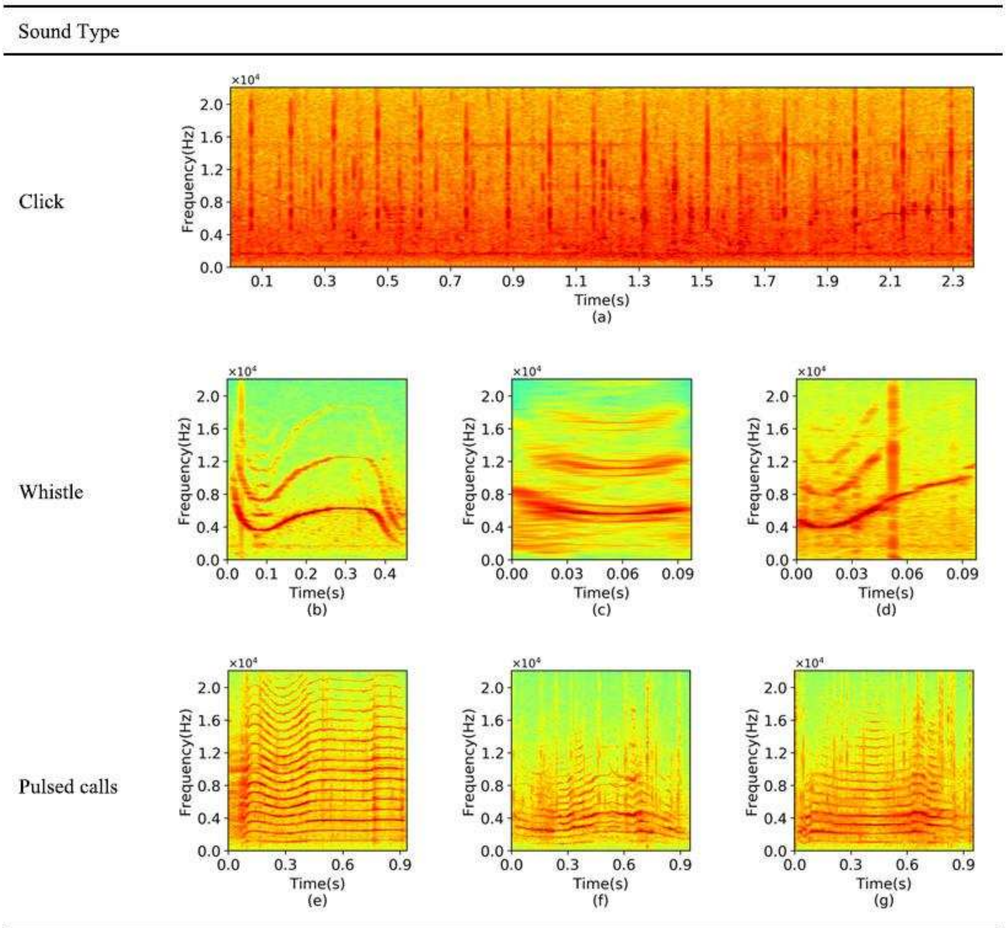

Figure 1. Spectrograms (frequency-time diagrams) showing examples of the three types of pilot whale sound. (**a**) Clicks. (**b**), (**c**) and (**d**) Whistles. (**e**), (**f**) and (**g**) Pulsed calls.

While the pilot whale sound was being recorded, the pilot whale kept swimming near the ship. The pilot whale may use sound for a variety of purposes such as detecting partners or prey, communicating with each other etc.. However, it is very difficult to identify the specific purpose of a certain type of sound only by recording the sound and observing the swimming of the pilot whale [14,15].

To relate the used sound to different purposes of the pilot whale so that we have a better understanding of its behaviour, an appropriate mathematical tool is necessary. It has been found that when detecting targets and communicating with others, pilot whales use sound in a manner that seems very similar to man-made sonar and communication systems. There are five important parameters (range resolution, speed resolution, sidelobe-to-mainlobe suppression ratio of range ambiguity function, sidelobe-to-mainlobe suppression ratio of speed ambiguity function and Doppler tolerance) for the signal waveform of the man-made sonar and communication systems. As demonstrated already in literature[16,17,18], the wideband ambiguity function is an effective tool to evaluate the five parameters of sound waveform. Therefore, different from some traditional analysis methods [1,3,10,11,13,14,19], in this paper, we use the wideband ambiguity function [16,18] to analyse different types of sound produced by the pilot whale. Through statistical analysis of the wideband ambiguity functions for a large collection of different sounds (clicks, whistles and pulsed calls), we find that the clicks have the best range resolution and their range ambiguity functions have the lowest sidelobe-to-mainlobe suppression ratio; pulsed calls and one part of whistles have excellent speed resolution and small Doppler tolerance and their speed ambiguity functions have the lowest sidelobe-to-mainlobe suppression ratio; the other part of whistles has large Doppler tolerance. Based on the results mentioned above, we can draw some possible conclusions about the relationship between the pilot whale sound and its behaviour. Firstly, to locate the prey accurately, clicks, with the best range resolution, are most likely to be used by pilot whales, which is consistent with the results in [1,11,19]. Secondly, for detecting the speed of other whales or prey, pulsed calls and one part of whistles, which have excellent speed resolution, are most likely to be utilized by pilot whales. At the same time, in order to communicate its speed to the others, pilot whales are most likely to use the pulsed calls and part of whistles, which have a small Doppler tolerance (an excellent speed resolution), and this is compatible with the results in the papers[3,10,13,14,15,20]. Thirdly, for communicating the herd movement instructions[20] which should hardly be affected by the relative speed, another part of whistles, which has a large Doppler tolerance, is most likely to be utilized by pilot whales, which is similar to the results in the papers[3,10,13,14,15,20].

Wideband ambiguity function

Ambiguity function (AF) is an important mathematical tool for evaluating the performance of radar and sonar waveform design, and it can provide some important characteristics about the designed waveforms, such as range resolution, speed resolution, Doppler tolerance, sidelobe-to-mainlobe suppression ratio[16,18]. According to the bandwidth of signals, the AF is divided into two types: narrowband ambiguity function (NAF) and wideband ambiguity function (WAF). Since the NAF is a special case of WAF [21], we use the general WAF to analyse the pilot whale sound in this paper.

When detecting its partners or prey, the pilot whale transmits a sound and then receives its echo. Due to the distance and relative speed between the pilot whale and its partners or prey, there are time delay (TD) and Doppler shifts (DS) between the transmitted and the received sounds. When the pilot whales communicate with each other, the sound will also produce DS due to existence of relative speed between the pilot whales transmitting and receiving the sound. Since WAF can be used to evaluate the range resolution and speed resolution of the sonar signal and the influence of DS on signal distortion, we can use WAF to evaluate the pilot whale sound's performance for distance and speed estimation and its ability to resist the influence of relative speed. The WAF can be written as:

$$\chi(\tau,\eta) = \sqrt{\eta}\int_{-\infty}^{+\infty} s(t)s^*(\eta t-\tau)\mathrm{d}t \tag{1}$$

where $s(t)$ is the sound transmitted by the pilot whale, $s(\eta t-\tau)$ is the echo reflected by targets, τ is the time delay and η is the Doppler shift. When the pilot whale detects its targets, the acoustic wave first reaches the targets and then is reflected back to the transceiver; in this case, τ and η satisfy the following relationship:

$$\tau = 2\frac{d}{c} \quad , \quad \eta = \frac{c+v}{c-v} \tag{2}$$

However, when pilot whales communicate with each other, the acoustic wave only needs to reach other partners; then τ and η satisfy the following relationship:

$$\tau = \frac{d}{c} \quad , \quad \eta = \frac{2c+v}{2c-v} \tag{3}$$

where d is the distance between the pilot whale and its partners or prey, v is the relative speed between the pilot whale and its partners or prey, c is the propagation speed of sound in seawater which is assumed to be 1500m/s here.

Substituting (3) or (4) into (1) and setting v to 0, we obtain the range ambiguity function (RAF) $\chi(d)$; If we set d to

0, we then obtain the speed ambiguity function (SAF) $\chi(v)$.

The half-power beam width (HPBW) of RAF is called range resolution (RR)[16]. RR can be used to evaluate the pilot whale sound's performance for distance estimation between the pilot whale and its targets. With HPBW of RAF reducing, the RR becomes better.

The HPBW of SAF is called speed resolution (SR)[16]. SR can be used to evaluate the performance of the relative speed between the pilot whale and its targets. With HPBW of SAF reducing, the SR becomes better.

Doppler tolerance (DT) is an important measurement of a system's ability to tolerate velocity-induced mismatches between the transmitted sound and the received echo[17]. In numerical computation aspect, DT is related to SR; further, for detection of targets, DT and SR satisfy the relationship DT = 2SR/c, and for communication, they satisfy DT = SR/c. DT can evaluate the robustness of pilot whale sound against the influence of relative speed between the pilot whale and its partners. The signal with a larger DT will be more robust.

The ratio of side lobe maximum value to main lobe maximum value is called sidelobe-to-mainlobe suppression ratio (SMSR). A high side lobe of AF will lead to false detection and the missing of weak targets[18]. By computing the RR, SR, DT and SMSR corresponding to the pilot whale sound, we can obtain the pilot whale sound's performance in distance and relative speed estimation and its robustness against the influence of relative speed, so that we can have a good understanding of the possible relationship between the pilot whale sound and its behaviour.

Result

We extract 278 clicks from sound file E, 126 whistles and 77 pulsed calls from sound files A, B, C and D. Examples are provided in the following Materials and Methods Section. We first compute WAFs of the three types of sound and then analyse the five parameters of the WAFs: 1) RR, 2) SMSR of RAF, 3) SR, 4) SMSR of SAF, and 5) DT. One note is that RR and SR are computed according to (2) rather than (3).

		RR(m)	SMSR of RAF	SR(m/s)	SMSR of SAF	DT
Maximum	Clicks	0.0123	0.71	1.9257	0.70	0.002568
	Whistles	0.0857	0.94	0.8021	0.77	0.001069
	Pulsed calls	0.0673	0.90	0.1674	0.60	0.000223
Minimum	Clicks	0.0017	0.16	0.7539	0.12	0.001006
	Whistles	0.0056	0.28	0.0173	0.06	0.000023
	Pulsed calls	0.0165	0.47	0.0039	0.05	0.000005
Mean	Clicks	0.0048	0.50	1.0765	0.42	0.001435
	Whistles	0.0378	0.66	0.1486	0.29	0.000198
	Pulsed calls	0.0396	0.70	0.0396	0.27	0.000053
Standard deviation	Clicks	0.0020	0.11	0.2028	0.16	0.000270
	Whistles	0.0122	0.15	0.1374	0.15	0.000183
	Pulsed calls	0.0083	0.16	0.0351	0.12	0.000047

Table 1. Statistical results of RR, SMSR of RAF, SR, SMSR of SAF, and DT for clicks, whistles and pulsed calls

Tab. 1 shows the results of RR, SMSR of RAF, SR, SMSR of SAF, and DT for clicks, whistles and pulsed calls. It can be seen from Tab. 1 that the maximum, minimum and average RRs of clicks are smaller than those of the other two types of sound. The maximum RR of clicks is smaller than the minimum RR of pulsed calls. In general, the SR and DT values of clicks are much larger than the other two types of sound. The SR and DT values of both whistles and pulsed calls are small, but those of pulsed calls are smaller than whistles. However, the difference between the maximum and the minimum values of SR and DT for whistles is 0.7848 and 0.001046, respectively, and that for pulsed calls is 0.1635 and 0.000218, respectively. By contrast, the spans of SR and DT for whistles are larger. In addition, the clicks' RAFs have the lowest SMSR and their SAFs have the largest SMSR as a whole. Whistles and pulsed calls' RAFs and SAFs have a similar SMSR. However, there is no big difference among the three types of sound in terms of SMSR of SAF and RAF.

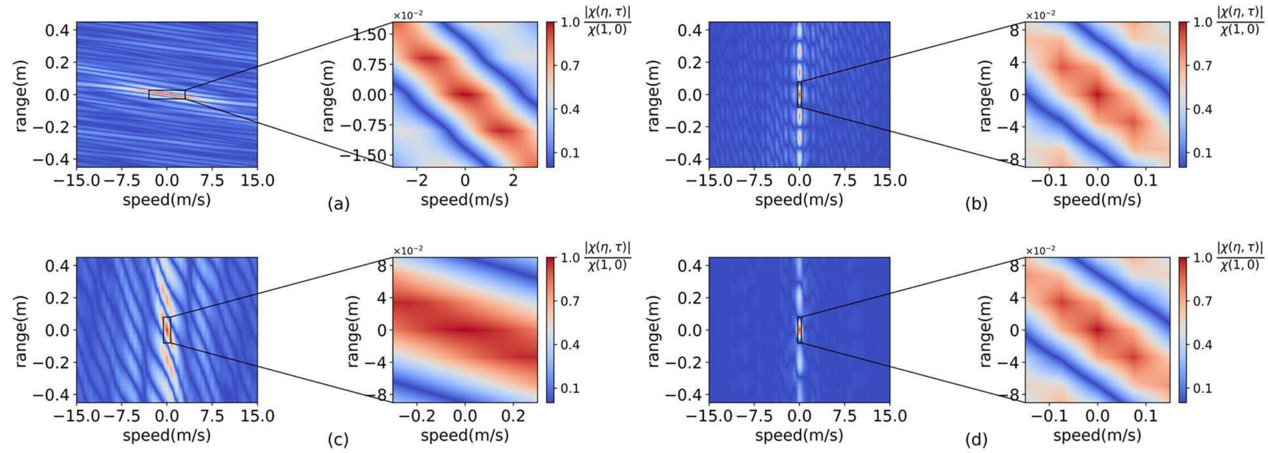

Figure 2. WAF examples of the three types of pilot whale sound. (**a**) WAF of a click. (**b**) (**c**) WAF of whistles. (**d**) WAF of a pulsed call.

Examples of the WAFs of clicks, whistles and pulsed calls are shown in Fig. 2. For the WAF of a click shown in Fig. 2a, the main peak is almost a straight line parallel to the speed axis. This indicates that the click has an excellent RR, a poor SR and a large DT. On the other hand, for the WAFs of two whistles shown in Fig. 2b and Fig. 2c, the main peakin Fig.2b is almost like a dotted line parallel to the range axis; however, in Fig. 2c, the main peak of the WAF is slant. Clearly the whistle in Fig. 2b has a better SR than the whistle in Fig. 2c. Finally, the WAF of a pulsed call is given in Fig. 2d, where the main peak is almost a dotted line parallel to the range axis, which indicates that the click has a poor RR, an excellent SR and a small DT. It should be noted that the WAFs in Fig. 2 are only representative examples and there are many variations among them.

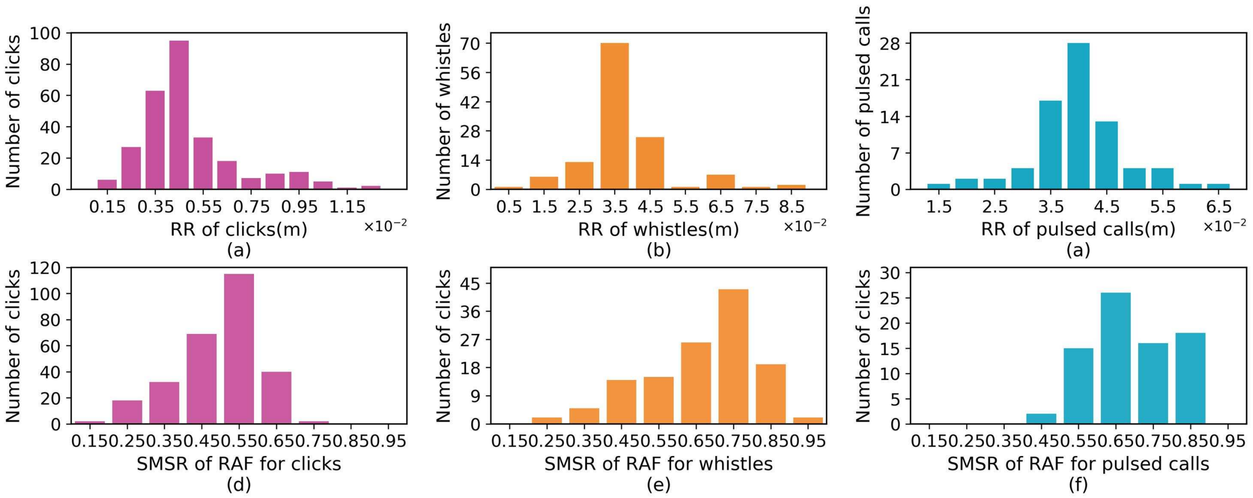

Figure 3. (**a**) Distribution of RR for clicks. (**b**) Distribution of RR for whistles. (**c**) Distribution of RR for pulsed calls. (**d**) Distribution of SMSR of RAF for clicks. (**e**) Distribution of SMSR of RAF for whistles. (**f**) Distribution of SMSR of RAF for pulsed calls.

RR. Fig. 3a-c shows the distribution of RR for clicks, whistles and pulsed calls, respectively. By comparing Fig. 3a-c, we can find that RR of 97.1% clicks is smaller than 0.0100m, and only one whistle has an RR smaller than 0.0100m and no pulsed calls have an RR smaller than 0.0100m. Moreover, most (78.4%) of the clicks have an RR between 0.0020m and 0.0060m, while 75.4% of the whistles and 75.3% of the pulsed calls have the RR between 0.0300m and 0.0500m. Therefore, the RR of clicks is much smaller than that of the other two types of sound.

SMSR of RAF. The distribution of SMSR of RAFs for clicks, whistles and pulsed calls is presented in Fig. 3d-f, respectively. Most (80.6%) of the clicks' RAFs have anSMSR between 0.4 and 0.6, with the peak at 0.55. There is a peak in the distribution of SMSR of whistles' RAFs at 0.75, with 69.8% of whistles' SAFs having an SMSR between 0.6 and 0.9. 77.9% of pulsed calls' RAFs have their SMSR between 0.6 and 0.9 without a clear peak. Therefore, the clicks' RAFs have a smaller SMSR than that of whistles and pulsed calls.

SR. According to Fig. 4a-c, we can see the SR distribution for clicks, whistles and pulsed calls, respectively. In Fig. 4a, there is no distinct peak position, with 88.5% of the clicks having SR between 0.8m/s and 1.3m/s. and the SR of all clicks is larger than 0.7m/s. As shown in Fig. 4b, the number of whistles drops with the SR increasing, with 50.8% of whistles having SR smaller than 0.1m/s. Fig. 4c shows that SR of 92.2% pulsed calls is smaller than 0.1m/s. By comparing Fig. 4a-c, we know that clicks have the largest SR while pulsed calls have the smallest SR. In addition, one part of whistles has a small SR while the other part has a large SR.

SMSR of SAF. Fig. 4a-c show the SMSR distribution of SAFs for clicks, whistles and pulsed calls respectively. The SMSR of 80.6% clicks is between 0.3 and 0.6. 73.8% of whistles' SAFs and 79.2% of pulsed calls' SAF have an SMSR between 0.1 and 0.4. So we can find that whistles' SAFs and pulsed calls' SAFs have similar SMSRs, while clicks' SAFs have the largest SMSR among SAFs of the three types of sound.

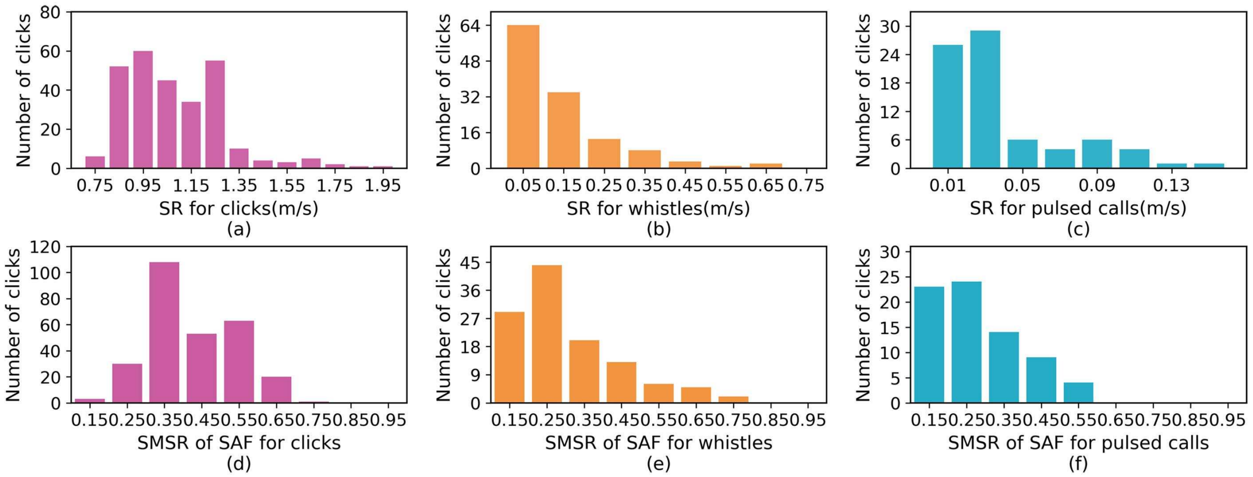

Figure 4. (**a**) Distribution of SR for clicks. (**b**) Distribution of SR for whistles. (**c**) Distribution of SR for pulsed calls. (**d**) Distribution of SMSR of SAF for clicks. (**e**) Distribution of SMSR of SAF for whistles. (**f**) Distribution of SMSR of SAF for pulsed calls.

DT. Combined with Fig. 4 and the relationship between SR and DT, we can see that the DT of clicks is the largest among the three types of sound and pulsed calls have the smallest DT. Some part of the whistles has a small DT, while the other part has a large DT.

Discussion

While the sound is being recorded, the pilot whales sometimes swam around the ship, sometimes away from the ship, and sometimes towards the ship. There may be various purposes corresponding to different types of sound. During their swimming, they may use sound to forage, to detect the relative speed between each other, to communicate with each other, or to do something else. But, only by observing pilot whales swimming and recording their sound, it is difficult to determine the specific purpose of a certain type of sound. Therefore, WAF has been used for studying the possible relationship between pilot whale sound and its behaviour. We have mainly discussed three questions:

- Firstly, which types of sound do pilot whales use to detect the distance of targets?
- Secondly, which types of sound do pilot whales use to detect the speed of targets?
- Thirdly, which types of sound do pilot whales use to communicate with each other?

Firstly, we think that pilot whales may use clicks to detect the distance of targets. Many papers [1,3,11,19] pointed out that odontocetes use sound for echolocation. Au and Martin[19] stated that dolphins can use sound to distinguish complex targets and Au *et al.*[11] also mentioned that killer whales can identify the prey types by their clicks. On the one hand, for acquiring the distance and profile of targets, the sound used for echolocation should have an excellent performance in distance estimation from a sonar perspective. This means that, the sound used for echolocation should have a good RR and its RAF should have a low SMSR. On the other hand, since the echo will be distorted because of the relative speed between pilot whale and its targets, to ensure the speed distorted echo can still be recognized by the pilot whale, the sound used for echolocation should be able to resist the influence of relative speed well. This shows that the echolocation-type sound should have a large DT. According to the results in Tab.1, Fig. 3 and Fig. 4, it can be seen that the SMSR of clicks' RAFs is the smallest, the RR of clicks is much better than that of whistles and pulsed calls, and the DT of clicks is much larger than that of the other two types of sound. As a result, we can surmise that the clicks most probably are used for echolocation. The same conclusions were reached by Kellogg *et al.*[1], Au *et al.*[11], Au and Martin [19].

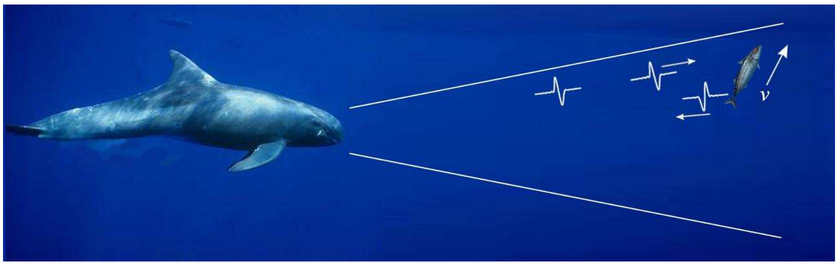

Figure 5. A situation for the pilot whale foraging

Secondly, we speculate that pilot whales may use pulsed calls and some part of whistles to detect the distance of targets. There are evidences[19,22] indicate that odontocetes sound has directivity. Au and Martin [19] pointed out that dolphins project their biosonar signal in a beam and receive echoes via a broader beam. Au *et al.*[22] did some measurement for killer whales which have many similar social structures and sound profiles with pilot whales[3,23], and found that when the major axis of the beam is directed to within ±5° of the hydrophone, the signal received by the hydrophone will be within 3 dB of the highest amplitude. Consequently, we speculated that the sound of pilot whales may also have directivity and this is a fundamental assumption of pilot whales' using sound to detect the speed of targets. On the one hand, if the pilot whale only knows the distance but does not know the speed of prey in a hunt, they probably miss their targets. Fig. 5 shows a possible situation for a foraging pilot whale. As shown in Fig. 5, the prey moves at the speed v and the first click has been reflected by the prey. The prey probably has swum out of the detection range of the pilot whale, before the second click reaches. Thus, for the pilot whale, it may only know the distance but does not know the swimming direction of the target. This probably also leads to the missing of a target. On the other hand, during travelling, pilot whales may move along the same course at closer speeds [10]. In order to travel at closer speeds, they need to adjust the relative speed between each other from time to time. Therefore, they may need to detect the speed of partners. Based on the analysis mentioned above, we think that detection of a target's speed is very important for pilot whales. Since the speed of targets is carried by the DS of echo from a technological perspective, pilot whales may use the sound which is sensitive to DS (namely the sound whose SR is good and whose SMSR is low) to detect the speed of targets. Hoffman *et al.*[24] gave a similar conclusion that blue whales may use their calls to measure the relative speed between each other. According to the results in Tab.1, Fig. 3 and Fig. 4, pulsed calls and one part of whistles have the best SR and their SAFs have the lowest SMSR among the three sound types. So, from a technological view of point, pilot whales may use pulsed calls and this part of whistles to detect the speed of targets. Yurk[25] also found that pulsed calls were heard in situations where the whales were spreading out foraging or when two or more pods met. This result[25] indicates that the pulsed calls are closely related to foraging and it offers support for our speculation.

Thirdly, for communication, there may be at least two types of communication information that pilot whales use sound to transmit between each other [10,20,24]:

- The first type should be sensitive to speed, such as the speed information of a pilot whale [24].
- The second type should not be influenced by speed easily, such as herd movement instructions information [10,20].

Based on the conclusions in literature [1,11,12] and our findings about the function of clicks, we assume that clicks are only for echolocation rather than communication. At the same time, Nemiroff [3], Ford [10], Weilgart and Whitehead [13], and Popov [14] pointed out that pulsed calls and whistles are used for communication; therefore, in the following content, we mainly analyse the WAFs of pulsed calls and whistles so as to understand which types of sound pilot whales use to transmit which types of communication information.

We surmise that pilot whales may use pulsed calls and one part of whistles to transmit the first type information. During the travelling, pilot whales need to adjust their speed between each other for moving along the same course at a closer speed [10], so pilot whales may also need to use sound to inform themselves of speed to their partners possibly in a similar way as the blue whale [24]. Based on the above analysis, we know that because of the relative speed between pilot whales, there is DS between the sound transmitted and received by pilot whales. If the transmitted sound is promissory between different pilot whales, the pilot whales can recognize the speed by perceiving the DS of received sound. Hoffman *et al.*[24] gave a similar surmise that a female blue whale might be able to locate the direction of a calling male blue whale by the DS of sound. To transmit the speed information via DS, the sound should have two characters from a technological perspective. First, it should be promissory between pilot whales of transmitting and receiving sound, which means that the sound should be stereotyped and should be the unique sound of c. Many researches[3,10,25,26,27,28] found that the pulsed calls are stereotyped and Nemiroff[3] proved that the pulsed calls of pilot whales are not easy to be imitated and eavesdropped. Therefore, the pulsed calls are most suitable for the promissory sound carrying the speed information. Second, pilot whale should use the sound, which has a small DT and a poor ability to resist the influence of relative speed, to transmit the speed information accurately between each other. According to the results in Tab.1, Fig. 3 and Fig. 4, it can be seen that pulsed calls and one part of whistles have the smallest DT among the three types of pilot whale sound. Therefore, pilot whales probably use pulsed calls and this part of whistles to inform their speed to other partners. Nemiroff[3], Ford[10] and Yurk[25] found that pulsed calls may be used for maintaining the cohesion of the whale group, which is similar with our surmise that pilot whales may use pulsed calls to inform their speed to other partners for maintaining the cohesion.

We surmise that pilot whales may use the other part of whistles to transmit the second type of information. The pilot whale also uses sound to transmit some information such as herd movement instructions[3,20]. However, the relative speed between pilot whales will distort the sound carrying the instructions. To avoid information transmission failure caused by sound distortion, the sound signal should have a large DT and a strong ability to resist the influence of relative speed from a technological perspective. According to the results in Tab.1, Fig. 3 and Fig. 4, it can be seen that one part of whistles has the largest DT and the strongest ability to resist the influence of relative speed. Therefore, we surmise that this part of whistles is possibly used to transmit the herd movement instructions which should not be affected by relative speed easily. Nemiroff [3], Ford [10], Weilgart and Whitehead [13], and Taruski [20] obtained similar conclusions. Taruski [20] also speculated that the V-shaped whistle might be used for herd organization or cohesion. A WAF example of a V-shaped whistle is shown in Fig. 2b. We can see that the DT of the V-shaped whistle is large and this result also provides further evidence for our surmise.

Materials and Methods

Sound files. The pilot whale sound files are provided by the Macaulay Library at the Cornell Lab of Ornithology and the Watkins Marine Mammal Sound Database. There are five sound files: A, B, C, D, and E. The file A was recorded by a Mono Sennheiser MKH 30 and the file E was recorded by a WHOI Pemtek tape recorder, an Ithaco 602M108 hydrophones and an Ithaco 450 amplifiers. The remaining files were recorded by a Mono Sennheiser MKH 20. Sound files A, B, C, and D were recorded at North Atlantic Ocean and the sound signals were digitized at 44100 Hz. The sampling frequency of file E is 166000Hz. File A recorded the sound of four small pilot whale groups and one large group on Sep. 6th 1971. File B was recorded on Sep. 2nd 1971. File C recorded the sound of two pilot whales on Aug. 28th 1971 and they are about 20 yard away from the hydrophone. File D recorded the sound of 10 pilot whales which are 50-100 yard away from the hydrophone on Aug. 28th 1971. File E recorded the sound of the whales consisting of seven pilot whales which are 30-40 feet away from the hydrophone on September 8th, 1975, at Northwest Atlantic Ocean (43º42'N 59 º04'W).

Data analysis. The software tools Matlab R2014b and Adobe Audition 3.0 were used to analyse the pilot whale sound. Because the frequency of clicks is high, we extracted clicks from file 75001 whose sampling frequency is the highest. To extract the clicks more accurately, we used wavelet denoising to the process sound file firstly. Then we used short-term energy to detect the endpoint of clicks. According to the endpoint, we can extract all clicks from the sound files. For whistles and pulsed calls, their time-frequency spectrum features are outstanding. Therefore, we use Audition 3.0 to observe the time-frequency spectra of sound files and then extracted pulsed calls and whistles manually. Next, we used Matlab R2014b to compute the WAF of clicks, whistles and pulsed calls and further evaluate its parameters, such as RR, SR, DT, SMSR of SAF and SMSR of RAF.

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Acknowledgements

This work was supported in part by the TianJin Natural Science Foundations of China under Grant No. 17JCQNJC01100, National Natural Science Foundations of China under Grant No. 61501319, 51775377, 61505140, National key research and development plan (2017YFF0204800), Young Elite Scientists Sponsorship Program By Cast of China under Grant No. 2016QNRC001, Open Project (MOMST2015-7) of Key Laboratory of Micro Opto-electro Mechanical System Technology, Tianjin University, Ministry of Education, Photoelectric Information and Instrument-Engineering Research Center of Beijing Open Project No.GD2015007. We appreciate the Macaulay Library at the Cornell Lab of Ornithology and the Watkins Marine Mammal Sound Database for their help.