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TEMPORAL DIFFERENCE PERCEPTION BY *TURSIOPS TRUNCATUS*

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Abstract

The outcomes of an echolocation experiment involving threshold detection performance are compared in relation to other data taken from a behavioural situation in which tonal frequencies of rather long duration were used to establish difference limens.

It is noted that discrimination of time intervals in the case of an echolocation task agree remarkably well with the figures obtained from a method in which single tonal stimuli were presented to the animal. The Weber fraction obtained from the echolocation task appears to be in the order of 0.054-0.057. The reliability of this latter figure is enhanced by considering that the dolphin is processing echo information obtained by his own emitted short sonar pulses.

Discussion

The well-developed hearing sensitivity in the bottlenose dolphin *Tursiops truncatus* has been reported in literature for a considerable time by several researchers (NORRIS, 1969; JOHNSON, 1967; HERMAN and ARBEIT, 1972; JACOBS, 1972). The sophisticated sonar system relies for final decisions about echo structure and thus about some properties of an object being echolocated on the information-processing capabilities of the animal.
If a sonar system is conceived of as a general information-transmission system, it will consist of (1) a sound-producing source, (2) an information-transmission channel that transports the sonar signal and (3) an echo-receiving part.
This third part can best be studied in behavioural situations, as knowledge about the information-processing capabilities of the dolphin is still insufficient.
In contrast, the first part, the sound-producing part, of the sonar system, can be studied by established physical methods, for the animal produces a series of clicks, which can easily be recorded with the proper apparatus and subsequently studied to investigate the signal parameters of the sonar sounds involved.
Perusing the recent literature on the discrimination of auditory temporal acuity, we note an interesting study involving auditory temporal differences in *Tursiops truncatus* and in the human (YUNKER and HERMAN, 1975), in which difference limens for standard tonal durations were determined for an adult female bottlenosed dolphin as well as for a human subject.
We will focus our attention on the results obtained from the animal, already the subject of previous auditory studies (HERMAN and ARBEIT, 1972; HERMAN and GORDON, 1974).
An underwater sound projector was used to present pure tones as a temporal stimulus, with frequencies of 9 kHz and 25 kHz, and a combination of the two.
Standard stimulus durations of 0.3, 0.6 and 1.2 sec were chosen. To obtain a threshold in the perception of temporal difference, a comparison duration at least longer than 33% of the standard was gradually reduced until a 75% correct response was obtained. The temporal discriminations of the dolphin are expressed as the Weber ratio $\Delta T/T$, with ΔT being the absolute difference between the standard duration T and the longer comparative duration. The relative difference limens reported by YUNKER and HERMAN are given in Table I.

Table I Relative values of difference limen; from YUNKER & HERMAN, 1974.

Frequency (kHz)	T 0.3 sec	T 0.6 sec	T 1.2 sec
9	0.059	0.076	0.054
25	0.090	0.061	0.058
both	0.061	0.049	0.041

As can be noted from this table, the relative difference limens are generally in the order of 0.06 and 0.08 for the standards used. Although the results of the successive method they used are interesting in relation to human performance, some questions may arise. First, the ability of a dolphin to make discriminations in the time domain is worthy of note, all the more so as we bear in mind that the manipulation of pure tonal durations of a length used in the procedure described above is not a usual situation for a dolphin, who relies on the information-processing of echos obtained by ensonifying targets with short durational clicks of less than 100 sec, having a dominant frequency around 50 kHz.
Furthermore, the frequency of 9 kHz, used in the experiment poses the question of whether it doesn't lie too far outside the range of the animal's optimal hearing sensitivity.
Finally, one could postulate that, given certain evidence that the animal uses temporal information, another type of experiment could be devised, one which relies more on the normal behaviour of the echolocating dolphin.

An experiment which involves a time-difference perception as a cue in a detection experiment has been carried out by the author (KAMMINGA, 1976; HOL and KAMMINGA, 1979). These experiments were originally intended to provide insight into the sonar signal

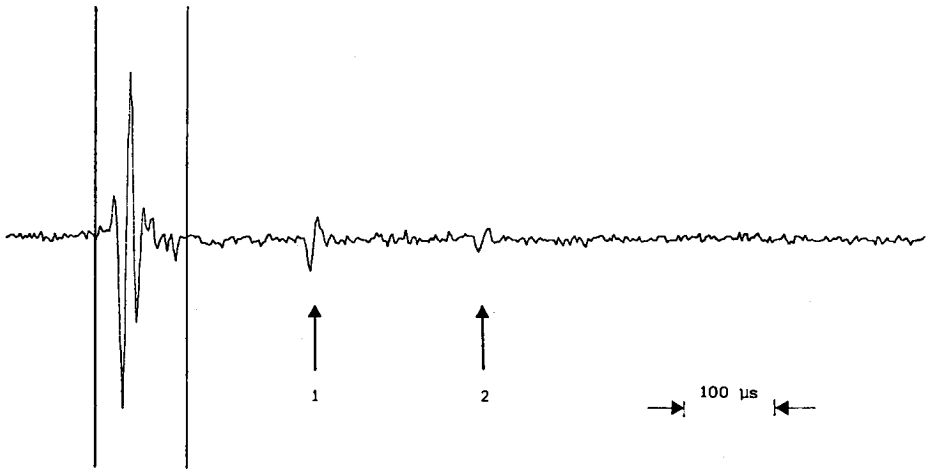

Fig. 1. *Tursiops* sonar pulse together with reflections from the solid sphere. Arrows 1 and 2: first and second echo.

performance of a dolphin. The detection task was to distinguish between a pair of metal spheres, made out of the same material, one of which was solid and the other hollow. For a diameter ratio of the inner to outer radius of the hollow sphere of 0.4, the animal's correct detection responses approached a score of 75%. If the animal uses a time-difference parameter to make a decision between the solid and the hollow spheres, the threshold could be used to investigate the difference limens for time perception.
Before taking a closer look at the time parameters, we first turn our attention to the emitted sonar signal and the echo structure as received by the dolphin. Fig. 1 indicates the sonar click together with the echoes coming from the solid sphere.

As the reflectivity of an iron sphere submerged in salt water is in the order of 94%, only a small part of the emitted sonar energy penetrates into the sphere. Obviously, the echoes that result from the resonances in the material have a rather small amplitude and tend to be quickly drowned in the noise so that only the first and second echoes can be observed. For a proper measurement of the time duration between the first echo and the second one

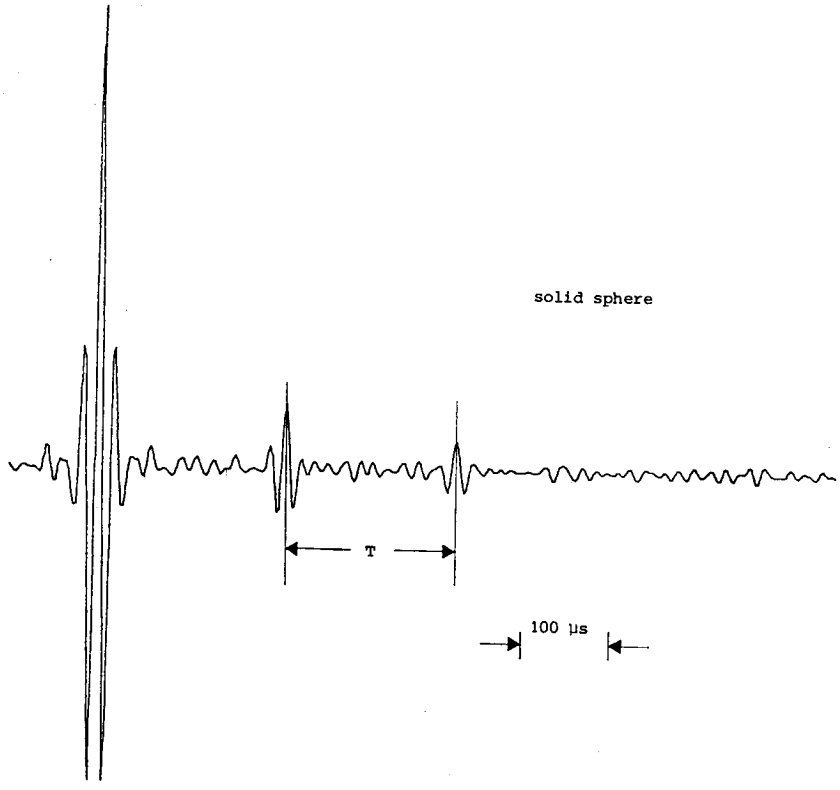

Fig. 2. Matched filter output from *Tursiops* sonar pulse - solid sphere.

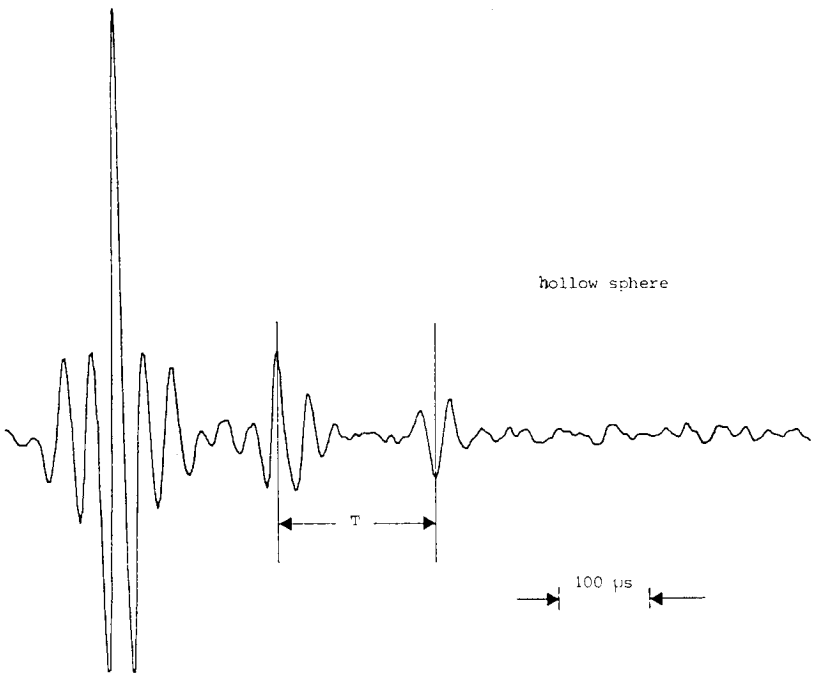

Fig. 3. Matched filter output from *Tursiops* sonar pulse - 0.4 hollow sphere.

it is necessary that some method of signal enhancement be performed. A common method is to apply a correlation technique between the emitted signal and the received echo. In the case of additive white Gaussian noise the correlation technique is a theoretically optimal means for detecting signals buried in noise.
To this end, a crosscorrelation is performed between the emitted sonar pulse (between the two vertical bars) and the complete time function, given in Fig. 1.
The result of this operation is shown in Fig. 2, representing an increase in the signal-to-noise ratio. The first and the second echoes can now clearly be distinguished with regard to their time separation.

This same technique of filtering out the echoes is applied in the case of the hollow sphere, and is displayed in Fig. 3. It is interesting to note that here the secondary echo is phase-inversed with respect to the secondary echo for solid sphere.
The echo enhancement allows us to determine to a high degree of accuracy the time difference between the successive echoes.
If we compare the two time durations, indicated by T in figures 2 and 3 we note the following data:

solid sphere	$T = 186\,\mu sec$	
0.4 hollow sphere	$T = 176\,\mu sec$	$\Delta T = 10\,\mu sec$

From these data we arrive at a Weber ratio $\Delta T/T$ of 0.054 or 0.057, depending on which time duration is chosen as a reference. It is not known which of the two is selected by the dolphin as the reference time duration, because the animal only observes that a difference exists; but this is of minor importance.
Bearing in mind that in most cases Weber ratios are found in the range 0.01 - 0.1, there is no edge effect to be corrected for high or low values of the stimulus.

These results agree remarkably well with the figures as obtained by YUNKER and HERMAN and confirm the discrimination capability of the dolphin *Tursiops*, in the auditory time domain.
Moreover, the data obtained from the sphere detection experiment seem to be highly reliable as the animal performs the task as he normally does: with its sonar signal.
Nevertheless, the question remains whether the accuracy of a target-distance estimation in the order of 6% is sufficient for normal behavioural situations.
In the opinion of the author the described experiment should be repeated in a (more) noise-free environment with priori-determined Weber fractions. These standard time durations could be established by separate, accurate measurements on a range of different spheres that are ensonified by short impulses.
This would enable a successive range of standard durations to be hidden in a detection experiment in which the dolphin has to rely on a time cue only.

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