An experiment in two-way communication in *Orcinus orca* L.

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Summary

This paper describes a behavioural experiment in which an Orca was encouraged to attempt elementary two-way communication, i.e. choosing between two objects, by spontaneously using a learned connection between a visual object and a corresponding auditory stimulus. Frequency-modulated signals, which were related to and within the range of the natural vocalisations of the animal, were used as stimuli. Two signals were made to represent action words, i.e. the verbs "take" and "bring", and the three other signals were used as the names of familiar objects. Initial results indicate the orca's ability to incorporate the stimulus signals into her vocalisations and to use them spontaneously in a meaningful context.

Introduction

Information processing of complex vocalisations and echoes requires sophisticated development of the auditive parts of the brain. It is, indeed, well-known that odontocetes have impressive brains, mostly characterised by large size and intricacy. This fact has given rise to much speculation as to its significance. In many papers the assumption is made that the capacities of the odontocete brain surpasses the above requirements and enables the animals to communicate at the level of "language". The reasoning, on which these assumptions are based, is carefully exposed by Reysenbach De Haan (1966). In this respect Lilly's attempts to achieve interspecific communication, between man and dolphin, are well-known. If there is any chance for such an interspecific communication, we postulate that it is with the killer whale (*Orcinus orca* L.), the most advanced species in the delphinid family as far as behaviour is concerned. We are supported in our opinion by the survey on trainability and behavioural reliability of eight captive species conducted by Defran and Pryor (in Herman, 1980). We base our opinion on behavioural observations of Gudrun, a female orca, with respect to the other dolphins with whom she had contact. Therefore, when this female killer whale was placed at our disposal, preparations for a communication experiment were set in motion. Whatever definition of "language" is used, it will be obvious that object-naming forms much of the basis for practical use of language. The easiest way to incorporate this element in our experiment is by assigning and acoustical symbol to a visual object. However, this requires that the animal is able to associate an auditory stimulus with a visual stimulus. One can not take it for granted that the necessary cerebral interconnections (Geschwind, 1964) exist in the orca. If they do, however, the possibilities to continue the experiments beyond an elementary stage are far better. Therefore it is worth while to examine the object-naming abilities of the killer whale in this way first. The ultimate goal of this experiment was to learn whether a killer whale would be able not only to learn and understand the meaning of certain simple, basic sentences of two elements (acoustic commands), but also whether she would be able to use these sentences herself in a proper context to transfer a message to the experimentators.

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Figure 1: Gudrun

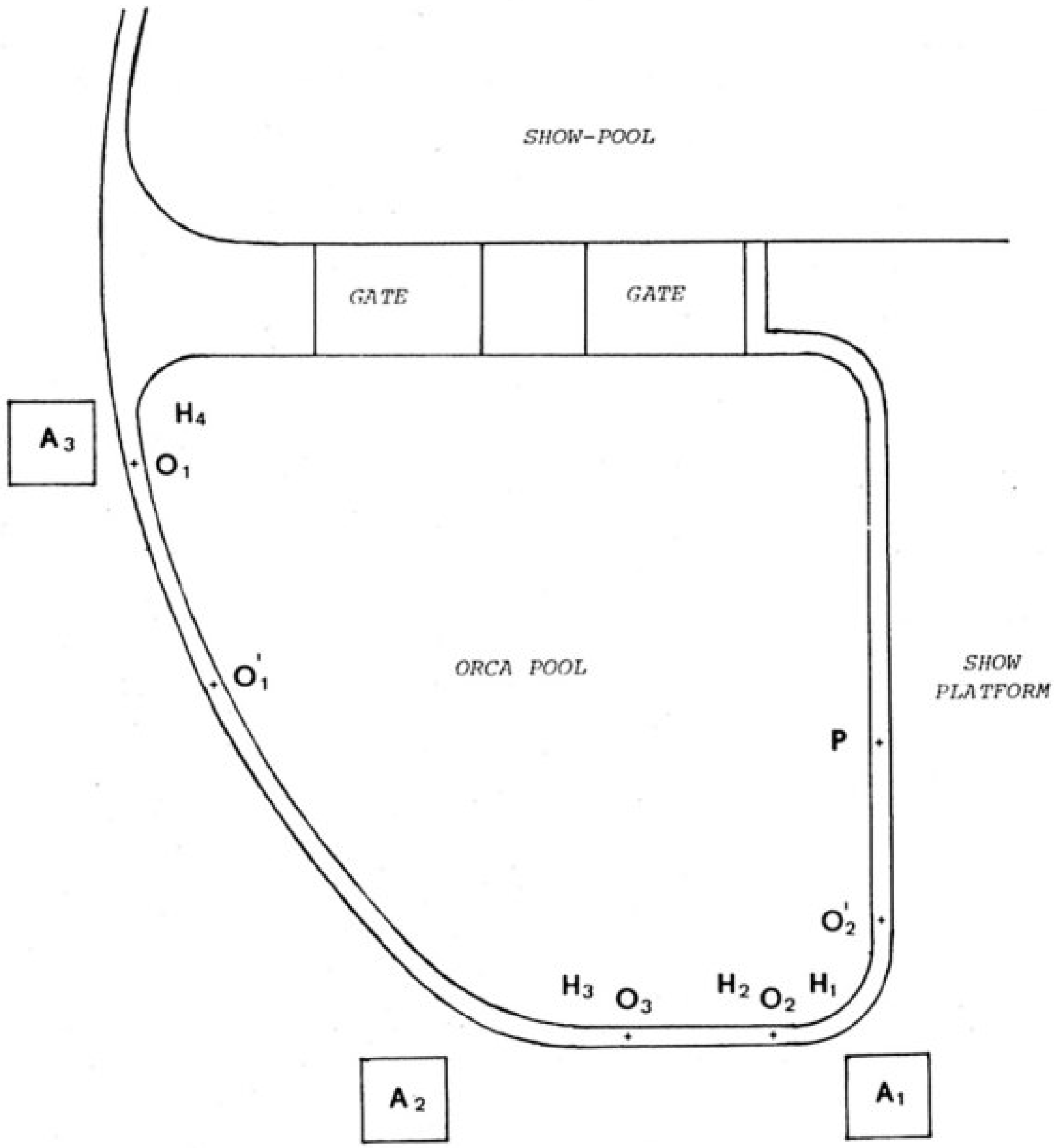

Figure 2: Orca pool, the experimental site

Subject and training

The subject of this experiment was a female killer whale, *Orcinus orca*, from the North-Atlantic ocean, named Gudrun (**Figure 1**). She was caught in October 1976 off the southeast coast of Iceland and transported to the Dolfinarium in Harderwijk. At the moment of capture she was about 1½ years old, and weaned, 2.70 metres long and weighed 300 kilos. In October 1980 she was measured for the last time and was found to be 4.50 m long and to weigh approx. 1300 kilos. She was in the company of the orca who had been captured with her until May 1977, after which she spent the summer in the company of several. bottlenose dolphins, *Tursiops truncatus*, and even voluntarily took part in the show. In November 1977 she was briefly joined by six orcas, the last two of which left in May 1978. After the beginning of December 1977 she did not have direct contact anymore with other orcas, although she could hear the two orcas that still remained. There were no indications that she was in contact with these two. She was, however, continuously in the company of the dolphins, with whom she built up an intense social contact. She has always shown a great deal of interest in people, and has also needed much human attention, indeed, more than the dolphins. When she doesn't get enough attention, her motivation decreases rapidly and she appears to be bored, i.e. is not interested anymore. If the situation does not alter, she eventually refuses to cooperate, retires to a corner to rest or sleep. Offering food does not evoke interest. As a result of the experiments with sound she became more and more active in the acoustic domain. We note that Gudrun, unlike the captive orca reported by Schevill and Watkins (1966), often used tonal vocalisations, as described by Steiner et al. (1979) from wild animals. This is most probably due to the fact that one of the authors, from the beginning of his acquaintance with Gudrun, consistently reacted to and encouraged vocalisations. This encouragement was greatly facilitated as his office was beside the pools occupied by Gudrun and visual and acoustical contact was always possible through large windows. When he did not answer familiar calls, she quickly developed the habit of using new sounds and/or behaviours to attract attention and establish contact anew. The training

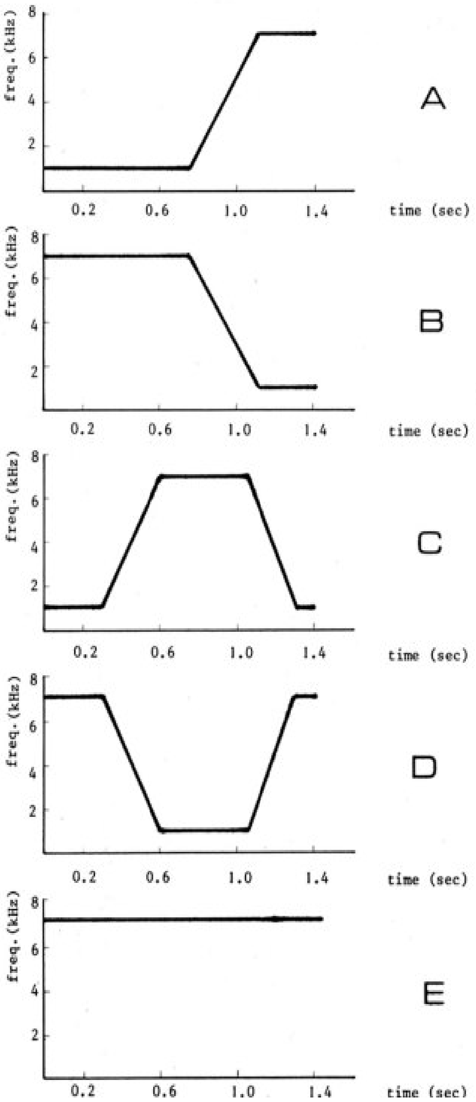

Figure 3: Time-dependent frequency contours used as stimuli. A. signal A, B. signal B, C. signal C, D. signal D, E. signal E

with sound signals as they occurred within the experiment was completely new for Gudrun. Prior to this experiment she had only worked with hand gestures. The training methods employed were the basic methods as used by the trainers at the Dolfinarium. In order to prevent strained relationships we decided not to use more sophisticated methods. We note that the amount of fish that she got every day was never correlated with her motivation to perform the experiment.

Environment

The experiments always took place in Gudrun's own, 4.5 m deep, holding pool, which has a total capacity of 360 m^3 and a water depth of 4 m (**Figure 2**). The pool is only separated by a gate from the main pool of 1450 m^3 and 4 m deep, which is occupied by the orca and the dolphins in free time during the day and all through the night. In **Figure 2** the positions of the hydrophone are indicated by H_1 to H_4, and the places where the objects were presented are represented by O_1 to O_3. A_1 to A_3 indicate equipment locations.

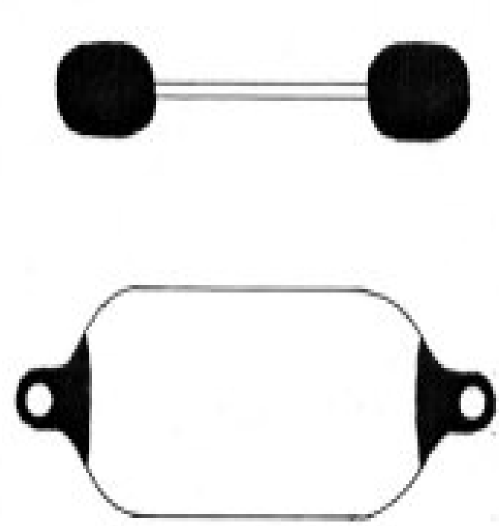

Figure 4: The objects associated with the signals: the dumbbell (signal C) and the fender (signal D).

Signals

After making an initial inventory of the vocalisations made by Gudrun, we were able to classify the sounds into some 12 different contour groups. The signals used in the experiment were then designed on the basis of this classification. Consequently, we designed five types of stylised replicas of Gudrun's vocalisations, and assigned to them certain, meanings. Two of the signals represented action words or verbs, namely "*take*" (signal **A**) and give or "*bring*" (signal

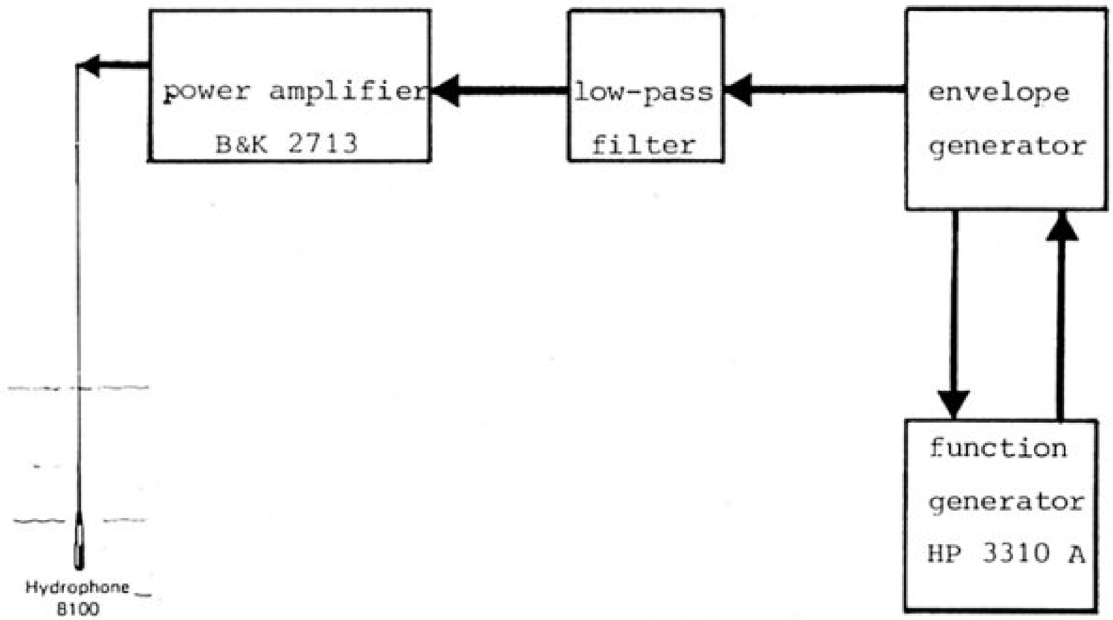

Figure 5: Diagram of the stimulus generator

B). Two toys with which Gudrun was already familiar were selected to serve as nouns: a lightweight dumbbell (signal **C**) and a fender (signal **D**) of the type used as buffers between boat and dock (see **Figure 4**). A third noun, namely one signifying "*large fish*" (signal **E**) was added to her repertoire at a later stage. In devising these signals, care was taken to see that they would fit well in the audiogram (Hall and Johnson, 1972). Using frequency-modulated patterns as information carriers is preferable to using constant-tone stimuli due to the number of degrees of freedom that can be modified. Without going into detail, we offer a short description of the analysis and coding of the structural information content of the patterns used in our experiment in the appendix. The frequency modulation patterns of the signals are represented in **Figure 3**. Note that the description of the tonal vocalisations as given by Steiner et al (1979) for the wild killer whale fits these signals.

The equipment

The equipment used in the experimental setup of the communication experiment is schematically indicated in **Figure 5**. The envelope generator is the central part of the pattern generating system and contains the electronic circuits necessary to deliver a set of five control signals, which activates the function generator HP type 3310 A to obtain the time-dependent frequency contours. These pattern contours are fed into the power amplifier **B&K** type 2713, to get an adaptation for the underwater transducer **B&K** type 8104. The slope of 12 dB of the transmitting voltage response of the 8104 transducer is linearised in the envelope generator by a low-pass filter of -12 dB, resulting in a flat transmitting frequency response over the bandwidth of interest. From phase 8 onwards the projected signals were monitored via another hydrophone and made audible on headphones. Finally, a tape recorder was added to register the transmitted stimuli and corresponding responses of the orca. During the experiments a monitoring microphone was incorporated in the recording chain to register Gudrun's vocalisations above water.

The experiment

The experiment was divided into 11 phases. Each successive phase was based on the results obtained in the preceding phase and/or changes in the electronic equipment. The sequence of signals presented during phases 1 to 4 and phase 8 was determined on the basis of a list of random numbers between 0 and 100. If two signals were used one after another to form a message, the action signal was given first and then the noun signal. Normally there were 8 runs per day in which about 15 signals or signal sequences were presented.

Phase 1 [1]

Dates
June 30, 1980 through July 9, 1980

Methods
Places used: Equipment A_l, Hydrophone H_1, dumbbell O_1 and fender O_1'

The experiment was initiated in the following manner: first a "*noun*"-signal was given and afterwards the object belonging to that signal was held above the surface of the water for Gudrun to touch. Sometimes the object was held up without giving a signal, but then Gudrun was not allowed to touch the object. Each object had its own place, which later facilitated the control.

Results
After Gudrun had learned to touch the object at the appropriate signal, it was checked to see whether she came toward the objects or toward the trainer. To that end, the objects were placed in the water at the moment that the signal was given and the trainer walked away. Once a signal was given, she was supposed to swim to the object and afterwards was rewarded accordingly with fish. In these cases, Gudrun went toward the object and not toward the trainer. In fact, she always swam toward the objects, even if no signal was given. After some time she began to be noticeably nervous, probably because she could not understand why she was rewarded one time and not the other.

From the fact that Gudrun always touched the objects which were offered and that she was clearly nervous we concluded that she could not hear the signals or in any case not well enough. It was therefore decided to discontinue this plan. The control situation in which Gudrun had to make a choice was not carried out anymore.

Phase 2

Dates
July 10, 1980 through July 20, 1980

Methods
Places used:
Equipment A^1, Hydrophone H^1, Objects O^2.

The advantage of this rearrangement was that Gudrun found herself more often near the hydrophone. The sequence was as follows: first a signal was given, and afterwards an object was held above the water. If the object presented belonged to the signal given, Gudrun was supposed to touch the object and she was then rewarded. If the object did not match the signal, Gudrun was not supposed to touch it. If in that case she did not touch the object, she was rewarded. If she wanted to touch the object anyway, it was removed and she was not given a reward.

Results
We started with signal **C**, which meant that she could touch the dumbbell but not the fender. The second day she refused very clearly to touch the fender. She surfaced within ca. 1 metre of the fender and made a lot of noise. The next day we began with signal **D**. Now she was allowed to touch the fender but not the dumbbell. The first two times that the signal was given she didn't want to touch the fender. Afterwards, however, she began to touch it, initially hesitantly, but the hesitation quickly disappeared. Later that day, signal **C** was used once and the fender presented. She refused directly, in her characteristic manner, to touch this. Since July 13 series of both signals **C** and **D** were used, thus a combination of the dumbbell and the fender were offered. The score was good: depending on her motivation 80 to 95% correct reactions. The speed with which she reacts to the signals is a good measure for her motivation. When she reacts very slowly, her score decreases, although at least 80%, and when she reacts very quickly her score is very high, about 95%. We conclude that now Gudrun is able to hear the signals, she also reacts correctly. Because she clearly behaves differently when she doesn't want to touch an object than when she does, interpretation mistakes regarding her reactions can be ruled out. We may thus conclude that at this point Gudrun is capable of distinguishing between the two signals and further that she knows which object belongs to each signal.

Phase 3

Dates
July 21, 1980 through August 13, 1980

Methods
Places used: Equipment Al, Hydrophone H1, Objects O2.

The aim of this phase was to stimulate Gudrun to produce the signal herself if the artificial signal was delayed. Now Gudrun was expected to touch the object first and then wait under water for the appropriate signal, after which she was rewarded.

[1]With all phases, compare **Figure 2**

Results

No registrations resembling the artificial signals were made. On August 1st her motivation clearly began to decline, which was made obvious by her continued attempts to "eat" the hydrophone. It appeared that Gudrun wasn't ready to produce the signals herself

Phase 4

Dates
August 15, 1980 through October 3, 1980

Methods
Places used: Equipment A_1, Hydrophone H_1, Objects O_2 and O_2'.

In this phase Gudrun, upon hearing a signal, had to make a choice.

To prevent her from having a preference in orientation, both objects were laid down at the edge of the pool, one to the left and one to the right of the hydrophone, and they were interchanged at random. The meaning was to get Gudrun, having heard the signal, to move in the direction of the object belonging to that signal.

Results
Already at the end of the first round Gudrun began hesitantly to turn. Within a week a score of 95% correct reactions was obtained. But once again, her motivation began to decrease after some time. This was concluded among other things from the observation that she began purposely to make mistakes, then scoring less than 5%. After a 3-week break she was able to react correctly from the first run, but as the day wore on she began to get bored again.

From the fact that within a week Gudrun was able to react almost faultlessly to the signals we conclude that she could distinguish between them very well, and further that she learned very quickly. However, her motivation decreased as time went on, because no changes in the course of the experiment were made. The rapid speed of learning and the fact that a high score could be obtained points to the conclusion that she primarily made mistakes on purpose. Had she simply made a random choice the score would have been 50% instead of the 5% which she then actually scored.

Phase 5

Date
October 6, 1980

Methods and results
Places used: Equipment A_1, Hydrophone H_2, Objects O_3.

After the nouns we now turn our attention to the action words, the verbs. As preparation for the introduction of the verb signals a new object was introduced, namely a skippy ball. Because she was already trained to fetch objects that were thrown in the water, this phase was directed toward first presenting signal **B** and then throwing the object in the water. Already at the end of the day Gudrun had learned to wait for the signal. However, this phase was quickly terminated because the risk was too great that Gudrun would simply interpret the signal as a '*go-signal*'.

Phase 6

Date
October 7, 1980

Methods
Places used: Equipment A_1, Hydrophone H_2, Objects O_3.

The method is the same as that in phase 3, namely touching objects and waiting for the signal.

Results
During these runs Gudrun imitated both signal **C** and signal **D** several times. A few times, if the signal was deliberately delayed, Gudrun produced the correct signal herself. The verity of the reproduction was initially ascertained by ear, but a later analysis of the tapes confirmed that Gudrun's imitations very closely resembled the artificial signals. These registrations confirmed the expectations that Gudrun was able to produce the sounds herself. That she was able to do this correctly and even to use them intelligently appears from the fact that when she spontaneously gave a signal it was always the correct one.

Phase 7

Dates
October 8, 1980 through October 9, 1980

Methods
Places used: Equipment A_1, Hydrophone H_2, Objects O_3.

Phase 7 was a continuation of phase 5. To avoid the risk of having signal **B** considered as a start signal, **B** was now combined with the object signals to form the message **BC** and **BD**. It was important to keep Gudrun under the water long enough so that she could hear both signals belonging to the message.

Results
The fetching of the signalled objects presented no problems. It was more difficult to get Gudrun to stay under water long enough to hear both signals, since she tended to come directly to the surface. Because the stimulation of the use of signals was considered of the utmost importance at this point, this phase was discontinued.

Phase 8

Dates
October 10, 1980 through November 10, 1980

Methods
Places used: Equipment A_1, Hydrophone H_2, Objects O_3.

The method was the same as in phase 3, thus touching objects and waiting for the signal.

Because it was now possible to listen to Gudrun's vocalisations under water we tried to stimulate her to make the signals herself. In the beginning she was given an extra reward if she made the sound under water. The time delay in presenting the signals was made longer and longer to stimulate her to make the signal herself at the proper moment. If she produced the signal she was royally rewarded. If not, an artificial signal was presented as a reminder.

Results
On October 21st she imitated the signals four out of five times. Three days later she often produced the correct signal spontaneously when an object was shown. She never made the wrong signal. She produced signal **D** 80% of the times the fender was shown, but signal **C** only in 35% of the cases the dumbbell was shown. The reason for this preference for signal **D** is unknown.

We concluded that she was able to correlate the signals with the objects shown.

Phase 9

Dates
November 11, 1980 through January 26, 1981 (with a break from November 26, 1980 through December 22, 1980).

Methods
Places used: Equipment A_1, Hydrophone H_2, Objects O_3 and O_1, later Equipment A_2, Hydrophone H_3, Objects O_3 and O_1.

In this phase both verbs were introduced, that is, signal **A** for "*take*" and signal **B** for "*bring*" or "*give*". To introduce the new action word "*take*" Gudrun was first offered the signal combination **AC** or **AD**. She then received the object from one trainer and was obliged to bring it to a trainer waiting at the other side of the pool, and then to swim back without the object to the hydrophone on the other side of the pool, where she was rewarded.

Results
After only one day the help of the extra trainer was unnecessary. Gudrun herself, after receiving the signal **AC** or **AD**, brought the object from O_3 to O_1, or from O_1 to O_3 after message BC or BD.

On November 24th she reacted correctly to both objects, even when they had floated to the middle of the pool. Upon hearing the signal combination **AC** or **AD** she brought the correct object away from the trainer and after **BC** or **BD** she brought the object closer to the trainer.

After a few days Gudrun obviously became bored. She became less and less cooperative and she tried to remove the objects from the pool. The objects were always returned, however, and the experiment continued. The aim was to make it clear that she could only have it her way if she "asked" for it by producing a signal sequence. On December 23rd Gudrun pushed the fender against the hydrophone and gave, above water, the signal **AD**, that is, the message "take the fender". The fender was taken away and she was of course rewarded. Later, she used both **AC** and **AD**, always in a meaningful context, by which is meant that she used the signal combinations only in situations where it was possible to react by taking the object concerned. There are 3 important points in Gudrun's use of signals:

1. She only made the signals above water, in the neighbourhood of the trainer, and always with the object concerned next to her.

2. She always brought the object to the trainer first before giving the signal **AC** or **AD.**
3. She apparently interpreted the signals as an indication of direction with respect to the one who produces the signals. She used signal **A** to indicate the direction away from her, i.e. the "speaker" She did not use signal **B** in this case.

Phase 10

Dates
January 27, 1981 through March 2, 1981

Methods
Places used: Equipment A_3, Hydrophone H_4, Objects O_1.

The objective of this phase was to ensure that Gudrun did not associate the actions with fixed positions but that the direction was determined by the location of the trainer. It was intended to emphasize the idea that signal **A** was to be interpreted from the "speaker" and **B** as going toward the "speaker", independent of what position the "speaker" might take.

Results
The training started by presenting as an initial test the message **AC**. Gudrun took the dumbbell, swam away with it and set it down at position P, the same point which she later used to respond to signal **AD**[2]. Even when the objects had drifted to the middle of the pool she reacted correctly to the signals. Also in this phase she time and again used **AC** and **AD**.

The fact that she had interpreted **AC** and **AD** as indications of direction had now been emphasized. It is clear that points O_1 and O_3 themselves were not the determining factors for her movements, with the objects, but that the most important point was the indication of the direction with respect to the speaker. We further note that as a means of documentation at this point, films and tape recordings were made of Gudrun going through this and all previous phases. (ATV/CT Documentary "*The Talking Whale*").

[2] Position P had not been used before during the experiment

Phase 11

Dates
February 16, 1981 through March 2, 1981 (alternating with Phase 10 sessions)

Methods
Places used: Equipment A_3, Hydrophone H_4, Objects O_1.

Because Gudrun has not yet used signal **B**, that is, she had not yet asked for something to be given her, a situation was created in which she would be stimulated to produce her own signal **B**. As she had already worked so often with the dumbbell and the fender, a new signal, signal **E** meaning a '*large fish*' was introduced.

Three objects were used: the dumbbell, the fender and a large fish (mackerel or herring). It is important to note that these fish were used only for the training and not as a reward. Initially, Gudrun was expected, just as in previous phases, to touch the object and then wait for the signal that belonged to it: first the dumbbell, then the fender and finally the fish. In the first two cases, the object was given to Gudrun, released and then taken away, after which she was to wait for the signal. In the last case, however, the fish was extended to her, she held it in her mouth: and after she had given it back to the trainer and signal **E** was given she was rewarded with a number of fish. Later it was attempted to get Gudrun to perform the same actions with the fish that she had with the dumbbell and the fender. Therefore, as with signals **BC** and **BD**, the signal **BE** was presented and Gudrun was expected to take the fish to the trainer on the other side of the pool.

It was only necessary in the early phase of the training of signal **E** to hold the fish in order to prevent Gudrun to swallow it. After that early phase - which only lasted about 10 minutes - she returned the fish without being restrained by hand.

Results
The speed at which she learned signal **E** was amazingly fast. Already the second time the signal was presented she imitated it perfectly under water and then later regularly above water as well. Later the same day she began spontaneously to produce signal **E** herself above water, for which she was consequently rewarded.

The speed at which she was able to learn signal **E** suggest that she found it very easy to learn. On February 19th the signal **BE** was introduced twice in an unsuccessful attempt to teach Gudrun to bring the fish to the trainer. She took the fish, turned in the appropriate direction, but apparently overcome by temptation, swallowed the fish.

Unfortunately, due to circumstances beyond our control, the experiment had to be stopped, on March 2nd.

The numerous times that Gudrun spontaneously produced signal **E** shows that she indeed correlated this signal with fish. She had never done this so quickly with other objects. Nevertheless, there is no reason to assume that this signal is any easier to reproduce than the others. This was a difficult experiment for Gudrun because she was expected not to swallow the fish immediately. That she first turned in the direction of the trainer indicates that she understood what was expected of her but that it cost her too much self-control to bring the task to its proper end.

We postulate that, had the experiment been continued, Gudrun would have eventually been able to apply her knowledge of the new signal **E** to form the message **BE**, that is to ask for the fish to be given to her. Note that she had already begun to use signal **E** to demand fish in the beginning of this phase. At this stage in the experiment, no care was taken to remove the trainer, which rnight seemingly imply that we allowed the "*Clever Hans* syndrome" to operate. However, the syndrome does not play a part at all in the crucial phase of the experiment. The animal was not asked to make a choice, which could be influenced because of the syndrome. On the contrary, Gudrun was given the option to take the initiative to act i.e. to communicate. To us the task to await, to absorb her question c.q. command and to act accordingly.

Discussion

During the first phases of the experiment it appeared that the orca could visually choose the correct object when an acoustical stimulus was presented. Moreover, she proved to be able to produce the correct acoustical signal at the sight of an object. As explained by Geschwind (1964) a connection between the visual and acoustical association areas in the brain must exist in order to be able to perform such tasks. There can be little doubt that this condition is realised in the orca. It means that the planning of future communication experiments with this species is considerably facilitated.

The next step was to teach the animal the meaning of two action words, "*take*" and "*bring*", in combination with the object signals. Within a short time she was able to respond correctly to the four combinations of signals. As usual as things go on unchanged, Gudrun became bored and tried to get rid of the objects. She discovered that her attempts were only successful if she gave the signal sequence "*take fender*" or "*take dumbbell*", interpreting the signal "*take*" as away from the speaker. She never asked to be given one of the objects, in which she was no longer interested. In order to make "*give*" more interesting, a new object signal "*fish*" was introduced. She learned the meaning of the signal amazingly fast. A combination of the signals "*give*" and "*fish*" could not be accomplished before the experiments had to be terminated. However, her initial reactions suggest that she would have eventually been able to produce the required signal message.

Conclusions

The outcome of this experiment forms a good launching pad from which further research on man-orca communication can be carried out.

The use of frequency-modulated signals, which were to a certain extent related to the animal's natural tonal vocalisations, enables more structural information to be contained in the same time span as constant frequency stimuli.

Acknowledgements

Undoubtedly, an experiment of this scope involves the help and interest of several people also outside the field of delphinid research. To single out a few of these we would like to mention Dr. E. Leeuwenberg and Dr. H. Buffart (University of Nijmegen, Netherlands) for their help on the coding of the stimulus contours, Prof. dr. Fl. Verheyen (University of Utrecht) and Prof Ir. Y. Boxma (Delft University of Technology). The technical part of our experiment would not have been possible without the skilled assistance of Mr. B.M. van den Boom and the work of the student Mr. J.VI. Akkermans.

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We are grateful to Anglia Television (formerly A.T.V. now C.T.), in particular Mr Robin Brown, director of the documentary "*The Talking Whale*", which covers the experiment with Gudrun, for their interest and cooperation and not in the least for their donation to the Netherlands Foundation for Aquatic Mammal Research.

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References

Geschwind, N. (1964)
The development of the brain and the evolution of language.
Monograph series on language and linguistics no.**17**:155-170. Georgetown Univ. Press.

Hall, J.D. and C.S. Johnson (1972)
Auditory thresholds of a killer whale *Orcinus orca* Lineaeus.
J. Acoust. Soc. of Am. 51-2(2): 515-519.

Herman, L.M. (1980)
Cetacean Behavior: Mechanisms & Functions. Wiley & Sons, New York.

Reysenbach De Haan, F.W. (1966)
Listening Underwater: Thoughts on Sound and Cetacean Hearing.
In: **K.S. Norris** (Ed.), Whales, Dolphins and Porpoises. Univ. of California Press, Berkeley and Los Angeles.

Schevill, W.E. and W.A. Watkins (1966)
Sound structure and directionality in *Orcinus orca*.
Zoologica **51**: 71-76.

Steiner, W.W., J.H. Hain, H.E. Winn, P.J. Perkins (1979)
Vocalisations and feeding behaviour of the killer whale (*Orcinus orca*).
J. of Mammalogy **60(4)**: 823-827.

Documentary

Central Television (formerly ATV) Documentary: "*The Talking Whale*", directed by Robin Brown.

Appendix I: Time-dependent frequency stimuli

Intuitively we note that constant-frequency stimuli possess a minimum transportable amount of information with regard to a frequency-modulated pattern. Moreover, constant-frequency stimuli are not quite natural stimuli in information-processing experiments, although they are easily generated and well-established patterns in most psycho-physical experiments.

The information theoretical description of the stimuli used is based on the outcomes of the study of pattern dimensions as developed by Leeuwenberg and Buffart in the last decade. This pattern-coding theory enables one to calculate the structural information load of a pattern (the number of degrees of freedom), in contrast to the well-known selective information theory proposed by Shannon (1963).

The amount of structural information gives a measure for the - perceptual - complexity of a pattern, as short as possible. Without going into detail about theoretical backgrounds of coding theory - the interested reader is referred to the coding manual by Buffart and Leeuwenberg (1982)- we shall describe the information load of the various patterns used in our experiment.

The five types of stylised tonal patterns we used are represented in **Figure 3** A to E.

If we take a closer look at the pattern indicated in **Figure 3** A, representing the time-dependent frequency structure, the following parameters are included:

a the starting point is at the frequency axis at *f1*.
b proceeding along the time axis, the only parameter involved until a change in frequency occurs is the time duration of 0.8 sec.
c from now on, there is not only a continuance in time for 0.3 sec, but also an increasing frequency up to *f2*; thus two parameters are involved.
d after frequency *f2* is attained, the only parameter that is involved for the rest of the stimulus pattern is a time duration of 0.3 sec.

Summing up the independent changes that occur in the pattern over time; we arrive at 5 degrees of freedom, i.e. 5 parameters that might change our basic pattern. So we observe that the minimum information load in this configuration is equal to the number of degrees of freedom, that is I=5.

In exactly the same way we can describe the phase-inverted pattern as is presented in **Figure 3** B. It contains the same structural information load, although the perceptive value of the information is not included: a pattern going from a low frequency via some path to a higher frequency gives another perceptive sensation then the inverted one.

We thus arrive for the signal **B** at a value of I=5 for the amount of structural information.

We now take **Figure 3** C and proceed along the pattern in time to note the degrees of freedom. At first glance the three segments of this pattern cover **Figure 3** A's evolution in time up to 1.0 sec. From then on there is not only the continuance in time for 0.3 sec but also a decreasing frequency present. After attaining the original starting point with regard to the frequency domain, the pattern ends after 0.1 sec without any change in the frequency.

Summing up the various points of change and the corresponding changes in time and frequency at these points, we arrive at an information load in this pattern of I=8.

If we were to take into account the fact that in the second part of the pattern, where we arrive at a frequency that has already been determined (indicating that a certain 'memory' in the perceptive experience is built-in), we could decrease the information load to I=7. However, as there is by no means evidence for such a phenomenon in the auditory perception of delphinids, we are inclined to insist on the higher information load of 8 degrees of freedom.

Proceeding along the same lines as for **Figure 3** C in the case of signal **C**, we encounter no problems in defining a structural information load of 1=8 for the case of the phase-inverted pattern, signal **D**. By virtue of this reasoning, it is now clear that a constant-frequency stimulus as presented in **Figure 3** E yields the minimum information load contained in such a pattern, namely 1=2 (see the JANUS research program of J.C. Lilly, 1977).

As far as concatenated patterns to form a message are concerned, we could simply add the amounts of information by using the additivity theorem of the individual patterns if we treat them to be independent of each other.

Thus, a message like the one used in our experiment in the form of **A+C** or **B+D** gives a total amount of structural information as $I(A)+I(C) = 13$ and similarly $I(B)+I(D) = 13$.

References

Buffart, H. and E. Leeuwenberg (1982)
Coding visual patterns, a manual. In: Psychophysical judgment and the process of perception. Eds.: **H. Geissler, H. Buffart, P. Petzoldt, Y. Zabrodin.**
Amsterdam, North Holland Publ. Comp.

Lilly, J.C. (1977)
Janus. A publication of the Human-Dolphin Foundation, Malibu, Cal., U.S.A.

Shannon, C.W. and W. Weaver (1963)
The mathematical Theory of Communication. University of Illinois Press, Urbana.

Appendix II: Considerations with respect to future research

If Gudrun would become available for research again, which is not possible at present, it would be very interesting to continue the initial experiment in order to see what level she would be able to master in two-way communication. However, if at some stage she would not be able to improve her language capabilities the following argument should be taken into account.

A nightingale male chicken has at a very distinctive period in its early life to hear an adult male sing. If it does not and the critical period has passed, this male chicken will, once adult, not be able to sing the characteristic male nightingale song. In the same way children will have to learn and speak before the age of at best 8 years, otherwise the mastering of the human language to its full extent (i.e. expressing abstract thoughts) is impeded.

We have no prove whether an orca has such a critical learning period, neither at which age this period, if present, may end. However, the existence of this period is most likely.

Gudrun was about 5½ years of age at the time of the experiment. If her training would continue and a maximum level would be established, this would mean, if my view is correct, that there are two possibilities. Either *Orcinus orca*, i.e. this particular individual, is not intelligent enough to reach a more complicated level, or we were too late in Gudrun's life to give her a full chance to develop her innate capabilities. Therefore I am strongly in favour of repeating this experiment with the youngest possible animals.

Gudrun when caught was only 270 cm long, but completely weaned and she was no exception as we learned. This is an indication that the Icelandic population probably grows to a smaller length than the NE Pacific population, of which the juveniles are weaned at a length of at least 300 cm.

Paper history

This paper was originally published in Aquatic Mammals **9(3)**: 69-82. In this online version, a picture of Gudrun and drawings of the objects used in the experiment were added. Consequently, the figure numbering has been adjusted. With the exception of some text markup changes, the original text has been left untouched. A Table of Contents has been added as well as the following short history of Gudrun.

About Gudrun

Gudrun was caught in Iceland, in the Skeiðarársandur area (SE Iceland) in October 1976 in an operation led by Jón Gunnarson (see Sigurjónsson and Leatherwood, 1988) and was transported to the Dolfinarium in Harderwijk, the Netherlands. . She was caught together with Kim, a female that was transported to Marineland, France and Kenau, a female that was transported to Sea World in San Diego in May 1977 (Hoyt, 1990). She was named after the boat that was used in the capture operation, the M/V *Guðrún*. Although she occasionally had other killer whales for company (whales in transit to other parks) she spent most of her time in the company of a group of bottlenose dolphins. She was part of show performances. In 1987, the Dolfinarium decided to move Gudrun, officially on a breeding loan, to Sea World of Florida, in Orlando. At first she had to get used to being with other killer whales after years in the company of bottlenose dolphins only. As Sea World trainers put it: *she was behaving as a dolphin and had to learn to behave as a killer whale*. She adapted quite well to her new environment. Within a year she was integrated in the Sea World performances. In 1988, she became pregnant and had her first calf, Taima, the next year. A few years later she had another calf. Unfortunately, Gudrun died on February 25, 1996 of the complications of a miscarriage (her third pregnancy).

References

Hoyt, E. (1990)
Orca - The whale called killer (New Edition). Robert Hale, London.

Sigurjónsson, J.and Leatherwood, S. (1988)
The Icelandic live-capture fishery for killer whales, 1976-1988. in: **J. Sigurjónsson and S. Leatherwood**: North Atlantic killer whales. pp.: 307-316 Rit Fiskideildar, Vol. XI. Hafrannsóknastofnunin, Reykjavík, Iceland.