DISCRIMINATION OF QUANTITY IN CAPTIVE KILLER WHALES

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Introduction

The processing of arithmetical relationships is a hallmark of human cognition, and a number of non-human animals have also been shown to possess a degree of numerical competence. To assess an elemental level of numerical processing in the Orca, we trained whales to choose which of two stimulus cards displayed a greater number of dots. Thus, the paradigm/task employed here is an example of "relative numerousness judgment", and it is thought to reflect the most rudimentary of numerical processes.

Methods and Results

Two captive born, juvenile Killer Whales (of Icelandic stock) served as subjects of this investigation – an eight-year-old female and a four-year-old male.

During training and testing, the animal shuttled (across an 8 meter pool) between a stimulus station and a feeding station where it was presented with fish reward for correct responses. Each whale was tested separately and out of sight of the other.

Training Phase (Sequential Comparisons)

Over successive trials, the whales were presented underwater with two black stimulus cards, each of which contained small white squares (see Fig. 1). The whales were rewarded for touching their snouts to whichever of the two cards had the greater number of squares (Fig. 2). The size of the squares, the pattern of their placement on the cards and the side of the correct card (left/right) were varied pseudorandomly in counterbalanced fashion within and across days. The size of the stimulus squares was varied so that the total white area on the correct card was sometimes greater than, equal to, or less than that on the incorrect card.

Each whale was moved through a series of progressively more difficult comparisons – staying at each level until it reached a preset criterion of performance (18/20 or 12/14 in the two training phases respectively). The sequence of trials and each whales performance during this training in summarized is Table One.

During this training, Subject F8 successfully mastered 6 vs 5 and failed at 7 vs 6. Subject M4 successfully reached criterion up to 10 vs 9, the highest comparison used.

A consistent pattern of errors appeared in the early stages of training. Both whales made many more errors when the correct (greater number) squares were smaller in size (surface area) than the incorrect (lesser number) of squares. That is, at the outset the whales appeared to have difficulty separating "how much" from "how many". This pattern of errors may be called "Piagetian" in that it corresponds to the type of errors that human children make during cognitive development. Errors of this type gradually became less frequent and disappeared by the final Testing Phase of our study (Figure 3).

There was a decrease in the number of trials taken to reach criterion over successive comparisons (see Table 1) – evidence that is compatible with the notion of learning set formation.

Figure 1: Example of Testing Stimuli Before Placement

Figure 2: Subject F8 Approaching Stimuli

Table 1: Training Trial Sequence and Performance

Training Phase (a)

	Subject F8			Criterion	Subject M4			Criterion
Comparison	Trials	Days	(18/20)		Trials	Days		(18/20)
2-1	860	89	N		614	55	Y	
3-2	20	2	Y		60	6	Y	
3-2	60	6	Y		250	25	Y	
4-3	20	2	Y		20	2	Y	
4-3	20	2	Y		20	2	Y	
5-4	180	18	N		300	25	N	
5-4	20	2	Y		20	2	Y	
5-4	20	2	Y		20	2	Y	
5-4	110	12	Y		20	2	Y	
6-4	110	9	Y		300	25	N	
6-4	20	2	Y		20	2	Y	
6-3	20	2	Y		20	2	Y	
6-3	30	3	N		20	2	Y	
6-4	70	7	N		20	2	Y	
6-5					60	6	N	

Training Phase (b)

	Subject F8			Criterion	Subject M4			Criterion
Comparison	Trials	Days		(12/14)	Trials	Days		(12/14)
10-1	14	1	Y		14	1	Y	
8-1	14	1	Y		14	1	Y	
6-1	14	1	Y		14	1	Y	
5-1	14	1	Y		14	1	Y	
10-2	14	1	Y		14	1	Y	
8-2	14	1	Y		14	1	Y	
6-2	14	1	Y		14	1	Y	
5-2	14	1	Y		14	1	Y	
10-3	14	1	Y		14	1	Y	
8-3	14	1	Y		14	1	Y	
6-3	14	1	Y		14	1	Y	
5-3	28	2	Y		14	1	Y	
4-3	28	2	Y		14	1	Y	
10-4	14	1	Y		14	1	Y	
8-4	14	1	Y		14	1	Y	
6-4	14	1	Y		14	1	Y	
5-4	28	2	Y		28	2	Y	
10-5	14	1	Y		14	1	Y	
8-5	14	1	Y		14	1	Y	
7-5	43	3	Y		14	1	Y	
6-5	14	1	Y		14	1	Y	
10-6	14	1	Y		14	1	Y	
8-6	28	2	Y		14	1	Y	
7-6	140	10	N		56	4	Y	
10-7	14	1	Y		14	1	Y	
9-7	30	3	N		14	1	Y	
8-7					70	5	Y	
10-8					14	1	Y	
9-8					70	5	Y	
10-9					14	1	Y	
Total	2210	194			2240	180		

Figure 3: Performance as a Function of Stimulus Area and Stage of Training

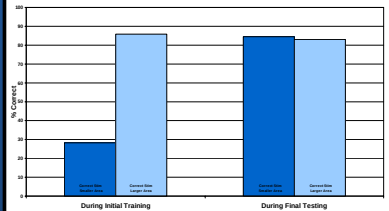
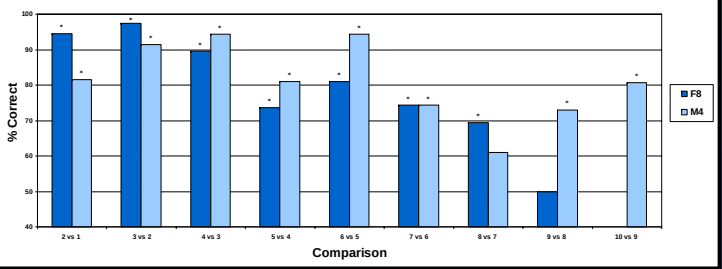


Figure 4: Testing Phase Intermixed Trials



Testing Phase (Intermixed Comparisons)

Over a period of 20 days, we presented each whale with a varied sequence of adjacent numerical comparisons (18 trials per day). That is, in this testing phase the trials presented an intermixed sequence of comparisons such as 7 vs 6, 3 vs 4, 1 vs 2, 9 vs 8, and so on. The trial sequences were presented pseudorandomly – meaning without discernable pattern, but counterbalanced by size, side and number.

The results are depicted in Figure 4. Subject F8 reliably discriminated comparisons up to 8 vs 7. Although, by contrast, Subject M4 did less well at 8 vs 7, he reliably discriminated 9 vs 8 and 10 vs 9.

Logistically, it was impossible for us to conduct all training and testing trials with *de novo* stimuli and in "blind" fashion. However, in this phase we included probe trials which presented entirely novel stimulus cards and in which all control signals, stimulus presentations and fish rewards were given by individuals unable to see the stimuli or know the correct responses. The performances by both subjects on these probe trials did not differ significantly from that on our ordinary trials.

Discussion

The large brainedness (cephalization) of cetaceans may be expected to be associated with a refined perceptual and cognitive processing of information. In this regard, it is noteworthy that the performance in our study by our two Killer Whales (reaching 8 vs 7 and 10 vs 9) meets or exceeds the abilities of other non-human species tested on this paradigm.

Ecologically, it can be argued that the perception of quantity might be important to non-human animals within cost/benefit analyses during predator-prey and/or social interactions. Nevertheless, the very large number of trials needed during initial training suggests that Killer Whales are not predisposed to readily attend to number as a stimulus dimension.

In evolution, the cephalization of cetaceans can be taken as parallel to (and independent of) the same trend in primates. It might therefore be anticipated that cetaceans could possess a "different" kind of intelligence from that of primates. However, the fact that our subjects initially showed the same "Piagetian" pattern of errors that are shown by human children and non-human primates when presented with the same task is more compatible with a common form of processing in the two taxons.

To further explore this dimension of Orca cognition and more fully determine the extent to which their numerical processing corresponds to primates, it will now be interesting to test their abilities (a) to make "absolute" discriminations of quantity (e.g., find the "5" regardless of its comparator), (b) to place stimuli with quantitative content into ordinal relationships, and (c) to process combinations (additions) or separations (subtractions) of stimulus quantities.

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