Two-choice discrimination learning in African elephants *(Loxodonta africana)*

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Abstract

A study of two-choice discrimination learning across 22 pattern pairs was conducted with three African elephants (*Loxodonta africana*) at the Atlanta/Fulton County Zoo with rates of acquisition and retention observed to be similar to those earlier reported for the Asian species (*Elephas maximus*). A significant difference was found in trials to criterion for the second half of the stimulus pairs compared with the first, indicating potential development of the learning set; after seven months with no exposure to the pattern problems, one of the subjects correctly selected the appropriate pattern on 16 of 20 pairs, and the other subject demonstrated improvement on a computer joystick task. This study extends learning research to the African species and indicates potential for further cognitive skill development.

Résumé

Une étude de l'apprentissage de discrimination de deux-choix parmi 22 paires de motifs s'est menée avec trois éléphants africains (*Loxodonta africana*) au zoo d'Atlanta/Fulton County où les niveaux d'apprentissage et mémoire se ressemblaient à ceux que Rensch (1957) a présenté pour l'espèce asiatique (*Elephas maximus*). Une différence considérable s'est trouvée dans les chemins de critères pour la deuxième moitié des paires stimulantes par comparaison à la première, ce qui indique le développement possible de l'ensemble de connaissance ; et après sept mois sans exposition aux problèmes, un des sujets a sélectionné correctement le motif approprié avec 16 des 20 paires, et l'autre sujet a démontré de l'amélioration sur une tâche avec un joystick de l'ordinateur. Cette étude étend la recherche de connaissance à l'espèce africaine et indique la possibilité du développement plus profondément des compétences cognitives.

Introduction

Elephants have been studied relatively little under experimentally controlled conditions. Yet they are intriguing subjects for examination in view of their large brains (a cerebral mass of 6,000 g) and field studies that suggest that they routinely engage in 'intelligent' behaviour, including the use of tools and complex social interactions (Douglas-Hamilton and Douglas-Hamilton 1975; Moss 1988). Complicating the accurate evaluation of elephant behaviour are centuries of folklore regarding the animal's alleged capacity for memory and intelligence (e.g. Williams 1989). It is therefore surprising that no experimental studies of learning by African elephants have been published, while only basic studies of learning have been attempted with the Asian species.

In early work, Murnin and Burckhardt (1949) described without data their procedures to determine just-noticeable differences in shades of grey by an African elephant at the Bronx Zoo. Grzimek (1949) studied delayed responding in elephants to hidden food items with widely mixed results. Heffner and Heffner (1980, 1982) trained discriminative responding to right and left paddles by an Asian elephant in determining a hearing range of 17 hertz to 10.5 kilohertz for the species. Markowitz et al. (1975) describe how three Asian elephants learned to operate a light/dark key panel to obtain food rewards. With no exposure to the apparatus for eight years, one subject demonstrated significant retention of effective performance with the apparatus. More recently, Nissani et al. (2005) explored simultaneous visual discrimination between black and white and between large and small stimuli in 20 Asian logging elephants, finding an age effect in acquisition abilities favouring younger animals over those older than 20 years. Nissani (2006) questioned claims of causal reasoning in Asian elephants, which continued to displace food lids even when not required to do so to obtain available food rewards. Povinelli (1989) found that although two Asian elephants confronted with a mirror failed to demonstrate self-recognition, they did use the mirror to locate hidden food objects. Plotnik et al. (2011) claim that elephants readily learn nuances of cooperation in a food retrieval task, and Plotnik et al. (2010) discuss implications and benefits of cognitive research and mirror recognition studies on captive elephants, including the expansion of scientific knowledge, improved animal husbandry techniques and increasing public understanding of endangered species.

The most extensive study of elephant learning was conducted by Rensch (1957), who trained a juvenile female Asian elephant at the Münster Zoo to discriminate 20 pairs of 21-cm × 32-cm symbol cards to an 80–100% criterion. With no exposure to the stimuli for a year, the animal remembered 13 of the symbol pairs above a 67% criterion. In preliminary studies, Rensch and Altevogt (1953, 1955) had developed two-choice discrimination performance in tests of visual learning. Altevogt (1955) continued to test the visual acuity of elephants with various grades of patterned lines, reporting that their vision was not as good as that of humans, although he failed to control for or vary luminosity or stimulus distance and size.

Many details are noticeably absent from Rensch's published reports. For example, his 1957 article does not specify the number of total training trials that were required to acquire all 20 problems in serial rotation, although his 1953 study reports that 13 out of 15 problems were then being performed above a 67% criterion. Nor does Rensch report the total number of trials, trial length or the intertrial interval imposed in his experiment, although he did state that the animal could perform 600 trials over 3 hours with occasional breaks. To address these experimental variables, and to extend learning research to the domain of the African elephant, a systematically controlled replication of Rensch's (1957) discrimination learning experiment was conducted in 1989–1990 as part of a master's thesis project in experimental psychology at the Georgia Institute of Technology.

Method

Subjects

The subjects used were three female African elephants: Victoria (pretest subject), Zambesi (Subject no. 1) and Starlet (Subject no. 2). Aged approximately 6–7 years old at the time the study began, all were wild-born between 1981 and 1982 in or near Zimbabwe or Namibia in southern Africa and orphaned by the effect of culling operations. Purchased by Zoo Atlanta in 1985 and 1986, the animals' history before capture is not known. While naive to systematic behavioural experimentation, they were trained to respond to approximately 40 different vocal commands as a part of the zoo's management programme.

Apparatus

Functionally similar to a modified Wisconsin General Test Apparatus, a pretest apparatus consisting of two 32 cm × 32 cm × 32 cm 3/4″ plywood boxes was created and employed for 2,050 trials with the pretest subject and for 200 trials with Subjects no. 1 and 2 without satisfactory results. Set 68 cm above the ground and 90 cm apart, the boxes had 5-cm diameter rear holes for delivery of food reinforcers and swinging frontal doors containing 15-cm × 15-cm stimulus pattern cards.

The revised apparatus more closely resembled Rensch's original design and consisted of 44 black or white plastiboard stimulus cards (50 cm × 68 cm) placed over two of the animals' black rubber food tubs (50 cm diameter × 11 cm deep, set 68 cm apart and 1 m back from a 1.5-m × 2.25-m door opening) (see Figure 1).

Figure 1. Revised apparatus (curtain not shown).

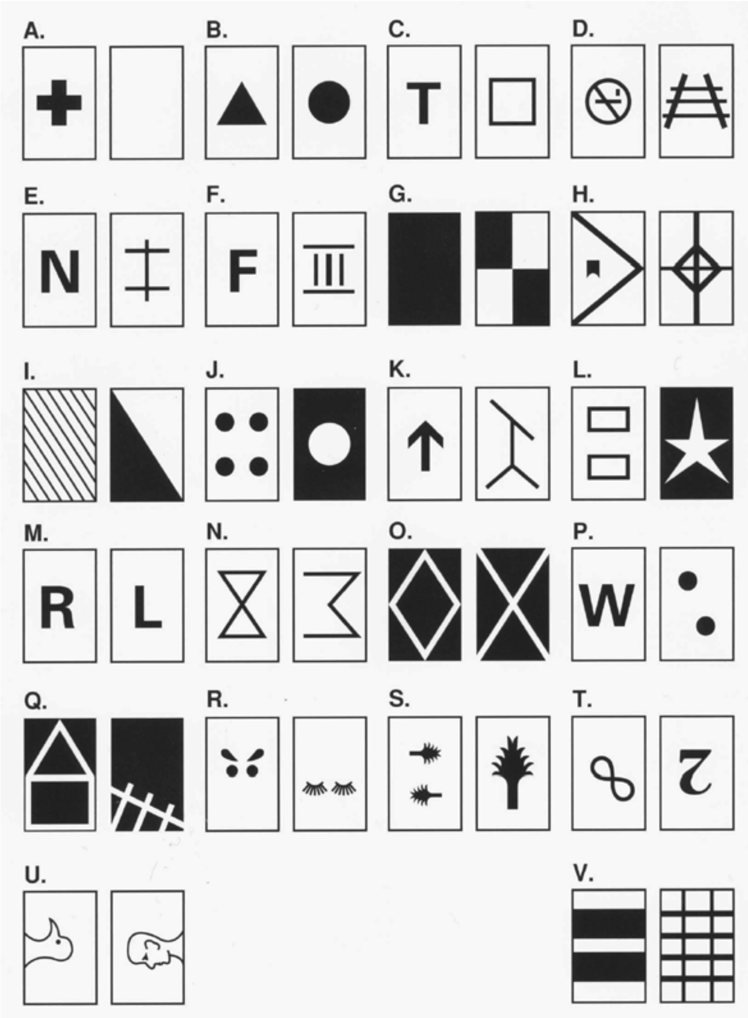

Figure 2. Stimulus pairs.

Stimulus patterns were constructed of 5-cm wide white or black plastic adhesive tape, shown in Figure 2. Stimulus pair U consisted of two photographs. Across the doorway a 1-cm × 10-cm steel bar was placed to separate the subject from the experimenter, who observed unseen from behind an opaque plastic curtain.

Procedure

The Zoo Atlanta trainer readily developed consistent corrective responding to the apparatus by the subjects. On a verbal signal 'All right', the subject was to move into the doorway, reach over the dividing bar, and with her trunk displace a stimulus card from its tub. An incorrect choice (S–) received a sharp 'No!' from the trainer followed by the opportunity to reselect. A correct response (S+) received a 'Good girl!', additional auditory reinforcement from a 'clicker', and the 3–6 g piece of carrot or apple underneath the card. The subject then retrieved and consumed the food item and was told to 'Back up' out of the doorway and turn to the side so she could not see the apparatus resetting.

Trials took 10 seconds each, followed by a 10-second intertrial and resetting interval. For safety, at least two keepers were always present, although when the animal was responding, she could not see them. (One stood behind the subject, and one in front of it, hidden with the experimenter behind the curtain.) The subjects were not food deprived, but the experimentation immediately preceded their regular afternoon feeding. The criterion for acquisition was set at 12 correct in a block of 15 consecutive trials (80%).

Subject no. 1 (S1)

After 210 trials, S1 achieved 12 of 15 criteria on the first problem (cross/blank). She then was provided stimulus pair B (triangle/circle) and the other 20 problems. She received 50–100 trials per day on new patterns several days per week for 70 sessions over four months. In general, she was trained to acquisition for each symbol pair before the next pair was introduced. However, with continued side or stimulus perseverations, trainer and experimenter would employ time-outs, non-corrective procedures, or the occasional introduction of a new stimulus pair. A brief warm-up of 10–20 trials of a previously learned pattern also regularly began each daily session.

Subject no. 2 (S2)

The same procedures were used with S2. She was presented with the 22 pattern pairs, with A and B presented first but with the next 20 in reverse ranked order, based on the speed of acquisition by S1. At the time the experimenter believed that the order of presentation should have had no effect on improvement in learning unless certain stimuli were preferred, which might be best observed if the order was varied, although in hindsight, keeping the presentation order consistent with S1 would have yielded its own set of insights. Because of time limitations, learned problems were not rehearsed or tested for retention in S2. After mastery of the 22 symbol pairs, this subject was introduced to a computer joystick task, based on the stick designed for monkeys by Rumbaugh et al. (1989) (level one: 'side'). If the elephant had been able to acquire stimulus control on this device, the discrimination study could have been continued on the computer.

Results

Subject no. 1

After 4,766 trials in 59 experimental sessions over 5 months, Subject no. 1 had reached 12 of 15 criteria on 22 stimulus patterns, shown in Figure 3. She received 1,215 further practice trials over 15 more sessions and then was tested on 20 of the problems presented in blocks of 5 non-corrective trials each, varying randomly the S+/S– from left to right, and placing food reinforcers in both tubs to avoid smell cueing. Seventeen of the 20 stimulus pattern problems were performed at 60% or better with a 71% overall success rate. Practice trials are included in this total number of trials but not in the data reported in Table 1 or Figure 3. After 241 days with no exposure to the stimuli, Subject no. 1 repeated the test, performing 16 of the 20 problems at 60% or better with 67% correct overall.

Subject no. 2

After 2,819 trials over 44 sessions in three months, S2 acquired 13 problems to criteria, was forced to take 10 weeks off, and then completed the other 9 problems in 1,600 more trials over 17 sessions in two months, also recorded in Figure 3. As stated, her retention was not practised or tested due to administrative time limitations. After approximately thirty 15-minute practice sessions working the

Table 1. Trials to criterion for stimulus pairs by presentation order

Presentation order	Card pair	S1	Card pair	S2
1	A	210	A	160
2	B	135	B	270
3	C	317	I	79
4	D	350	J	25
5	E	213	G	50
6	F	98	L	62
7	G	51	U	81
8	H	59	Q	96
9	I	52	R	263
10	J	45	H	97
11	K	277	O	81
12	L	38	M	81
13	M	73	D	256
14	N	49	S	37
15	O	211	P	49
16	P	32	N	164
17	Q	35	T	26
18	R	33	K	57
19	S	168	V	177
20	T	146	E	59
21	U	73	F	59
22	V	84	C	203
Mean		124.954		110.545

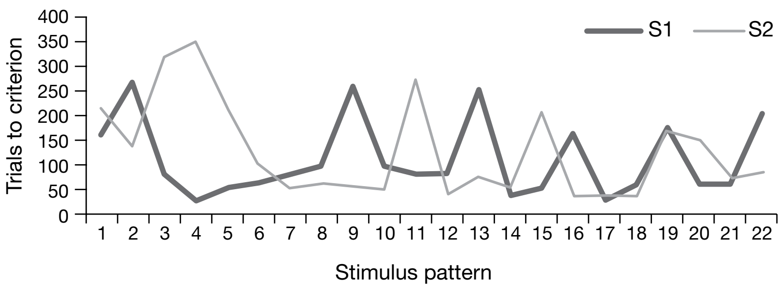

Figure 3. Two-choice discrimination learning for 22 stimulus pairs.

computer joystick, she had developed better control of it with her trunk and appeared to pay attention to the cursor moving on the computer screen as she moved the joystick, but she had not progressed beyond the first level of the first task in the software package before logistical and administrative issues ended the project altogether (Figure 4).

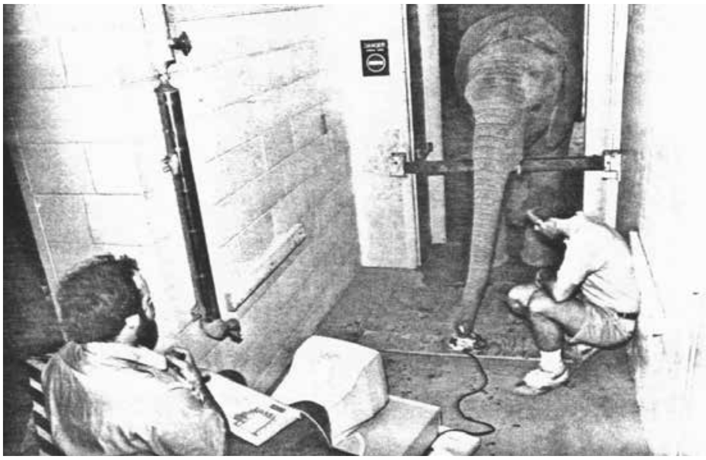

Figure 4. Elephant with joystick.

Both subjects

The two subjects' trials to criteria were averaged across stimulus pairs based on presentation order. A Pearson product-moment correlation (Olson 1987) was conducted and indicated a negative but statistically non-significant relationship between trials to criteria over an increased number of problems ($\underline{r}$ = –0.44). However, when a correlated *t*-test was conducted between the number of trials to criteria for first 11 pattern pairs when compared with the second 11 pairs, a significant difference was found ($t(10) = 2.26, p < 0.025$) indicating a learning effect had occurred, and that with practice the subjects significantly decreased the number of trials needed to reach criteria on new stimulus pairs.

Discussion

Learning

The relationships noted for the subjects' performance suggests that elephants have the potential to 'learn to learn'. However, traditional learning set testing as developed by Harlow (1949) was not conducted here, and so interpretation of this effect must be made cautiously. Potential distractions within the zoo setting compared with a controlled laboratory may have contributed to errors, and since elephants have such a large diet (more than 50 kg of food per day), the motivational quality of a single reinforcer may be diminished. Traditional learning set research would be valuable with elephants, but it would prohibitively require a larger subject pool, hundreds of six-trial problem blocks, and thousands of elephant-sturdy stimuli.

While Rensch (1957) did not use the vocabulary of Harlow's learning set, the experiment was essentially a set of learned two-choice discrimination problems, much like this study. But the author's claims on p. 47 of that study are unclear. The statement that the elephant gained 'know-how' over successive problems with acquisition improving steadily with each new symbol pair is not statistically justified by the data reported in 1953. Yet if the 20 symbol pairs were 'missed only one or two times' over 600 trials, this would yield at least a 93% performance level and indicate definite improvement with time on the overall task. Since training continued for over two years, it may be assumed that rehearsal improved the subject's performance to the level of 'mastery' reported. With more time, our subjects might have reached that performance level as well.

The trials to reach criteria across problems encompass similar ranges for each of the African and Asian elephants studied. For all three subjects, some patterns required more than 300 trials to learn and others less than 30 (mean = 129). Initial acquisition of two-choice discrimination learning appears to be much slower for elephants than for humans (Shepard 1957) and many primate species (Hayes et al. 1953; Rumbaugh and Pate 1970), although the number of trials necessary to acquire the first discrimination problem to criterion are absent from many of Harlow's studies (e.g. 1945, 1949). Rensch (1957) also reported examining retention of two-choice discrimination learning in a horse, a zebra and an ass. He found that the horse was able to learn all 20 problems that the elephant had learned; the ass learned 13 and the zebra 10. It can be problematic to make comparisons between species tested with differing methodologies and training histories.

The size, colour and dimension of stimuli are other important factors in studies of this type. Whether elephants see colours is unknown, although Yokoyama et al. (2005) determined that elephants and human colour-blind deuteranopes have identical sets of visual pigments. Stone and Halasz (1989) examined the physiology of the Asian elephant eye, but its acuity in detecting and processing stimuli is still unknown. These authors note that the visual field of the elephant is specialized to accommodate that area directly in front of the trunk. It may be that with the repositioning and increasing in size of the stimulus patterns, the success of the revised testing apparatus more appropriately fit this line of sight than the pretest apparatus.

Harlow (1945) found that three-dimensional stimuli were more easily discriminated by primates than were two-dimensional stimuli, and Meyer and Harlow (1949) found colour to be a more salient cue than size or shape for primates. Rensch (1958) was later interested in possible aesthetic factors in stimulus preferences of animals. While he mentions stimulus similarity as a possible factor in elephant learning in 1953, he does not elaborate on this further in 1957. This study chose to vary stimulus patterns from Rensch's to explore the variety of symbols that elephants could learn. No cheating or cueing as described by Rosenthal (1965) in the case of Clever Hans was reflected in the elephants' performance, but variations in subjects' interest levels were evident, and they could easily become distracted by conspecific activity.

Learning and memory may also play key roles in elephants' development and survival in the wild. Douglas-Hamilton and Douglas-Hamilton (1975) and Moss (1988) have both discussed how long maturation periods in young elephants may be associated with the learning of food and water acquisition strategies in large and shifting ecosystems as well as the learning of large numbers of conspecifics in home and extended herds. Foley et al. (2008) noted that survival of calves in a period of drought was higher in family groups with older mothers than in those with younger, indicating that knowledge and experience learned over time may be important elements of survival passed on to future generations.

Retention

With no exposure to the stimulus patterns for eight months, African S1 responded correctly to 16 of 20 patterns, while Rensch's Asian subject demonstrated retention for 13 patterns with no exposure for one year. Strong (1959) found rhesus monkeys performed significantly better on discrimination problems that had been presented to them before, and Gardner and Gardner (1969) and Rumbaugh (1977) have reported that chimpanzees can recall items from a vocabulary of more than 75 lexical items.

In each of the elephant studies, some relearning of stimuli may have been possible but was not indicated. It is also interesting to note that, even after thousands of trials, human investigators relied on written notes to refresh their identification of the correct stimuli. An evolutionary explanation for the elephants' performance might suggest that searches for food and mating opportunities over large geographic and social ranges have encouraged selection of retention skills, while elephants' sheer size and lack of predators may have lessened the need for learning to discriminate quickly.

Benefits and implications

Beyond its scientific merit, this study provided opportunities for the education and entertainment of the zoo-going public as well as simple, useful and demonstrable enrichment activity for captive animal wellbeing, as described by Hediger (1964). As large animals with active brains and bodies, elephants can benefit from behavioural enrichment, as described by Forthman et al, (2009), and further cognitive research into management and basic processes as described by Plotnik et al. (2010). The elephants were regularly observed waiting at their gate at the experimentation time, indicating the apparent reinforcing functions of the procedures. Training potentially dangerous captive animals to 'target', or attend and respond to certain symbols in developing hands-off management may also be aided by research on cognition.

Finally, studies of this kind may contribute to the survival of wild elephants, which have suffered dramatic reductions in the past 50 years. After a brief decline in the rate of poaching in the 1990s, illegal kills rebounded significantly in the decade following (University of Washington 2008). The demonstration of complex elephant learning may heighten public awareness of the value of conserving wild populations in their native habitats.

Conclusions

This study demonstrated that two African elephants can learn at least 20 two-choice discrimination problems. One of the subjects showed significant retention of 16 of the problems after not being exposed to them for eight months. Similar patterns of acquisition and retention were noted for these elephants as for the Asian elephant trained by Rensch (1957).

These findings suggest rich potential for learning in this highly tractable animal. The development of stimulus control in the elephant may facilitate further research, enhance wellbeing for captive elephants and their caretakers, and increase public awareness to the issue of the long-term survival of elephants. Additional research with a greater sample size will provide more reliable assessments of learning ability in this species.

Statement on ethics

No animals were harmed as a result of this study. Zoo Atlanta is a member of the American Association of Zoological Parks and Aquariums whose guidelines were followed in the care and handling of subjects.

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